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The CEU quiz for the December 2002 issue (Volume 37, Number 4) of the Journal of Athletic Training will be located in the January 2003 NATA News.

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The NATA Research and Education Foundation currently has the following seven (7) active Requests for Proposals. Detailed information regarding each RFP, as well as the application process, may be found at the NATA Foundation web site at www.natafoundation.org.

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Welcome to this Special Issue of the Journal of Athletic Training dedicated to the topic of ankle instability. This issue follows 3 previous special issues that have provided positive domestic and international exposure to the profession of athletic training with regard to contemporary clinical practice and research into important topics in sports medicine. We are confident this issue on ankle instability will reach the same high level of quality set by previous special issues dedicated to anterior cruciate ligament injuries in female athletes, shoulder injuries, and mild brain injuries.

Ankle sprains are a frequent occurrence in the physically active population, accounting for a significant amount of lost time from work and play on a daily basis. What is often frustrating is the patient or athlete who, despite your best efforts at rehabilitation, continues to suffer repetitive bouts of ankle instability. Although hundreds of articles have been published on this topic, suggesting a wide array of treatment options over the past few decades, the incidence of initial and recurrent ankle sprains remains a substantial clinical problem. The goal of this issue on ankle instability is to elucidate many aspects of this complex phenomenon and provide insight for broadening your clinical expertise.

As researchers, we are delighted to have this forum to discuss the most contemporary views on chronic ankle disability. You will notice that we have chosen to use the term chronic ankle instability throughout the special issue as a means of adding consistency and lessening confusion on the part of the reader. Furthermore, we feel that because there is still so much about this enigmatic phenomenon that we do not know, this terminology may be more appropriate in many cases than more specific terms such as functional ankle instability or mechanical ankle instability.

One of the most exciting features about this special issue is that we have assembled an internationally renowned group of experts on ankle instability, representing such disciplines as athletic training, physical therapy, and orthopaedics. Our intent is to frame the scope of the clinical entity with a series of in-depth literature reviews, then provide the reader with the current state of both the art and science of ankle-injury evaluation and treatment, and lastly, highlight contemporary research reports related to ankle instability. Equally exciting is the special commentary by Hans Tropp, MD, PhD, considered by many to be a pioneer in the area of ankle-instability research. We have purposely attempted to push the boundaries of traditional methods of managing ankle injuries and offer evidence for alternative ways of evaluating and treating these injuries. For example, we hope that you will find articles such as Denegar and Miller's illustration of manual therapy approaches to the injured ankle and Kovaleski et al's research report of ankle-joint arthrometry both intriguing and thought provoking.

Perhaps the most helpful thing to come about from our experience as Guest Editors is the fact that we have developed camaraderie with a group of clinicians and researchers sharing a common interest, the end result being a mechanism for future collaboration. Although we have made considerable advances in our understanding of ankle instability in the last 30 years, many unanswered questions remain. Leading the way is the need to establish a uniform set of criteria to define individuals who truly do and do not have ankle instability. Uniform criteria will allow for a better means of comparing research reports across various dependent measures and populations. Additionally, we see the area of prevention as one beckoning future research. Can initial ankle sprains and subsequent ankle instability be prevented? These questions, along with many others, remain unanswered.

We thank our distinguished group of authors for their hard work and dedication to making this special issue a reality. Additionally, we thank the manuscript reviewers and Associate Editors for their contributions to the special issue. Special thanks must go to David Perrin, PhD, ATC, Editor-in-Chief, and Leslie Neistadt, Managing Editor, for their careful guidance and help along the way. Whether you are a clinician, educator, or researcher, or any combination of these, we believe this issue will improve your understanding of ankle instability in athletes and serve as a contemporary reference and resource on this topic.

Enjoy!

Editor's Note: Jay Hertel, PhD, ATC, is an Assistant Professor of Kinesiology and Director of the Athletic Training Research Laboratory at Pennsylvania State University, University Park, PA. Thomas W. Kaminski, PhD, ATC/R, is Department Head and Associate Professor, Department of Sports Medicine and Athletic Training, Southwest Missouri State University, Springfield, MO. Doctors Hertel and Kaminski are Guest Editors for this Special Issue of the Journal of Athletic Training.
Injuries to the lateral ligaments of the ankle complex are among the most common injuries incurred by athletes. Lateral ankle sprains are thought to be suffered by men and women at approximately the same rates; however, one recent report suggests that female intercollegiate basketball players have a 25% greater risk of incurring grade I ankle sprains than their male counterparts. More than 23,000 ankle sprains have been estimated to occur per day in the United States, which equates to one sprain per 10,000 people daily. The most common predisposition to suffering a lateral ankle sprain is the history of at least one previous ankle sprain. In sports such as basketball, recurrence rates have been reported to exceed 70%. Repetitive sprains have also been linked to increased risk of osteoarthritis and articular degeneration at the ankle.

Residual symptoms after lateral ankle sprain affect 55% to 72% of patients at 6 weeks to 18 months. The frequency of complications and breadth of longstanding symptoms after ankle sprain has led to the suggestion of a diagnosis of the "sprained ankle syndrome" and to the conclusion "that there is no such thing as a simple ankle sprain." It has also been estimated that 55% of individuals suffering ankle sprains do not seek injury treatment from a health care professional. Thus, the severity of ankle sprains may often be underestimated by athletes, and current treatment strategies for lateral ankle sprains may not be effective in preventing recurrent injuries or residual symptoms.

Lateral ankle sprains are also referred to as inversion ankle sprains or occasionally as supination ankle sprains. Individuals who suffer numerous repetitive ankle sprains have been reported as having functional instability, chronic instability, and residual instability. The multitude of terms used to describe the phenomenon of repetitive ankle sprains has led to confusion in terminology. For the purposes of this article, the following definitions will apply: lateral ankle sprain, talocrural joint, subtalar joint, mechanical instability, functional instability, and chronic ankle instability.

Objective: To describe the functional anatomy of the ankle complex as it relates to lateral ankle instability and to describe the pathomechanics and pathophysiology of acute lateral ankle sprains and chronic ankle instability.

Data Sources: I searched MEDLINE (1985-2001) and CINAHL (1982-2001) using the key words ankle sprain and ankle instability.

Data Synthesis: Lateral ankle sprains are among the most common injuries incurred during sports participation. The ankle functions as a complex with contributions from the talocrural, subtalar, and inferior tibiofibular joints. Each of these joints must be considered in the pathomechanics and pathophysiology of lateral ankle sprains and chronic ankle instability. Lateral ankle sprains typically occur when the rearfoot undergoes excessive supination on an externally rotated lower leg. Recurrent ankle sprain is extremely common; in fact, the most common predisposition to suffering a sprain is the history of having suffered a previous ankle sprain. Chronic ankle instability may be due to mechanical instability, functional instability, or most likely, a combination of these 2 phenomena. Mechanical instability may be due to specific insufficiencies such as pathologic laxity, arthrokinematic changes, synovial irritation, or degenerative changes. Functional instability is caused by insufficiencies in proprioception and neuromuscular control.

Conclusions/Recommendations: Lateral ankle sprains are often inadequately treated, resulting in frequent recurrence of ankle sprains. Appreciation of the complex anatomy and mechanics of the ankle joint and the pathomechanics and pathophysiology related to acute and chronic ankle instability is integral to the process of effectively evaluating and treating ankle injuries.

Key Words: ankle sprain, talocrural joint, subtalar joint, mechanical instability, functional instability.
specific insufficiencies interact to create either mechanical instability or functional instability. Functional instability may be caused by specific insufficiencies in proprioception, neuromuscular control, postural control, or strength. Mechanical instability may be caused by factors that alter the mechanics of one or more joints within the ankle complex. Potential mechanical insufficiencies include pathologic laxity, impaired arthokinematics, synovial inflammation and impingement, and degenerative changes. Chronic ankle instability may be caused by mechanical instability, functional instability, or a combination of these entities.21,23

The purposes of this review article are to describe the functional anatomy of the ankle complex as it relates to lateral ankle instability and to discuss the pathomechanics and pathophysiology of acute lateral ankle sprain and CAI.

FUNCTIONAL ANATOMY

The ankle complex comprises 3 articulations: the talocrural joint, the subtalar joint, and the distal tibiofibular syndesmosis. These 3 joints work in concert to allow coordinated movement of the rearfoot. Rearfoot motion is often defined as occurring in the cardinal planes as follows: sagittal-plane motion (plantar flexion-dorsiflexion), frontal-plane motion (inversion-eversion), and transverse-plane motion (internal rotation-external rotation).24 Rearfoot motion, however, does not occur in isolation in the individual planes; rather, coordinated movement of the 3 joints allows the rearfoot to move as a unit about an axis of rotation oblique to the long axis of the lower leg. Rearfoot motion does not occur strictly in the cardinal planes because the talocrural and subtalar joints each have oblique axes of rotation. Coupled rearfoot motion is best described as pronation and supination. In the open kinetic chain, pronation consists of dorsiflexion, eversion, and external rotation, while supination consists of plantar flexion, inversion, and internal rotation.25 In the closed kinetic chain, pronation consists of plantar flexion, eversion, and external rotation, while supination consists of dorsiflexion, inversion, and internal rotation.25

The 3 major contributors to stability of the ankle joints are (1) the congruity of the articular surfaces when the joints are loaded, (2) the static ligamentous restraints, and (3) the musculotendinous units, which allow for dynamic stabilization of the joints. The functional aspect of each of these as it relates to lateral ankle instability will be discussed later.

Talocrural Joint Anatomy

The talocrural, or tibiotalar, joint is formed by the articulation of the dome of the talus, the medial malleolus, the tibial plafond, and the lateral malleolus. The shape of the talocrural joint allows torque to be transmitted from the lower leg (internal and external rotation) to the foot (pronation and supination) during weight bearing. This joint is sometimes called the “mortise” joint and, in isolation, may be thought of as a hinge joint that allows the motions of plantar flexion and dorsiflexion. The axis of rotation of the talocrural joint passes through the medial and lateral malleoli. It is slightly anterior to the frontal plane as it passes through the tibia but slightly posterior to the frontal plane as it passes through the fibula. Isolated movement of the talocrural joint is primarily in the sagittal plane, but small amounts of transverse- and frontal-plane motion also occur about the oblique axis of rotation.26

In an in vivo study of loaded ankles in the closed kinetic chain, 30° of physiologic plantar flexion (actual motion) from the neutral position was composed of 28° sagittal-plane movement (plantar flexion), 1° transverse-plane movement (internal rotation), and 4° frontal-plane movement (inversion).26 Comparatively, 30° of physiologic dorsiflexion (actual motion) in the closed kinetic chain was composed of 23° sagittal-plane movement (dorsiflexion), 9° transverse-plane movement (external rotation), and 2° frontal-plane movement (eversion).26 Closed kinetic chain dorsiflexion occurs when the tibia moves anteriorly on the fixed talus during weight bearing. The concept of triplanar motion at the talocrural joint is important in understanding the stability of the talocrural joint (Figure 1).

When the ankle complex is fully loaded, the articular surfaces are the primary stabilizers against excessive talar rotation and translation; however, the contribution of the ligaments to talocrural joint stability is crucial. The talocrural joint receives ligamentous support from a joint capsule and several ligaments, including the anterior talofibular ligament (ATFL), posterior talofibular ligament (PTFL), calcaneofibular ligament (CFL), and deltoid ligament. The ATFL, PTFL, and CFL support the lateral aspect of the ankle, while the deltoid ligament provides medial support.

The ATFL lies on the dorsolateral aspect of the foot and courses from the lateral malleolus anteriorly and medially toward the talus at an angle of approximately 45° from the frontal plane.28 The ATFL is an average of 7.2 mm wide and 24.8 mm long.28 In vitro kinematic studies have shown that the ATFL prevents anterior displacement of the talus from the mortise and excessive inversion and internal rotation of the talus on the tibia.27,29,32 The strain in the ATFL increases as the ankle moves from dorsiflexion into plantar flexion.29 The ATFL demonstrates lower maximal load and energy to failure values under tensile stress as compared with the PTFL, CFL, anterior inferior tibiofibular ligament, and deltoid ligament.33 This may explain why the ATFL is the most frequently injured of the lateral ligaments.34
The CFL courses from the lateral malleolus posteriorly and inferiorly to the lateral aspect of the calcaneus at a mean angle of 133° from the long axis of the fibula. The CFL restricts excessive supination of both the talocral and subtalar joints. In vitro experiments have demonstrated that the CFL restricts excessive inversion and internal rotation of the rearfoot and is most taut when the ankle is dorsiflexed. The CFL is the second most-often injured of the lateral talocural ligaments.

The PTFL runs from the lateral malleolus posteriorly to the posterolateral aspect of the talus. The PTFL has broad insertions on both the talus and fibula and provides restraint to both inversion and internal rotation of the loaded talocural joint. It is the least commonly sprained of the lateral ankle ligaments.

Subtalar Joint Anatomy

The subtalar joint is formed by the articulations between the talus and the calcaneus and, like the talocural joint, it converts torque between the lower leg (internal and external rotation) and the foot (pronation and supination). The subtalar joint allows the motions of pronation and supination and consists of an intricate structure with 2 separate joint cavities. The posterior subtalar joint is formed between the inferior posterior facet of the talus and the superior posterior facet of the calcaneus. The anterior subtalar, or talocalcaneonavicular, joint is formed from the head of the talus, the anterior-superior facets, the sustentaculum tali of the calcaneus, and the concave proximal surface of the tarsal navicular. This articulation is similar to a ball-and-socket joint, with the talar head being the ball and the anterior calcaneal and proximal navicular surfaces forming the socket in conjunction with the spring ligament. Viladot et al reported great individual variation in the architecture of the anterior subtalar joint.

The anterior and posterior subtalar joints have separate ligamentous joint capsules and are separated from each other by the sinus tarsi and canalis tarsi. The anterior joint has a center of rotation farther medial and has a higher center of rotation than the posterior joint, but the 2 joints share a common axis of rotation. This discrepancy results in an oblique axis of rotation of the subtalar joint, which averages a 42° upward tilt and a 23° medial angulation from the perpendicular axes of the foot (Figure 2). Great variations have been identified in the position of the axis of rotation across individuals.

The ligamentous support of the subtalar joint is extensive and not well understood. Marked discrepancies exist in the literature regarding the terminology for the individual ligaments and the functions these ligaments serve. Essentially, the lateral ligaments may be divided into 3 groups: (1) deep ligaments, (2) peripheral ligaments, and (3) retinacula.

The deep ligaments consist of the cervical and interosseous ligaments. Together these ligaments stabilize the subtalar joint and form a barrier between the anterior and posterior joint capsules. These ligaments, which cross obliquely through the canalis tarsi, have been described as the “cruciate ligaments of the subtalar joint.” The cervical ligament lies anterior and lateral to the interosseous ligament and runs from the cervical tubercle of the calcaneus anteriorly and medially to the talar neck. The cervical ligament lies within the sinus tarsi and provides support to both the anterior and posterior joints. It is the strongest of the subtalar ligaments and has been shown to resist supination during in vitro kinematic experiments.

The interosseous ligament lies just posterior to, and courses more medially than, the cervical ligament. The interosseous ligament originates on the calcaneus just anterior to the posterior subtalar joint capsule and runs superiorly and medially to its insertion on the talar neck. Because of its diagonal orientation and oblique fiber arrangement across the joint, portions of the interosseous ligament are taut throughout pronation and supination. This ligament is sometimes called the ligament of the canalis tarsi.

Fibers of the inferior extensor retinacula (IER) have also been proposed to provide support to the lateral aspect of the subtalar joint. Three roots of the IER have been identified within the sinus tarsi: lateral, intermediate, and medial. Only the lateral root of the IER has been shown to significantly affect subtalar joint stability; however, injury to any of the
Medial

Lateral

Talus

Calcaneus

Figure 3. The intrinsic subtalar ligaments: (1) interosseous ligament, (2) cervical ligament, and (3) deep fibers of the extensor retinaculum. Reprinted with permission of Hertel J, Denegar CR, Monroe MM, Stokes WL. Talocrural and subtalar joint instability after lateral ankle sprain. Med Sci Sports Exerc. 1999;31:1501-1508; Lippincott Williams & Wilkins. 

Figure 4. The lateral ligaments of the ankle: (1) anterior talofibular ligament, (2) calcaneofibular ligament, (3) posterior talofibular ligament, (4) cervical ligament, and (5) lateral talocalcaneal ligament. Reprinted with permission of Hertel J, Denegar CR, Monroe MM, Stokes WL. Talocrural and subtalar joint instability after lateral ankle sprain. Med Sci Sports Exerc. 1999;31:1501-1508; Lippincott Williams & Wilkins.

roots has been suggested in the cause of sinus tarsi syndrome. The peripheral ligaments of the subtalar joint include the CFL and lateral talocalcaneal (LTCL) and fibulotalocalcaneal (FTCL) ligaments. The CFL is integral in preventing excessive inversion and internal rotation of the calcaneus in relation to the talus. While the CFL does not normally connect the calcaneus to the talus, various attachments of the anterior aspect of the CFL to the talus have been reported.

Lateral Ankle Ligaments

The LTCL runs parallel and anterior to the CFL but only crosses the posterior subtalar joint (Figure 4). While the LTCL is smaller and weaker than the CFL, it helps prevent excessive supination of the subtalar joint. Various shapes of the LTCL have been reported, and occasionally its fibers are continuous with those of the CFL. The FTCL, or ligament of Rouviere, runs from the posterior surface of the lateral malleolus to the posterolateral surface of the talus and then to the posterolateral calcaneus. It lies distinctly posterior to the CFL and assists in resisting excessive supination.

The bifurcate ligament also deserves mention as a static supporter of the lateral ankle complex. It consists of 2 branches: (1) dorsal calcaneocuboid, and (2) dorsal calcaneonavicul.

Distal Tibiofibular Joint Anatomy

The third joint of the ankle complex is the distal articulation between the tibia and fibula. This joint is a syndesmosis that allows limited movement between the 2 bones; however, accessory gliding at this joint is crucial to normal mechanics throughout the entire ankle complex. The joint is stabilized by a thick interosseous membrane and the anterior and posterior inferior tibiofibular ligaments. The structural integrity of the syndesmosis is necessary to form the stable roof for the mortise of the talocrural joint. The anterior inferior tibiofibular ligament is often injured in conjunction with eversion injuries, and damage results in the so-called high ankle sprain rather than the more common lateral ankle sprain.

Muscles and Tendons

When contracted, musculotendinous units generate stiffness, which leads to dynamic protection of joints. The muscles that cross the ankle complex are often described based on their concentric actions; however, when considering their role in providing dynamic stability to joints, it may be helpful to think about eccentric functions. The peroneal longus and brevis muscles are integral to the control of supination of the rearfoot and protection against lateral ankle sprains.

In addition to the peroneals, the muscles of the anterior compartment of the lower leg (anterior tibialis, extensor digitorum longus, extensor digitorum brevis, and peroneus tertius) may also contribute to the dynamic stability of the lateral ankle complex by contracting eccentrically during forced supination of the rearfoot. Specifically, these muscles may be able to slow the plantar-flexion component of supination and thus prevent injury to the lateral ligaments.

Innervation

The motor and sensory supplies to the ankle complex stem from the lumbar and sacral plexes. The motor supply to the muscles comes from the tibial, deep peroneal, and superficial peroneal nerves. The sensory supply comes from these 3 mixed nerves and 2 sensory nerves: the sural and saphenous nerves. The lateral ligaments and joint capsule of the talocrural
and subtalar joints have been shown to be extensively innervated by mechanoreceptors that contribute to proprioception. The major importance of muscle spindles, especially of those in the peroneal muscles, to proprioception about the ankle complex has been described.

**PATHOMECHANICS OF ACUTE LATERAL ANKLE SPRAIN**

Lateral ankle sprains most commonly occur due to excessive supination of the rearfoot about an externally rotated lower leg soon after initial contact of the rearfoot during gait or landing from a jump. Excessive inversion and internal rotation of the rearfoot, coupled with external rotation of the lower leg, results in strain to the lateral ankle ligaments. If the strain in any of the ligaments exceeds the tensile strength of the tissues, ligamentous damage occurs. Increased plantar flexion at initial contact appears to increase the likelihood of suffering a lateral ankle sprain.

The ATFL is the first ligament to be damaged during a lateral ankle sprain, followed most often by the CFL. Cadaveric-sectioning studies have demonstrated that after the ATFL is ruptured, the amount of transverse-plane motion (internal rotation) of the rearfoot increases substantially, thus further stressing the remaining intact ligaments. This phenomenon has been described as "rotational instability" of the ankle and is often overlooked when considering laxity patterns in the sprained ankle. Concurrent damage to the talocrural joint capsule and the ligamentous stabilizers of the subtalar joint is also common with lateral ankle sprains. Martin et al demonstrated significantly greater strain in the cervical ligament after complete disruption to the CFL. The incidence of subtalar joint injury has been reported to be as high as 80% among patients suffering acute lateral ankle sprains. Injury to the PTFL is typical only in severe ankle sprains and is often accompanied by fractures or dislocations or both.

A pathomechanical model described by Fuller suggested that the cause of lateral ankle sprain is an increased supination moment at the subtalar joint. The increased supination moment is caused by the position and magnitude of the vertically projected ground-reaction force at initial foot contact. Fuller hypothesized that a foot with its center of pressure (COP) medial to the subtalar-joint axis has a greater supination moment from the vertical ground-reaction force than a foot with a more lateral relationship between the COP and the joint axis. This increased supination moment could thus cause excessive inversion and internal rotation of the rearfoot in the closed kinetic chain and potentially lead to injury of the lateral ligaments. Individuals with a rigid supinated foot would be expected to have a more laterally deviated subtalar axis of rotation and a calcaneal varus (inverted rearfoot) malalignment, which could predispose those with a rigid supinated foot to lateral ankle sprains.

Inman described great variation in the alignment of the subtalar-joint axis across individuals, and it is possible that those with a more laterally deviated subtalar-joint axis may be predisposed to recurrent ankle sprains. A foot with a laterally deviated subtalar-joint axis would have a greater area on the medial side of the joint axis. Thus, during initial foot contact, the likelihood is greater that COP would be medial to the subtalar-joint axis and the ground-reaction force would cause a supination moment at the subtalar joint. Additionally, the further medial the COP is in relation to the subtalar-joint axis, the longer the supination moment arm is. If the magnitude of this supination moment exceeds the magnitude of a compensatory pronation moment (produced by the peroneal muscles and the lateral ligaments), excessive inversion and internal rotation of the rearfoot occur, likely causing injury to the lateral ligaments.

Some have questioned whether the peroneal muscles are able to respond quickly enough to protect the lateral ligaments from being injured once the ankle begins rapid inversion. Ashton-Miller et al estimated that the span of the inversion motion upon landing may be as short as 40 milliseconds. Konradsen et al reported that a dynamic protective reaction from the peroneal muscles would take at least 126 milliseconds to occur after sudden, unexpected inversion perturbation of the ankle. This includes 54 milliseconds for reaction time of initial electromyographic activity after the onset of inversion perturbation and 72 milliseconds of electromechanical delay needed to generate force in the muscle after electromyographic activity has been initiated. This value assumes no preparatory electromyographic activity in the peroneal muscles before initial contact of the heel with the ground. In fact, the peroneal muscles are active before initial foot contact during stair descent and landing after a jump. This preparatory activity, along with similar activity in the other muscle groups that cross the ankle, is likely to create stiffness in tendons before initial foot contact with the ground. If the peroneal muscles are to protect against unexpected inversion of the rearfoot, preparatory muscle activation before foot contact with the ground is necessary.

Relatively few research reports in the literature have described predispositions to first-time ankle sprains. Structural predispositions included increased tibial varum and nonpathologic talar tilt, whereas functional predispositions included poor postural-control performance, impaired proprioception, and higher eversion-to-inversion and plantar flexion-to-dorsiflexion strength ratios. Further research into prevention programs based on these predisposing factors is clearly warranted.

After acute injury, the ankle typically becomes swollen, tender, and painful with movement and full weight bearing. Depending on the severity of the injury, function usually returns over the course of a few days to a few months. What remains elusive to clinicians and researchers is why most individuals who suffer an initial ankle sprain are prone to recurrent sprains.

**PATHOMECHANICS OF CHRONIC INSTABILITY**

The mechanism of recurrent ankle injury is not thought to be different than that of initial acute ankle sprains; however, adverse changes that occur after primary injury are believed to predispose individuals to recurrent sprains. Two theories of the cause of CAI have traditionally been postulated: mechanical instability and functional instability. These 2 terms, however, do not adequately describe the full spectrum of abnormal conditions related to CAI. By further clarifying the potential insufficiencies leading to each type of instability, we can better describe the full complement of potential causes of CAI. Mechanical instability and functional instability are probably not mutually exclusive entities but more likely form a continuum of pathologic contributions to CAI (Figure 5).
Mechanical Instability

Mechanical instability of the ankle complex occurs as a result of anatomic changes after initial ankle sprain, which lead to insufficiencies that predispose the ankle to further episodes of instability. These changes include pathologic laxity, impaired arthrokinematics, synovial changes, and the development of degenerative joint disease, which may occur in combination or isolation.

Pathologic Laxity. Ligamentous damage often results in pathologic laxity of injured joints, thus causing these joints to be mechanically unstable. The extent of pathologic laxity of the ankle depends on the amount of ligamentous damage to the lateral ligaments. Pathologic laxity can result in joint instability when the ankle is put in vulnerable positions during functional activities, resulting in subsequent injury to joint structures. Pathologic laxity may be assessed clinically with physical examination, stress radiography, or instrumented arthrometry. After lateral ankle sprain, pathologic laxity most often occurs in the talocrural and subtalar joints.

Talocrural instability is caused primarily by injury to the ATFL and CFL. Injury to the ATFL is often assessed by determining the amount of anterior displacement of the talus from the tibiofibular mortise using an anterior drawer test. Integrity of the ATFL may also be assessed by inverting the talus with the talocrural joint in a plantar-flexed position and determining the amount of talar tilt present. Calcaneofibular ligament integrity is best assessed by determining the amount of talar tilt present when inverting the rearfoot with the talocrural joint in a dorsiflexed position. The amount of inversion talar tilt assessed with stress radiography increases dramatically with combined lesions of the ATFL and CFL. Whereas pathologic laxity is often present in those with CAI, 11% of healthy individuals also have asymmetric ankle laxity as assessed by the anterior drawer and talar tilt tests.

Mechanical instability of the talocrural joint is traditionally explained in single planes, although this disregards the normal triplanar movement allowed at this joint. An excessive anterior drawer represents laxity in the transverse plane, while increased talar tilt indicates laxity in the frontal plane. These simplifications disregard the fact that the talocrural joint normally moves about a triplanar axis and ignore the issue of rotary instability of the talocrural joint. Specifically, in the absence of an intact ATFL, the talus is able to excessively supinate, with a large internal-rotation component in relation to the tibia. Comprehensive assessment of the unstable talocrural joint should focus on uniplanar and triplanar instability patterns.

Injury to the CFL also causes pathologic laxity of the subtalar and talocrural joints. On arthrography, many injuries to the CFL are accompanied by injury to the subtalar-joint capsule, cervical ligament, and other lateral ligaments. Rupture of the LTCL has also been implicated in chronic instability of the lateral subtalar joint. Stress radiography has been used to quantify the amount of subtalar tilt and anterior displacement of the calcaneus from the talus, although the validity of the most common method used for these assessments, the modified Broden view, has been challenged. Hertel et al described the medial subtalar glide test, which assesses the amount of medial translation of the calcaneus on the talus in the transverse plane (Figure 6). The results of the medial subtalar glide test compared favorably with the results of stress radiography.

Arthrokinematic Impairments. Another potential insufficiency contributing to mechanical instability of the ankle is impaired arthrokinematics at any of the 3 joints of the ankle complex. One arthrokinematic restriction related to repetitive ankle sprains involves a positional fault at the inferior tibiofibular joint. Mulligan suggested that individuals with CAI may have an anteriorly and inferiorly displaced distal fibula. If the lateral malleolus is indeed stuck in this displaced position, the ATFL may be more slack in its resting position. Thus, when the rearfoot begins to supinate, the talus can go through a greater range of motion before the ATFL becomes taut. This positional fault of the fibula may result in episodes of recurrent instability, leading to repetitive ankle sprains. The findings of 2 case studies and one pilot study present preliminary evidence for restriction of posterior fibular glide after lateral ankle sprain, suggesting that the lateral malleolus may be subluxated in an anteriorly displaced position.

Hypomobility, or diminished range of motion, may also be thought of as a mechanical insufficiency. Restricted dorsiflex-
ion range of motion is thought to be a predisposition to lateral ankle sprain.\textsuperscript{84} If the talocural joint is not able to fully dorsiflex, the joint will not reach its closed-pack position during stance and, therefore, will be able to invert and internally rotate more easily. Limited dorsiflexion in the closed kinetic chain is also typically compensated for by increased subtalar pronation. Some evidence demonstrates dorsiflexion restrictions in athletes with repetitive ankle sprains.\textsuperscript{85,86} Greene et al\textsuperscript{87} recently demonstrated that altered arthrokinematics may limit dorsiflexion after acute ankle sprain. Patients with acute ankle sprains who were treated with posterior mobilization of the talus on the tibia recovered their dorsiflexion range of motion more quickly than those not treated with joint mobilization. Denegar et al\textsuperscript{88} found restricted posterior talus glide in athletes 12 weeks after acute ankle sprain. Interestingly, these athletes did not have significantly decreased dorsiflexion range of motion as assessed through standard clinical measures. This suggests that dorsiflexion may be returned to normal ranges in the absence of normal arthrokinematics due to extensive stretching of the triceps surae. Further research is needed to elucidate the clinical implications of altered arthrokinematics after ankle sprain.

**Synovial and Degenerative Changes.** Mechanical instability of the ankle complex may also occur due to insufficiencies caused by synovial hypertrophy and impingement or the development of degenerative joint lesions. Synovial inflammation has been shown in the talocural and posterior subtalar joint capsules. Patients with synovial inflammation often report frequent episodes of pain and recurrent ankle instability, which are due to impingement of hypertrophied synovial tissue between the respective bones of the ankle complex. DiGiovanni et al\textsuperscript{89} identified anterolateral impingement syndrome of the talocural joint in 67% and talocural synovitis in 49% of patients requiring surgery for lateral instability. Sinus tarsi syndrome, or synovitis of the lateral aspect of the posterior subtalar joint, often occurs as a sequela to repetitive bouts of ankle instability.\textsuperscript{43,90}

Repetitive bouts of ankle instability have also been related to degenerative changes in the ankle complex.\textsuperscript{10} Individuals undergoing surgery for ankle-ligament repair were 3.37 times more likely to have osteophytes, or loose bodies, than those with asymptomatic ankles.\textsuperscript{74} Similarly, Gross and Marti\textsuperscript{111} demonstrated more osteophytes and subchondral sclerosis in volleyball players with a history of repetitive ankle sprains compared with a group of healthy controls. Greater varus angulation of the tibial plafond has also been identified in subjects with CAI when compared with those suffering initial acute sprains.\textsuperscript{91} It is unclear whether this is a developmental change in response to numerous bouts of ankle instability or a structural predisposition to recurrent ankle sprains.

**Functional Instability**

Injury to the lateral ligaments of the ankle results in adverse changes to the neuromuscular system that provides dynamic support to the ankle. Freeman et al\textsuperscript{16,17} first described the concept of functional instability in 1965. They attributed impaired balance in individuals with lateral ankle sprains to damaged articular mechanoreceptors in the lateral ankle ligaments, which resulted in proprioceptive deficits. The contribution of impaired proprioception, while important, does not fully explain why ankle-ligament injury predisposes athletes to functional ankle instability. The pathoetiologic model is not complete without including impaired neuromuscular control, thus resulting in inadequacies of the dynamic defense mechanism protecting against hypersupination of the rearfoot.\textsuperscript{92} Figure 7 illustrates the links between proprioception and neuromuscular control of joint stability. Over the past 2 decades, functional insufficiencies among individuals with either acute ankle sprains or CAI have been demonstrated by quantifying deficits in ankle proprioception, cutaneous sensation, nerve-conduction velocity, neuromuscular response times, postural control, and strength.

**Impaired Proprioception and Sensation.** Proprioception at the ankle is impaired in individuals prone to repetitive ankle sprains on measures of kinesthesia\textsuperscript{93–95} and active replication of joint angles.\textsuperscript{96–98} While Gross\textsuperscript{99} did not find significant differences in active and passive replication of joint angles in subjects with unilateral CAI, most studies assessing proprioception in subjects with CAI demonstrate impairments. Recent evidence suggests that alteration in muscle-spindle activity in the peroneal muscles may be more important than altered articular mechanoreceptor activity in the manifestation of proprioceptive deficits at the ankle.\textsuperscript{100} The clinical relevance of proprioceptive deficits is not fully understood at this time, and whether proprioception is improved through rehabilitation exercises has not yet been conclusively demonstrated.\textsuperscript{100}

Impaired cutaneous sensation\textsuperscript{101–104} and slowed nerve-conduction velocity\textsuperscript{102,105} have been reported as indicators of common peroneal nerve palsy after acute lateral ankle sprain, but no evidence exists that such impairments are present in patients with CAI. Further research in this area is warranted.

**Impaired Neuromuscular-Firing Patterns.** Impaired neuromuscular-recruitment patterns have been demonstrated in individuals with a history of repetitive lateral ankle sprain.\textsuperscript{104,106–111} This has been most commonly shown by assessing the reflexive response times of the peroneal muscles to inversion or supination perturbations. Conflicting results in the literature may be due to methodologic differences among investigators.\textsuperscript{107,112–116} If peroneal response is impaired in those with CAI, it may be due to impaired proprioception, slowed nerve-conduction velocity, or central impairments in neuromuscular-recruitment strategies. Evidence of the latter was presented by Bullock-Saxton et al,\textsuperscript{111} who found bilateral deficits of gluteus medius recruitment in subjects with a his-

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**Figure 7. Paradigm of proprioception and neuromuscular control.** CNS indicates central nervous system.
tory of severe unilateral ankle sprain. This finding suggests that neuromuscular impairments are not only present in structures that cross the affected ankle but also exist along other neuromuscular pathways in both limbs, thus indicating central neural adaptations to peripheral joint conditions.

Impaired Postural Control. Impaired postural control during single-leg stance has been demonstrated frequently in individuals after acute ankle sprain, and in those with a history of repetitive ankle sprains. Non-instrumented assessment of the modified Romberg test has been performed by having subjects stand as motionless as possible on one leg for a period usually ranging from 10 to 30 seconds. This task is performed while standing on the involved limb and then the uninvolved limb, first with eyes open and then with eyes closed. Both the subject and the examiner make a subjective judgment as to which limb either feels or appears to cause greater postural instability. Subjective assessment of postural control has consistently identified functional insufficiencies in those with chronically unstable ankles.

Instrumented assessment of postural control has also been used to discriminate between functionally stable and unstable ankles. Piezoelectric force plates allow for assessment of the COP during single-leg standing. Two very common dependent measures of postural control include the overall length of the path of COP and the velocity of COP excursions during the duration of an entire trial of single-leg standing. Shorter length of COP displacement and slower velocity of COP excursions are associated with better postural control. Dozens of dependent measures of postural control have been reported related to balance deficits and ankle instability. Despite varying methods, postural-control deficits have consistently been demonstrated between stable and unstable ankles when using instrumented assessment, although conflicting findings exist.

Postural-control deficits are likely due to a combination of impaired proprioception and neuromuscular control. When balancing in single-leg stance, the foot pronates and supinates in an effort to keep the body’s center of gravity above the base of support. This is referred to as the “ankle strategy” of postural control. Individuals with CAI have been shown to use more of a “hip strategy” to maintain unilateral stance than uninjured individuals. The hip strategy is less efficient than the ankle strategy in maintaining unilateral stance. This alteration in postural-control strategy is likely due to changes in central neural control that occur in the presence of ankle-joint dysfunction. Further evidence of central changes in neuromuscular control were presented by Friden et al., who found bilateral impairment of postural control in subjects with acute ankle sprains.

Interestingly, side-to-side differences in postural control often return to insignificant levels in the weeks and months after initial injury, whether structured rehabilitation programs are adhered to or not. Holme et al. reported that 4 months after acute ankle sprain, both subjects who did and those who did not perform a comprehensive rehabilitation program emphasizing balance and coordination exercises showed no significant postural-control deficits. However, subjects who did not undergo rehabilitation were more than twice as likely to suffer recurrent sprains than those who did rehabilitate their ankles. Thus, while quantification of postural control may not be able to predict those at risk of recurrent sprain in all instances, retraining of postural control after ankle sprain is nonetheless advantageous.

Strength Deficits. Strength deficits have been reported among individuals with CAI. Diminished strength has been reported for both eversion and inversion, although reports of no strength deficits also exist. Assuming that strength deficits do exist in some patients with CAI, the reason for such impairments is unclear. Is this weakness due to muscle damage or atrophy? Or could deficits be due to impaired neuromuscular recruitment in the presence of ankle-joint abnormality and, therefore, be causing functional insufficiency in the dynamic defense mechanism? Further research is needed to elucidate the role of strength deficits in CAI.

Relationships Between Functional Insufficiencies

The individual symptoms of functional ankle instability do not occur in isolation but are likely all components of a complex pathoetiologic paradigm. Joint injury results in proprioceptive decrements, which also lead to impairments in neuromuscular control. These changes limit the dynamic defense system of the ankle and predispose the ankle to recurrent episodes of instability. Altered muscle-spindle activity, as mediated through the γ-motoneuron system, may be the keystone to these interrelated symptoms. Figure 7 illustrates the feedback loop among the somatosensory system, the central nervous system, and the α- and γ-motoneuron systems. The key to treating functional insufficiency may lie in restoration of normal γ-motoneuron activity.

Relationships Between Mechanical and Functional Insufficiencies

The interactions between mechanical insufficiency and functional insufficiency and the relationships between the specific insufficiencies have not been clearly elucidated. Research is needed to examine the relationships between mechanical and functional insufficiencies and the effects of common treatment strategies on both types of insufficiency. While this new model of functional and mechanical insufficiency helps to explain the causative spectrum related to CAI, further developments are needed to improve the clinical outcomes of athletes who suffer from lateral ankle instability.

An example of an assessment technique that evaluates multiple insufficiencies is the Star Excursion Balance Tests. These tests are a series of dynamic postural-control tasks that require stabilization on one lower limb and a functional reach with the contralateral lower limb in different directions. In order to optimally execute these tasks, adequate postural control, strength, and range of motion must be present. Omstedt et al. demonstrated impairment in performance on the Star Excursion Balance Tests among a group of athletes with CAI. Further research is needed to identify which specific mechanical and functional insufficiencies are related to such impaired performance on these tests of dynamic balance. The development of more evaluation tools will allow the assessment of multiple insufficiencies simultaneously during functional activities.

Prevention of Chronic Instability

The natural progression of acute ankle sprains is for subjects to report gradual improvement as the initial symptoms of pain, swelling, and loss of function subside in the weeks after injury. The conundrum facing clinicians is how to convince patients with an ankle sprain that is improving that they need
to continue rehabilitation for several weeks or months after their initial symptoms have subsided. Comprehensive rehabilitation programs that emphasize proprioceptive, neuromuscular control, and balance training significantly reduce the risk of recurrent ankle sprains. While ankle taping and bracing also appear to be effective in preventing repetitive ankle sprains, it is unlikely that ankle taping or bracing alone is as effective as completion of a comprehensive rehabilitation program in combination with taping or bracing. Preventive measures to reduce the incidence of recurrent sprains must address pathologic laxity, arthrokinematic changes, and other mechanical insufficiencies related to mechanical instability and the proprioceptive and neuromuscular deficits seen with functional instability.

CONCLUSIONS

Lateral ankle sprains are among the most common injury seen in physically active populations, yet the treatment strategies being used by clinicians appear to be inadequate in preventing recurrence of these injuries. Appreciating the anatomy and mechanics of the rearfoot complex aids in understanding the pathomechanics of lateral ankle sprains and CAI. Mechanical instability of the ankle may be due to the specific insufficiencies of pathologic laxity, arthrokinematic restrictions, synovial irritation, or degenerative changes to the joints of the ankle complex. Functional instability is driven by insufficiencies in proprioception, neuromuscular control, postural control, and strength. The clinical management of patients with unstable ankles should include identifying symptoms of both mechanical and functional instabilities. Once specific insufficiencies have been identified, treatment efforts should focus on addressing these impairments and emphasis should be placed on reducing the risk of recurrent ankle sprains.

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Predictive Factors for Lateral Ankle Sprains: A Literature Review

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Objective: To review the prospective studies of ankle-ligament-injury risk factors.

Data Sources: We searched MEDLINE from 1978 to 2001 using the terms ankle, ligament, injury, risk factor, and epidemiology.

Data Synthesis: The results included many studies on the treatment and prevention of ankle injuries. There were, however, very few prospective studies focusing on identifying the risk factors that predispose an athlete to ankle-ligament trauma.

Conclusions/Recommendations: There is some agreement among authors with regard to the risk factors for ankle-ligament injury; however, considerable controversy remains. Although female athletes are at significantly greater risk of suffering a serious knee sprain, such as disruption of the anterior cruciate ligament, this does not appear to be the case for ankle-ligament sprains. Therefore, sex does not appear to be a risk factor for suffering an ankle-ligament sprain. Athletes who have suffered a previous sprain have a decreased risk of reinjury if a brace is worn, and the consensus is that generalized joint laxity and anatomical foot type are not risk factors for ankle sprains. However, the literature is divided with regard to whether or not height, weight, limb dominance, ankle-joint laxity, anatomical alignment, muscle strength, muscle-reaction time, and postural sway are risk factors for ankle sprains. Future research is needed on this topic to develop a consensus on all ankle-injury risk factors. This will allow future intervention studies to be designed that will reduce the incidence and severity of this common injury.

Key Words: ligament, injury, risk factor

Garlick was one of the first to identify the lateral ligaments of the ankle as the most commonly injured structures in athletes, and subsequent reports support this finding. As a result, retrospective and prospective studies have been performed to focus on the risk factors for lower extremity injuries and ankle-ligament sprains. In this review, we made an important distinction between retrospective and prospective studies. Only prospective studies can control the multiple variables that are difficult to reliably obtain and evaluate in a population of athletes at risk for suffering an ankle injury. For example, exposure data can only be documented through a prospective investigation, while variables such as baseline ankle laxity cannot be measured after the injury has occurred. There were too few well-designed studies available in the literature to perform a systematic review and, therefore, the purpose of our paper was to review prospective investigations of ankle-ligament-injury risk factors. We did not include studies of lower extremity injuries as a group, nor did we include retrospective studies. Our study was organized according to intrinsic (those from within the body) and extrinsic (those from outside the body) risk factors based on the classification system introduced by Williams. This review is important because the risk factors that predispose an athlete to ankle-ligament trauma should be understood before an intervention study designed to reduce the incidence of these debilitating injuries is implemented.

INTRINSIC RISK FACTORS

The intrinsic risk factors for sprains of the lateral ankle ligaments investigated through prospective studies include the following: previous sprain; sex; height and weight; limb dominance; anatomical foot type and foot size; generalized joint laxity; anatomical alignment, ankle-joint laxity, and range of motion of the ankle-foot complex; muscle strength; muscle reaction time; and postural sway.

Previous Sprain

Perhaps the most frequently studied risk factor for lateral ankle-ligament sprains is a previous sprain of this complex. This is based on the fact that disruption of a ligament compromises an important biomechanical stabilizer and creates partial deafferentation of the ankle. The literature is divided with regard to whether or not a previous sprain has an influence on the risk for a future sprain. One of the original prospective risk-factor studies is the work of Ekstrand and Gillquist, who enrolled 124 soccer athletes, examined each player at the beginning of the year, and then followed them for 1 year while documenting exposure to practices and games. They reported an increased risk for lateral ankle-ligament injury in athletes who had suffered a prior ankle-ligament sprain. Subsequent studies of soccer and basketball athletes and military recruits undergoing basic training found that they were at increased risk for lateral ankle-ligament injury after suffering a prior ankle injury. In contrast, studies of athletes participating in similar sports have revealed no increased risk for lateral ankle-ligament injury after suffering a prior ankle injury. One explanation for the divergent findings may be...
that the condition of the joint after injury not only depends on the index injury and the associated damage to the ligaments, muscles, and deafferentation of the joint but also on what type of rehabilitation was administered, whether or not the subject complied with the rehabilitation program, and the quality of recovery that was achieved.

Sex

The incidence of knee injuries, particularly disruption of the anterior cruciate ligament, is considerably greater for female athletes in comparison with male athletes. In contrast, the disparity of ankle-ligament sprains between the sexes appears to be much smaller. Hosea et al performed a comprehensive, prospective study on high school and collegiate basketball players. Female athletes were at 25% increased risk of suffering a grade I ankle sprain compared with male athletes; however, the relative risk between the sexes for the more serious grade II and III sprains, ankle fractures, and syndesmotic sprains was not significantly different. In addition, for both male and female athletes, the relative risk of suffering an ankle sprain doubled as the level of competition increased from high school to the collegiate level. This interesting finding is in contrast to anterior cruciate ligament tears, which increase substantially with increasing levels of competition for female athletes but not for males.

Our group has recently completed a prospective study of Division I collegiate athletes who participated in soccer, lacrosse, or field hockey. Before the athletic season started, subjects without a history of lower extremity trauma were identified and suspected ankle-injury risk factors were measured. During the season, subjects were continuously monitored and all ankle-ligament injuries were evaluated and graded by the same investigator. Men and women differed substantially in terms of many of the preseason risk factors (eg, height, weight, isokinetic strength, muscle-reaction time, and range of motion of the foot and ankle), and this led us to analyze the risk factor data separately for each sex. The number of ankle injuries per 1000 person-days of exposure to sport was 1.6 for men and 2.2 for women, rates that were not significantly different.

Height and Weight

Height and weight have been implicated as risk factors: when an athlete is in an at-risk position for inversion ankle trauma, an increase in either height or weight proportionally increases the magnitude of inversion torque that must be resisted by the ligaments and muscles that span the ankle complex. The investigation of collegiate athletes by our group demonstrated that height and weight were not independent risk factors for ankle sprains. Similar findings were reported by Sitler et al. In contrast, Watson found that male soccer athletes who sustained ankle sprains had greater height than those who did not. Milgrom et al reported that during basic training, male military recruits who were taller and heavier were at increased risk of suffering an ankle injury.

Limb Dominance

Limb dominance has been implicated as a risk factor for lower extremity trauma because most athletes place a greater demand on their dominant limb. Therefore, they produce increased frequency and magnitude of moments about the knee and ankle, particularly during high-demand activities that place the ankle and knee at risk. The literature is divided with regard to limb dominance as a risk factor for suffering an ankle-ligament sprain. In our investigation, limb dominance was unrelated to risk of ankle injury for male and female athletes participating in soccer and lacrosse and female athletes participating in field hockey. Similarly, Surve et al found that soccer athletes reported no difference in the incidence of ankle injuries between dominant and nondominant ankles. In contrast, Ekstrand and Gillquist noted that the dominant leg sustained significantly more ankle injuries in male soccer players, with 92% of ankle injuries affecting the dominant leg. These contrasting findings may have been the result of different study designs or the methods used for data analysis.

Anatomic Foot Type and Foot Size

Anatomic foot type (pronated, supinated, or neutral) does not appear to be a risk factor for ankle sprains; however, the classification system that characterizes anatomic foot type as pronated, supinated, or neutral may be inadequate for identifying abnormalities in foot biomechanics. This approach has not been related to musculoskeletal abnormalities, it lacks the specificity and sensitivity to identify abnormalities in foot biomechanics, and it is evaluated while a subject is standing barefoot and not during a situation when the lower extremity is at risk for injury. Therefore, specific and sensitive measurements of foot-contact mechanics that can be used during dynamic, at-risk activity need to be developed and used to determine if they are capable of identifying an ankle at risk for an inversion sprain. Kaufman et al were the first to use such an approach. Dynamic measurements of arch contact in Navy Sea, Air, and Land trainees were collected while they walked barefoot and in military footwear. Dynamic pes planus, pes cavus, and increased hindfoot inversion were risk factors that predisposed trainees to lower extremity overuse injury. Similar studies of ankle- and knee-ligament injuries are needed in athletes who take part in high-risk sports.

Milgrom et al showed that increased foot width is associated with an increased risk of suffering a sprain of the lateral ankle ligaments. This finding can be explained, at least in part, by the fact that during an inversion injury, an increased foot width is associated with an increased moment arm and corresponding inversion moment in comparison with a narrow foot.

Generalized Joint Laxity, Ankle-Joint Laxity, Anatomic Alignment, and Range of Motion of the Ankle-Foot Complex

Generalized joint laxity has no predictive value for ankle sprains when considering all athletes as a group and men and women as separate groups. To most professionals involved with the diagnosis and treatment of ankle injuries, increased joint laxity is considered a “sure bet” risk factor for an ankle injury because it indicates that a soft tissue restraint and its contribution to stability and neural intervention of the ankle complex may have been compromised. However, the literature presents conflicting findings. Barrett et al demonstrated that ankle laxity, measured with the standard anterior drawer and talar tilt clinical examinations, did not predict ankle sprains. In our initial work on this subject, measurement...
of ankle laxity with the anterior drawer test showed a trend in which increased laxity was associated with an increased risk of ankle injury, while the talar tilt test was not associated with injury. In our most recent study of collegiate athletes, the same trend was observed among women, and increased talar tilt was associated with increased risk of injury among men. This finding is supported by the earlier work of Glick et al, who reported a higher incidence of lateral ankle-ligament sprains in American football athletes with an excessive talar tilt (defined as greater than 5°) in comparison with those whose talar tilt was less than 5°. Likewise, Chomiak et al reported a higher incidence of noncontact ankle sprains among soccer players with an excessive anterior drawer and talar tilt. The discrepancy among these previous studies may derive from the use of the clinical examination and a grading system to evaluate joint laxity, which are not sensitive means of evaluating joint laxity, or from an inadequate sample size, which may not have included a sufficient number of subjects with increased ankle laxity.

Our recent study of collegiate soccer, lacrosse, and field hockey athletes revealed that ankle injuries were more common among women with increased tibial varum and calcaneal eversion range of motion, while no such relationship was found for men. Thus, alignment of the hindfoot in combination with the lower extremity is important when evaluating risk factors for inversion injury of the ankle.

Ankle dorsiflexion and plantar-flexion range of motion does not appear to be related to the risk of suffering an ankle sprain among collegiate soccer, lacrosse, and field hockey athletes. Ankle range of motion is also not associated with injury in ballet and modern dancers.

Muscle Strength

Although most would consider it intuitive that lower extremity strength is related to the risk of suffering an ankle-ligament sprain, only our group has investigated this with a prospective study design, and the findings from these studies differ. In our earlier study of collegiate athletes participating in soccer, lacrosse, and field hockey, ankle sprains were associated with higher ratios between ankle inversion and eversion peak torques, higher peak torques produced by plantar flexion, and a lower ratio between dorsiflexion and plantarflexion peak torques. In contrast, our recent study of the same level of athletes participating in the same sports did not reveal differences in peak-torque values between injured and uninjured athletes for dorsiflexion, planatar flexion, inversion, and eversion motions. In addition, the ratios between ankle inversion and eversion peak torques and between dorsiflexion and plantarflexion peak-torque values were not related to the risk of suffering an ankle sprain. The differences between these studies may be explained by differences in the methods that were used to analyze the data. In the initial study, women and men were analyzed as a group, while in the most recent study, women and men were considered separately. This is important because peak torque is sex dependent, as are other risk factors, and the analysis used combined data from men and women. Even risk factors having similar effects in men and women may not be detected in analysis of combined data if high values for women correspond with low values for men. Conversely, variables whose values differ greatly between the sexes may falsely appear to have an effect on risk if women are inherently at higher risk. In addition, in the initial study, we did not document exposure data and used the Student t test to analyze the data without adjustment for different sports, which may have been associated with different baseline risk values. In the recent investigation, we evaluated exposure data and performed data analysis using the Cox regression model to take into account both time at risk for injury and differences in risk associated with different sports.

Muscle-Reaction Time

Although previous studies have measured the peak torque developed during isokinetic dorsiflexion-plantar-flexion and inversion-eversion motions, it is unclear how to interpret these outcomes because most ankle injuries occur within a time interval that is much faster than that required to develop peak torque and at much higher velocities that those used to measure peak torque. From this perspective, both the force and temporal response of the muscles that span the ankle are important to consider. Therefore, in our most recent study of ankle-ligament injury risk factors, muscle-reaction time, or the time lag between joint perturbation and muscle activation (sometimes called the closed-loop efferent reflex response), was measured for dorsiflexion and inversion motions of the foot. Muscle-reaction times for both modes of perturbation were not predictive of injury in men; however, an interesting trend occurred in women. Compared with uninjured female athletes, the gastrocnemius muscle of female athletes with ankle sprains required less time to react, while the anterior tibialis muscle required more time to react in response to dorsiflexion perturbation. This combination introduces the hypothesis that the protective effect of the leg muscles on maintaining joint stiffness and stability through cocontraction may be compromised and suggests that a neuromuscular deficit may exist in those athletes who are injured.

Postural Sway

Recognizing that an athlete’s center of gravity changes during upright posture and that this is under control of both the central and peripheral nervous systems, Tropp et al used a forceplate to characterize the change in an athlete’s center of gravity (eg, postural sway) and related it to the risk of suffering an ankle injury. Postural sway was measured during the preseason in soccer players who were then followed for a complete season. An elevated postural-sway value identified an athlete at increased risk of suffering an ankle sprain. Watson characterized postural sway with a practical approach that involved measurement of the duration of time a subject could maintain a single-leg stance without touching down to recover balance. Those who could maintain a single-leg stance for at least 15 seconds were considered to have normal posture, while those who touched down to regain balance within the 15-second test were considered to have abnormal posture. Ankle sprains affected more subjects with abnormal posture than with normal posture. Similarly, McGuine et al used the NeuroCom Balance Master (NeuroCom International Inc, Clackamas, OR) to measure postural sway among a cohort of high school basketball players and demonstrated that subjects with increased sway scores suffered a 7-fold increase in ankle sprains compared with those with normal sway. We also used the NeuroCom system to measure postural sway, but we studied collegiate soccer, lacrosse, and field hockey players who had not suffered prior injury to their lower extremities. We did
not find a relationship between sway score and risk of ankle sprain.

**EXTRINSIC RISK FACTORS**

Extrinsic risk factors that have been investigated through prospective studies include bracing and taping, shoe type, and the duration and intensity of competition and player position.

**Ankle Bracing and Taping**

Review of the prospective studies of the effect of bracing on reduction in ankle sprains revealed a consistent finding: athletes with a history of ankle sprains who use a brace or tape experienced a lower incidence of ankle sprains. Tropp et al\(^6\) were the first to investigate the effect of a brace on soccer players. Three groups of athletes, each with a history of ankle sprain, were studied. The first group received no intervention (eg, control group), the second used a brace, and the third performed ankle-disk training throughout their season. Athletes who wore a brace or underwent ankle-disk training experienced a significant decrease in the incidence of ankle sprains in comparison with the control group. The protective mechanisms of the 2 interventions were thought to be different: the brace was hypothesized to provide mechanical support, while the protection imparted by disk training was attributed to a decrease in the functional instability of the ankle. Using a prospective study design, Surve et al\(^7\) also studied the effect of braces on the incidence of ankle-ligament injury among soccer players. Athletes were divided into 2 groups: those with no prior ankle sprain and those with a history of ankle sprain. Subjects in each group were then randomly assigned to the semirigid brace or unbraced group. Those with prior ankle sprains who used the brace had a reduced incidence of ankle sprains, but there was no difference in the severity of ankle sprains with or without the use of the brace. These observations led the investigators to suggest that the protection provided by a brace was not accomplished through mechanical support of the joint but through an improvement in proprioception. Using a similar study design, Sitler et al\(^11\) performed the most comprehensive prospective study of the effect of bracing on reducing ankle sprains among collegiate basketball athletes. Athletes were divided into groups according to the presence or absence of previous ankle sprains and were then randomly assigned to a group that wore a brace or a group that received no brace or tape. All athletes wore the same high-top basketball shoes, which provided an important control of this ankle-support variable. The incidence of ankle sprains was lower in athletes with a history of ankle sprains who wore a brace, but there was no difference in the severity of ankle sprains between the groups. McKay et al\(^5\) also studied basketball players and reported that using ankle tape for support decreased the risk of reinjury in athletes with a history of ankle-ligament sprains.

**Shoe Type**

Another extrinsic risk factor that has undergone investigation is shoe type. One of the first studies revealed that the incidence and severity of knee and ankle injuries in high school football players were reduced when the length of the shoe cleats was reduced. In contrast, 2 prospective studies have shown no correlation between shoe type and ankle sprains for military trainees and basketball players. Milgrom et al\(^6\) performed a well-controlled study that followed male military trainees during basic training. Half of the trainees used three-quarter-height basketball shoes (approximately 11 cm high) to train, while the other half used lightweight infantry boots (approximately 22 cm high). The incidence of ankle sprains between the trainees using the basketball shoes and those using the infantry boots was different. Barrett et al\(^6\) also performed a well-controlled study of basketball players who were randomly assigned to groups wearing low-top shoes, high-top shoes, or high-top shoes with an inflatable air chamber. No difference in the incidence of ankle sprains among the shoe types was noted. Although this study was well controlled, the authors stated that the low number of ankle sprains limited their findings. This is a concern because shoe type might have been shown to reduce the incidence of ankle injury if a larger sample size had been used. In the McKay et al\(^5\) study of basketball players, athletes who wore shoes with air cells in the heel-cup portion were at significantly greater risk of injuring the ankle than those who wore shoes without air cells. Although most would agree that current athletic shoes offer limited support to an ankle in response to inversion trauma, it is important to recognize that specific characteristics of the shoe may either reduce the risk of injury (eg, certain design characteristics may provide increased proprioceptive input) or increase the risk of injury (eg, restricted ankle range of motion, abnormal foot-shoe and shoe-surface traction, or increased inversion moment arm about the ankle complex). We did not find information about the effect of different characteristics of athletic shoes on the risk of ankle injury.

**Duration and Intensity of Competition and Player Position**

Although several prospective studies have recorded exposure data, only Ekstrand et al\(^3\) and Arnason et al\(^33\) have separated their data by practices and games. Ekstrand et al\(^3\) found that twice as many injuries occurred in soccer games as in practice, and there was no difference in risk of ankle injury among player positions. Arnason et al\(^33\) reported 4.4 ankle sprains per 1000 hours of participation in soccer games and only 0.1 sprains per 1000 hours of practice. Similar to Ekstrand et al\(^3\), Sitter et al\(^11\) noted no difference in risk of ankle injury among basketball player positions.

**CONCLUSIONS**

Most professionals involved in the care of athletes would agree that prevention of injury is important. However, when one considers the most common injury experienced in sport, ankle-ligament sprains, a dilemma arises because there is very little consensus in the literature with regard to the risk factors for ankle injury derived from well-controlled, prospective investigations. Our review of the available prospective studies found some consensus: (1) sex does not appear to be a risk factor for suffering an ankle sprain, (2) the use of a brace is effective for reducing the risk of reinjuring the ankle, and (3) foot type (classified as supinated, neutral, or pronated) and generalized joint laxity are not ankle-injury risk factors. At this point, there is little consensus in the literature with regard to whether or not height, weight, limb dominance, ankle-joint laxity, anatomical alignment, muscle strength, muscle-reaction time, and postural sway are risk factors for ankle sprains.
Most proposed risk factors for lateral ankle sprains remain controversial and require further investigation. For example, our prior work on this subject revealed differences in many of the intrinsic factors between male and female athletes. This led us to perform separate analyses for each sex; however, very few researchers have taken this approach, and most studies have focused only on male athletes. The recent literature has provided important advances with regard to identifying ankle-injury risk factors through well-controlled, prospective studies, yet much work is needed to properly identify ankle-injury risk factors. Future studies must be prospective in design, provide an equal distribution of male and female athletes when the sport under investigation involves both sexes, evaluate men and women separately if the risk factors are sex dependent, include the collection of exposure data (accounting for both practices and games), use a well-accepted system to classify and grade the type of ankle injuries encountered, and consider analysis such as the Cox regression model, which takes into account both time at risk and differences in risk associated with different sports.

Once the risk factors for ankle-ligament sprains are determined, future intervention studies can be performed to reduce the incidence and severity of ankle-ligament trauma.

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Factors Contributing to Chronic Ankle Instability: Kinesthesia and Joint Position Sense

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Lars Konradsen, MD, provided conception and design; analysis and interpretation of the data; and drafting, critical revision, and final approval of the article.

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Objective: To present a comprehensive review of the influence of altered kinesthesia and joint position sense on chronic ankle instability and to present a model connecting deficits in ankle position sense with the increased risk of sustaining lateral ankle sprains.

Data Sources: I searched MEDLINE for the years 1966-2001 using the key words ankle and kinesthesia or position sense and books on proprioception.

Data Synthesis: Study findings suggest a risk for unprovoked lateral ankle sprains when the lateral border of the foot accidentally catches the ground surface during the late swing phase of normal locomotion. In normal situations, the lateral border of the foot clears the ground by only 5 mm, and a small increase in ankle-position error may substantially increase the risk of a collision. Findings of affected kinesthesia and joint position sense in subjects with chronically unstable ankles dominate over studies showing nonsignificant results, but the answer is far from clear.

Conclusions/Recommendations: Changes in joint position sense and kinesthesia of a magnitude found in subjects with chronically unstable ankles can lead to an increased risk of sustaining lateral ankle sprains. Results from a small number of studies suggest that balance and coordination training can restore the increased uncertainty of joint positioning to normal levels.

Key Words: ankle injuries, kinesthesia, proprioception, position sense, sprains

Why measure kinesthesia and position sense in connection with chronic ankle instability? Several reasons explain why these rather cumbersome methods of assessing sensorimotor function have been applied to chronic ankle instability (CAI). First of all, in neurophysiology, proprioceptive information from the lateral part of the ankle joint was primarily elicited by mechanoreceptors in the lateral ligaments. If the ligaments were disrupted by trauma and then healed in an elongated state, ligament tension for a given angle of ankle inversion would be reduced and, subsequently, the mechanoreceptors would misinterpret the degree of inversion angle.

Finally, the subjective feeling reported by many injured athletes after a lateral ankle sprain is often a “loss of contact” with their ankles: the feeling of not being absolutely sure of the inversion or eversion position of the ankle during locomotion. Tests of kinesthesia and position sense were thought to be most likely to give an objective measurement to this subjective feeling.

To these primarily theoretic considerations, I would like to add our pathogenetic model, which tries to connect a deficit in position sense to an increased risk of stumbling during locomotion and, thus, sustaining a lateral ankle sprain.

TESTING FOR KINESTHESIA AND JOINT POSITION SENSE

Kinesthesia (joint motion detection) and joint position sense are both very precise sensorimotor functions, and measuring deficits in these functions requires accurate and sensitive equipment. Threshold levels of joint movement are typically less than 2°. A number of external input possibilities to the neuromuscular system (for example, the pressure of the strapping system on cutaneous receptors or the sound of motors producing the movement) must be excluded in order to receive a clear signal. The proprioceptive input is thought to be elicited close to the ankle-joint area but need not necessarily be restricted to the lateral ankle ligaments; injecting local anesthetics into these ligaments does not result in any change in kinesthesia and joint position sense.

The ability to detect a threshold level can be tested in a variety of ways, but the basic idea is always to move the ankle slowly within the normal range of ankle movement to test whether or not the subject can detect the discrete movements. As an example, Garn and Newton measured kinesthesia by moving the foot 5° in a plantar direction at a speed of 0.3°·s⁻¹ in a percentage of situations of a total trial and then asked subjects whether or not they felt their foot had moved. The
sensitivity for the “yes” and “no” signals was calculated as a measure of kinesthesia. In contrast, Lentell et al used the degree of inversion before conscious detection of movement as the kinesthetic measurement.

Measuring joint position sense requires the subject to match a set of index angles set by the investigator. Here the differences also are small (<2°), and precise measurements also require a precise method with accurate registration of limb motion and the elimination of input from other sources. The subject is always required to match an index angle in which the foot has been placed. There are, however, a variety of ways in which the index angle can be matched: using a visual analog scale, replicating the index angle with the contralateral foot, and copying the index angle with the ipsilateral foot, either actively or passively. The number of angles matched, the magnitudes of the angles, and the directions of the matching angles vary from study to study, as does the investigational equipment. The results are typically expressed in terms of a mean absolute error value of joint-position assessment, but the real errors with corresponding standard deviations about the mean have also been used.

None of these methods is superior to the others. However, they might not all measure the same ability. In a study by Konradsen et al, an anesthetic ankle block resulted in a greatly increased ankle-position error when the ankle was moved passively to the index angle. If the subjects were allowed to reach the index angles by actively inverting their ankles, the anesthetic block did not influence position sense. Both methods have been used as a measure of position sense. In the passive trials, the proprioceptive ability of the ankle receptors was assessed. In the active testing situation, subjects relied on proprioceptors in the nonanesthetized muscle-tendon system.

Regardless of the method, it is necessary to have strict control of the equipment, the tests, and the testing situations when measuring kinesthesia and ankle-position sense. For that reason, frequent testing (as can be done with postural sway throughout a course of rehabilitation) is not feasible for kinesthetic and proprioceptive tests in clinical practice, and they are almost exclusively applied in research.

KINESTHESIA AND POSITION SENSE IN CHRONIC ANKLE INSTABILITY

Kinesthesia, or movement threshold, has not been studied as extensively in the unstable ankle as in the knee. As previously mentioned, researchers have used very different methods of kinesthetic measurement. Garn and Newton found a significantly increased frequency of error (P < 0.01) when 20 subjects with CAI had to indicate whether or not their ankles had been moved from 0° to 5° of plantar flexion at a rate of 0.3°/s. Similar results with a similar test were found for 11 gymnasts with unilateral unstable ankles by Forkin et al. Lentell et al noted that the amount of motion necessary to register movement was increased by 1° (P = 0.044) when comparing inversion threshold in the injured and uninjured ankles of 42 subjects. In contrast, Reifshaeger et al found no difference between 25 subjects with CAI and 18 healthy controls when detecting thresholds of passive plantar-flexion and dorsiflexion movements.

For ankle position sense, Jerosch and Bischof showed an increased absolute error when replicating 3 inversion angles (5°, 15°, and 20°) in 16 subjects with unilateral CAI when comparing the stable and unstable sides. The difference between sides was approximately 0.9°. When the inversion angles 10°, 15°, and 20° were replicated 10 times each, 23 subjects with functionally and mechanically unstable ankles demonstrated a significant difference of 0.9° over 40 control subjects with stable ankles. Boyle and Negus also found a greater error in joint position sense for the plantar-flexed and inverted foot of a group with functionally unstable ankles when testing both actively and passively. In contrast, Gross noted no difference between 14 subjects with stable ankles and 14 CAI subjects in both passive and active angle replications. The angles (10° eversion, 10° inversion, and 20° inversion) were replicated twice.

Why some researchers detected a difference between subjects with CAI and those without, whereas others did not, has been ascribed to differences in the definition of CAI and to differences in the testing protocols. However, no investigators have shown that using different measuring techniques on the same population of subjects with CAI can provide different results. Most studies published on CAI and ankle kinesthesia and position sense have shown a deficiency in those proprioceptive functions, but results are not definitive.

ACUTE INVERSION INJURY AND POSITION SENSE

Is the deficit in kinesthesia or position sense seen in CAI caused by a predisposition, the result of repeated ankle inversion injuries, or the result of a single inversion injury that was never rehabilitated? Tropp found that it was possible to predict which subjects had the greatest risk of sustaining ankle-inversion injuries during a soccer season based on their preseason postural-balancing ability. A similar study has not been undertaken for kinesthesia and position sense, and I am not aware of any longitudinal studies of subjects sustaining repeated injuries.

Some studies are concerned with the effect of an acute lateral sprain on ankle position sense. Konradsen et al found the passive ankle-position replication error was increased by approximately 100% one week after an acute ankle injury in 46 subjects with previously stable ankles. The subjects received no organized rehabilitation, and after 12 weeks, a 33% increase in errors was still present. In contrast, Holme et al noted no difference in position sense between sides 6 weeks after an acute injury but noted differences in both postural sway and peroneal muscle strength. After the same time span, Leanderson et al found no difference between sides in a population of 73 patients. However, Glencross and Thornton found increased errors in passive replication of plantar-flexion angles in 24 subjects months after the initial ankle sprain. Severe sprains seemed to result in greater degrees of replication error than mild sprains, and the replication error was greatest with the ankle plantar flexed.

These results seem to suggest that a single sprain can cause a substantial deficit in ankle-position assessment and that returning to normal function is a slow process and may be incomplete if organized rehabilitation is not instituted.

A PATHOGENETIC MODEL OF UNPROVOKED ANKLE SPRAIN

As mentioned earlier, a number of tests are used to assess different aspects of proprioception and sensorimotor control around the ankle. Kinesthesia and ankle position sense are par-
MINIMUM TOE CLEARANCE

Figure 1. Close proximity between the lateral border of the foot and the ground during the late swing phase of the gait cycle. (Reprinted with permission.20)

ticularly time consuming and difficult to test. A problem with the easier tests, such as single-limb balance tests and agility tests, is that although these tests may be excellent indicators of the general proprioceptive state of the ankle, the direct connection between impaired balancing ability and the multiple ankle sprains is not obvious. I believe that we can make this pathogenetic connection between a defect in ankle position sense and the increased risk of sustaining ankle-inversion injuries with the help of the following biomechanical model.

In CAI, subjects sustain many of their repeated ankle-inversion injuries in situations that would not put subjects with stable ankles at risk. It has been said, “these are the people who trip over the flowers in a rug.” When I interviewed subjects with CAI, they uniformly stated that their disability seemed to be a 2-phase occurrence: they tripped, and then the ankle twisted. Thus, it seemed appropriate to concentrate on the movements and control of the lower leg during the swing phase of locomotion.

In the normal stride during level-surface walking, the latter part of the swing phase seems to require very accurate sensorimotor control. In this part of the stride, the lateral border of the foot passes just 5 mm above the ground surface (Figure 1).20 In a cadaver study, when the swing phase of the lower limb was simulated (Figure 2), Konradsen and Voigt21 found that if impact occurs between the lateral border of a foot inverted 10° and the ground surface, the foot rotates into 40° of inversion, 40° of plantar flexion, and 30° of internal tibial rotation (the limit of our set-up). The foot-ankle complex had lost its bony restrictions in this position. When the complex was loaded with the body weight at the anticipated time of heel contact, an inversion torque would be produced. This inversion torque would cause further forced inversion of the ankle, rendering it susceptible to injury.

In the normal stride, the foot is brought forward in approximately 10° of inversion, and this balance of passive inversion and eversion restraints creates stability. If the degree of inversion is perceived to be too great in the midswing phase, lateral muscle contractions can be instituted for correction. This regulatory mechanism has not been demonstrated directly, but indirect evidence exists for it.22 The frequency of midswing-phase peroneal muscle activity was measured during 100 gait cycles of vigorous walking. Application of an ankle support that held the ankle in neutral inversion-eversion significantly reduced the frequency of peroneal activity. It was proposed that the reduced need for eversion corrections was responsible for this reduction in the frequency of peroneal muscle activation.22

If we then return to measurements of position sense, we find that subjects with healthy ankles had inversion-angle replication errors of 1.7° ± 1.1°.14 The subjects’ chance of not incurring a rotational error of approximately 8° to 10° (which would make the lateral border of the foot drop 5 mm and engage the ground during late swing phase) is extremely small (less than once every 100 000 steps). After acute ankle-inversion injury, we found the ankle-position replication error increased by approximately 100% after 1 week.17 For these subjects, given their mean ankle-position-sense error with its standard deviation and postulating a normal distribution of the error, the risk of making a rotational mistake of 8° or more is approximately 0.1%. In other words, statistically, they trip once every 100 steps. Not many subjects with CAI are, however, this disabled in their everyday life. This model is purely static and does not account for activation of the lower leg muscles, nor does every stumbling incident necessarily result in a complete ankle-inversion injury. The model does, however, provide a reasonable explanation for the frequent sprains of the population with CAI. It underlines the pathogenetic importance of the sense of joint positioning among the different sensorimotor functions.
that are discussed in this issue, and it illustrates that small differences in replication errors can have a substantial clinical impact.

KINESTHESIA AND ANKLE POSITION SENSE DURING PHYSICAL ACTIVITY

Very little is known about the effect of activity on kinesthesis and ankle position sense, and the available information is nearly exclusively based on subjects with healthy ankles. Konradsen and Magnusson14 found that a normal warm-up of 20 minutes enhanced ankle position sense in a group of experienced cross-country runners. With fatigue, greater absolute errors of movement detection were noted by Forestier et al23 included were 8 subjects who performed isometric lower leg muscle training to fatigue. Whether improved kinesthetic ability can be achieved by prophylactic taping is uncertain. There may24 or may not13 be enhancement of ankle kinesthesia with ankle taping.

THE EFFECT OF COORDINATION AND BALANCE TRAINING ON ANKLE POSITION SENSE IN SUBJECTS WITH CHRONIC ANKLE INSTABILITY

Coordination and balance training (often designated as proprioceptive training) has proven very effective in reducing the frequency of ankle sprains in subjects with CAI: 80% were functionally stable after completing a well-designed program.25 There is no doubt that rehabilitation programs concerned with balance, coordination, and strength reduce postural sway and increase peroneal muscle strength. Whether this kind of training also enhances kinesthesia and position sense is less well studied. In a study by Eils and Rosenbaum,26 a group of 20 subjects with CAI improved their angle-reproduction ability significantly after 6 weeks of balance training. The same was found for a group of 20 subjects with healthy ankles 6 weeks after instituting an ankle strength-training protocol. Bernier and Perrin,27 however, did not register a change in active or passive position sense after a similar period of coordination and balance training.

The specifics of the training programs applied in these studies were not described in detail. Researchers using balance tests as the proprioceptive assessment have gone further in studying the frequency of training, and their results are discussed in other articles. However, if rehabilitation of the kinesthetic and ankle position senses primarily serves to increase the sensitivity of the higher neural centers to the information received from the ankle area, the exact rehabilitation modality may be less important than a high degree of stimulation and activity provided to the ankle area.

SUMMARY

Although the evidence is somewhat ambiguous, there is a measurable deficit in ankle kinesthesia and ankle position sense in subjects with CAI. Whether these deficits were present before the subjects’ ankle disability as a predisposition, the result of repeated inversion injuries, or the result of a single injury with insufficient rehabilitation is as yet unclear. After acute injuries, however, substantial deficits are apparent and without rehabilitation they seem to prevail.

Both kinesthesia and joint position sense are difficult proprioceptive abilities to measure. Measurements require a sur-plus of time and advanced equipment and laboratory set-ups. These measurements, therefore, are not the choice when frequent tests are warranted. Postural-balance tests and agility tests are superior. However, contrary to other ankle sensorimotor measurements, I believe it is possible to link a deficiency in ankle position sense with the actual clinical problem of repeated ankle-inversion injuries during locomotion using a biomechanical model. Although little information is available, it seems possible to enhance ankle position sense by warming up, at least in experienced runners. Alternatively, fatigue seems to increase kinesthetic errors. Rehabilitation activities such as balance, coordination, or lower leg strength training seem to reduce kinesthetic and ankle-position errors, but studies to date are too few to draw a conclusion as to the best rehabilitation modality concerning kinesthesia and ankle position sense.

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Is There a Link Between Chronic Ankle Instability and Postural Instability?

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Objective: To provide clinicians and researchers with an expanded perspective on the association between functional ankle instability and postural control.

Data Sources: I searched MEDLINE and SPORT Discus for the years 1966–2001 using the key words ankle, instability, and balance. Additional information was obtained from cross-referencing pertinent articles.

Data Synthesis: Conflicting reports have been published about whether postural control is disrupted in people with chronic ankle instability. The variety of testing methods and operational definitions used by various investigators make drawing a consensus difficult. In contrast, the results of investigations considering postural-control strategy disruptions in persons with chronic ankle instability have been compatible.

Since the work of Freeman et al.1–5 describing postural-stability alterations in patients with chronic ankle instability (CAI), a large focus of the sports medicine community has been on using postural-control tasks to prevent, assess, and rehabilitate patients with CAI. Freeman et al.1–5 suggested that alterations in postural control could be attributed to deficits in the afferent input arising from mechanoreceptors residing in the ankle ligaments and capsule (articular deafferentation). In addition to providing a basis for explaining the source of CAI, articular deafferentation has also been expanded to explain the source of chronic instability existing at other joints.6,7 Specific to the ankle, in addition to postural-control applications, the theory has been used to explain characteristics exhibited by people with CAI, such as deficiencies in the conscious perception of proprioceptive sensations (kinesthesia and joint position sense).8–11 Despite the popularity of the theory developed by Freeman et al.1–5 direct evidence supporting the importance of articular afferent information to the postural-control system in healthy individuals is largely debated.12 Aside from mechanoreceptor disruptions, other components of the postural-control system (PCS), such as strength, mechanical stability, and range of motion, often become altered in patients with CAI. The importance of these factors within the PCS would, therefore, suggest additional potential reasons postural control may become disrupted after injury.

The purpose of this article is to examine the link between postural control and CAI with the goal of expanding future research and clinical practice directions. To accomplish this goal, I present basic principles surrounding the physiology and assessment of postural control, review the literature considering postural instability in CAI patients, and examine the research investigating the role of ankle-ligament receptors in postural control. I will conclude with a synthesis of the material supporting potential topics for future research and clinical direction.

MAINTAINING POSTURAL EQUILIBRIUM

The mission of the PCS is to continuously maintain postural equilibrium during all motor activities of the body (Figure). For the convenience of discussion, the process of maintaining postural equilibrium can be considered in 3 parts. First, the body's position relative to the support surface and gravity and the positions of each segment relative to one another must be determined from afferent information. With respect to postural control, pertinent afferent information arises from vestibular, visual, and somatosensory sources. Next, the afferent information gathered from these 3 sources must be integrated and processed to determine the necessary motor commands. The motor commands are then executed by muscles along the entire kinetic chain. The exact spatial and temporal organization of commands must meet the demands of the functional task and environmental conditions.13 The last part of postural control involves the actual execution of motor commands by the neuromuscular tissues. Aside from the functional status of the skeletal muscle (ie, strength, endurance), the final outcome of a motor command depends upon many peripheral physiological...
The first decision in assessing postural control is identifying the type of task employed. Generally, tasks can be grouped into 3 categories: maintaining equilibrium during quiet stance, perturbation, or performance of voluntary movement. Analyzing periods of quiet stance allows assessment of the potential open-loop control schemes and the steady-state behavior of the PCS.23 The unexpected displacements of the body and surrounding environment that often occur during activities of daily living provide the rationale behind using perturbations.24 During activities of daily living that involve voluntary movements, conscious attention is often not required for maintaining postural control.13,25 Typically, once a conscious motor command is initiated (eg, running) the specific details of the movement (ie, sequence of muscle activation) are programmed by supraspinal areas (cerebellum, motor cortex) and spinal neural networks, while the conscious shifts its focus to another thought. Thus, it naturally follows that a comprehensive postural-control assessment should include circumstances that attempt to duplicate similar scenarios. The challenge arises in finding the balance between attaining reliable measurements and maintaining a “natural” situation.

The second major aspect in the design of a postural-control assessment deals with the particular conditions that will be manipulated in conjunction with the task. In an attempt to better focus on particular aspects of the PCS, sensory information, base of support (BOS), and support-surface characteristics are often manipulated. Altering the BOS or support-surface characteristics alone can also change sensory information. A sensory alteration pertinent to examining the link between CAI and postural control is eliminating or altering visual information.31-35 The advantage of noninstrumented measures is the lack of sophisticated or expensive equipment required to conduct an assessment. The most commonly used support surface is a fixed, firm, level surface. Unstable surfaces, such as uniaxial and multiaxial platforms, require faster stabilization mechanisms that originate from proprioception.30,31 Whether they better differentiate postural-control deficits in CAI patients remains unknown.

The last major decision that surrounds postural-control assessment is the actual variables to be measured. Both instrumental and noninstrumented measures have been developed and used in sports medicine populations. Noninstrumented measures include variables such as length of time in equilibrium32,33 and error scoring systems.29,34,35 The advantage of noninstrumented measures is the lack of sophisticated or expensive equipment required to conduct an assessment. The largest disadvantage of noninstrumented measures resides in reduced sensitivity. Instrumented measures can be derived from force-platform, kinematics, or electromyographic data. Center-of-pressure (COP) excursion characteristics are most frequently calculated during postural-control assessments in sports medicine settings. Center-of-pressure-based variables should not be confused with movement of the body’s center of mass. Rather, they represent the location and movement of the net ground-reaction-force vector in response to the corrective action being taken to maintain equilibrium.56

**ASSESSMENT OF POSTURAL CONTROL**

Investigators studying CAI and postural control have employed a wide variety of assessment techniques. Thus, a prerequisite to gaining an understanding of the link between postural control and CAI is to be aware of several fundamental principles governing postural-control assessment. Not only are the following principles important to postural-control assessments, they are also applicable to the design of rehabilitation exercise activities.
It is important to recognize that the reliability, validity, and sensitivity in detecting deficiencies of the tasks and variables used to assess postural control are largely unknown. Because of the potent influence these measurement-related factors have on research results and, therefore, on clinical inference, it is strongly recommended that this be a priority area for future research. Furthermore, because postural control has been described as a task-specific process, one must question the relationship between performance of a traditional single-leg-stance task and a functional movement pattern. A preliminary examination of this issue failed to reveal any significant relationships between 2 voluntary movement tasks (single-leg-hop stabilization test and Star Excursion Balance Tests) and traditional stabilization tasks (quiet, single-leg stance on fixed and multiaxial surfaces). This issue is also very applicable to the tasks used in rehabilitation programs. In other words, the efficacy of unstable-platform stance exercises in restoring functional activity proficiency is unknown and represents an area for future research.

EFFECTS OF CHRONIC ANKLE INSTABILITY ON POSTURAL CONTROL

Is Postural Control Disrupted in Patients With Chronic Ankle Instability?

At first glance, answering this question seems to be straightforward. Unfortunately, an in-depth analysis of the literature quickly leaves one buried in confusion. As discussed in several works within this special issue, the first source of discrepancy among investigations resides in the lack of universally accepted operational definitions of functional, mechanical, and chronic instability. Further complicating the topic are the various assessment approaches used by researchers. In addition to task, condition, and instrumentation variety, the reference group has consisted of the contralateral uninjured limb (intra-individual differences) and a healthy reference group (inter-individual differences). This section will focus on a review of those investigations considering postural-control disruptions in CAI patients.

Again, Freeman et al introduced the premise that ankle injury causes a disruption in postural control. It is important to recognize that this frequently cited investigation used simple observation and patients’ self-description of their performance to compare single-leg stance between the involved and uninjured extremities. Comparison of the results before and after a training program prompted the investigators to conclude that a regimen of coordination exercises reduced both observed postural deficits and subjective symptoms.

Advancement of the idea of Freeman et al concerning the link between postural stability and ankle injury by more objective instrumented approaches occurred with a series of investigations performed by Tropp et al. Specifically, these researchers employed a force platform to record COP movement during single-leg stance with eyes open. Soccer players with functional instability had significantly higher COP excursions independent of mechanical stability. In a subsequent investigation, Tropp reported no significant bilateral differences (injured versus uninjured) in soccer players with functional instability. However, a comparison of both limbs in the patients with chronically unstable ankles with a healthy reference group revealed significantly higher COP excursions. This result immediately offers 2 interpretations: (1) The patients with functionally unstable ankles may have a predisposition to functional instability, as evidenced by the poorer performance in the contralateral healthy limb; and (2) Functional ankle instability affects the PCS at a level that is high enough to influence stability during stance on either extremity. Support for the former interpretation can be gathered from previous work by Tropp et al and a more recent report that will be discussed in the subsequent section.

Using a similar assessment task (single-leg stance, eyes open) as Tropp et al, Konradsen and Ravn reported significantly altered postural stability (as measured by average distance away from the mean COP position) in patients with functional ankle instability. Similarly, Perrin et al compared 15 professional basketball players with a “long history” of ankle trauma (10–15 episodes) with a control group consisting of 50 healthy people (nonathletes). Their static test battery consisted of double-leg stances under eyes-open or eyes-closed conditions on a force platform. The dependent variables (excursion velocity and area) were also based on COP data. Significant differences between the 2 groups were noted for area (eyes open and closed) but not velocity. Further statistical analysis of Romberg quotients (eyes-closed results divided by eyes-open results) failed to reveal significant differences between the groups. The basketball group consisted of taller participants who also had a higher activity level than the control group. Both of these factors complicate the ability to confidently attribute the significant differences to a history of ankle sprains alone.

Investigations using noninstrument measures with fixed, firm-surface stances have also revealed significant alterations in patients with functional ankle instability. Lentell et al using an examiner to evaluate stability, compared eyes-open and eyes-closed single-leg stance between limbs (injured versus uninjured) in patients with unilateral functional ankle instability. Although 45% of the patients demonstrated symmetric performance, 55% exhibited deficits during stance on the involved extremity. In a similar manner, Forkin et al reported that 63% of gymnasts (9 women, 2 men) with functional ankle instability exhibited deficits during eyes-closed single-leg stance.

In contrast to the investigations that found significant postural deficits during stance on fixed, firm-support surfaces, several studies failed to detect differences. Baier and Hopf did not find significant differences between 22 patients with functional ankle instability and 22 healthy controls during eyes-open single-leg stance. Participants with positive anterior drawer and talar tilt tests were excluded. Dependent variables consisted of a battery of 6 COP-based measures: confidence ellipse, anteroposterior velocity, mediolateral velocity, total horizontal velocity, angular movement, and linear movement. The 2 latter variables were developed by the authors to characterize how frequently and how much the COP changes direction during a trial.

Isakov and Mizrahi also failed to demonstrate bilateral differences in 8 gymnasts with a history of repeated unilateral ankle sprains. In contrast to using COP-based variables, these authors used the average amplitude of the anterior-posterior and medial-lateral ground-reaction-force signals. The testing was completed under both eyes-open and eyes-closed conditions. Lastly, Bernier et al examined single- and double-leg stance stability in 9 patients with unilateral functional ankle instability compared with 9 healthy controls and failed to show any significant differences between the groups.
As previously mentioned, unstable support surfaces are theorized to stimulate a higher reliance on proprioception. Using this idea, Rozzi et al. compared single-leg stance performance on a multiaxial surface in 13 healthy individuals and 13 with functional ankle instability. The participants were asked to keep the support surface as level and motionless as possible during 20-second trials. Unlike force-platform-derived measures that depend on the location and magnitude of ground-reaction forces, the instrumentation used in this investigation was purely related to the platform orientation with respect to the horizontal. Participants were assessed before and after a 4-week, 3-days-per-week multiaxial-surface training program. Initially, performance was significantly poorer in the patients with ankle instability than in the control participants during trials with decreased platform stability (lower resistance to tilt). Interestingly, after the training program, the deficits in the group with instability resolved, and both groups demonstrated significant performance improvement compared with the pretest scores.

In addition to the fixed, firm-surface condition, Bernier et al. incorporated 2 moving support-surface conditions into their investigation. The first involved a 4° medial-lateral tilt (0.5°·s⁻¹), while the second was a 1.91-cm medial-lateral horizontal displacement (0.31 cm·s⁻¹). Theoretically, these conditions would require continuous reorganization of the body's center of mass over the moving BOS. The ankle joint would have been the likely location for the adaptations necessary to remain in equilibrium. Assuming varying degrees of static (mechanical) or dynamic (neuromuscular) ankle instability in their sample of participants with instability, compensatory adaptations would have become necessary at a proximal location. Although nonsignificant results were reported, it is plausible that differences may have gone undetected due to uncontrolled proximal-joint or upper extremity (or both) motions. Proximal-joint compensations will be further considered in the subsequent section.

**Are Postural-Control Strategies Disrupted in Patients With Chronic Ankle Instability?**

Numerous sensory and motor redundancy avenues exist in the PCS. Under normal conditions, healthy individuals may consider the redundancies to be an unnecessary luxury. In contrast, in a person with an abnormal PCS, the ability to use multiple compensatory sensory and motor pathways may mean the difference in maintaining equilibrium. This may be especially true under varying environmental conditions. As an extreme example, consider an individual with total peripheral neuropathy who walks across an unstable (movable) support surface. Without vision to provide compensatory information regarding lower extremity joint positions, the person may not be able to complete the task. Afferent information concerning joint position is important for determining body position and configuration and the temporal, spatial, and magnitude characteristics of the efferent commands (ie, joint position influencing muscle length-tension relationships). Although this represents an extreme example, it is a reasonable assumption that similar subtle situations exist after orthopaedic injury. Thus, it appears important that future orthopaedic postural-control assessments be designed and conducted with the goal of answering 2 questions: (1) Is postural control disrupted? (2) Are the strategies used to maintain postural control disrupted?

Several investigations considering CAI have already sought to consider these questions. Tropp and Odenrick examined the ankle and hip kinematics of single-leg stance (eyes open) in 15 patients with functional ankle instability and 15 healthy people. Specifically, these authors measured the horizontal positions of the shank, anterior superior iliac spine, and sternum-manubrium in the frontal plane. From the positional data, the root mean square of the ankle angle (angle between the shank and the sagittal plane) and the hip angle (the angle between the trunk and the supporting limb) across each trial was calculated. Center-of-pressure excursion was significantly increased, and subjects with instability displayed a higher reliance on the hip joint for postural corrections than healthy participants.

Further supporting the results of the above investigation was a similar, subsequent project by the same researchers considering the efficacy of ankle-disk exercises in patients with functional ankle instability. Using identical kinematic variables, they revealed significant decreases in postural sway as evidenced by the COP excursion, amplitude of sternum and ankle displacements, and root mean square of the hip angle. Although only the symptomatic limb was exercised, a statistical reduction in COP excursion was also revealed in the contralateral (healthy) limb of 8 participants with unilateral instability. Additionally, when the results of the ankle-disk training in the group with functional instability were compared with the healthy subjects in the previous study, similar statistical differences were revealed.

Using randomly timed small and medium medial-lateral support-surface perturbations, Pintsaar et al. also demonstrated postural-control strategy changes in people with ankle instability. Three groups of female soccer players were included in the study: (1) 12 healthy players, (2) 13 players with functional ankle instability who underwent an 8-week ankle-disk training program, (3) 11 players with mechanical instability (confirmed with positive anterior drawer tests) without functional instability. Dependent variables included latency of force production (measured by the forceplate in the support surface) and strategy scores (based on the magnitude of horizontal shear forces). No significant group differences with respect to the latencies were seen. A significantly increased hip strategy was revealed in the functionally unstable group compared with the healthy group before training. After training, the strategy differences were resolved, as no significant between-group differences were noted.

**THE LINK BETWEEN CHRONIC ANKLE INSTABILITY AND POSTURAL CONTROL**

The previous section demonstrated that while it remains controversial whether postural control is disrupted (ie, increased postural instability evidenced by COP excursions), more consistent evidence suggested that the manner in which postural control was maintained appeared to be altered in patients with chronic instability (ie, increased reliance on corrective actions at the hip joint). Assuming the strategies used to maintain postural control are altered in CAI patients, with or without presentation of gross instability, the next step is to establish the underlying physiologic basis. In other words, "What is physiologically altered in CAI patients that could account for the demonstrated postural alterations?" In attempting to answer this question, I will examine the role of ankle articular mechanoreceptors in postural control and present other potential factors linking postural-control deficits to CAI.
THE ROLE OF ANKLE MECHANORECEPTORS IN POSTURAL CONTROL

Again, it was Freeman et al.1,2 who originally proposed that joint deafferentation, or a loss of sensory input from the lateral ankle-ligament mechanoreceptors, accounted for their observations of impaired single-limb postural control in patients with CAI. Unfortunately, little direct evidence exists documenting the function of ankle articular inputs in postural control. Most of the research into the sensory aspects of postural control has focused on the roles of each broad source (vestibular, visual, and somatosensory) as a whole.18,34–66 Specifically, under the umbrella of somatosensory inputs (cutaneous, muscle, articular), more inquiries have been conducted concerning the roles of the muscle and cutaneous receptors than the articular receptors.

One of the reasons for the limited number of studies may be the difficulty in experimentally isolating articular mechanoreceptor function in vivo. Additionally, the numerous interactions and compensatory pathways existing among mechanoreceptors located in cutaneous, muscle, and articular tissues make attributing results to one particular population of receptors difficult.67 The complexity of muscle-spindle function provides a good example. Muscle spindles, in addition to containing specialized afferent nerve endings for conveying muscle length and rate of change in length to the central nervous system, also contain peripheral contractile elements. The contractile regions are innervated by gamma motor neurons (γ-MNs) and provide for the sensitivity of the muscle spindle to be adjusted. The level of γ-MN activation is under both descending (supraspinal) and peripheral influence (ie, final common input hypothesis).68

To date, only 2 studies69,70 have been published that used methods allowing the contribution of articular inputs in postural control to be determined. Hertel et al.69 determined the effect of isolated joint-afferent reduction on postural control by anesthetizing the anterior talofibular ligament and lateral joint capsule. Single-leg postural-control assessments were conducted under eyes-open and eyes-closed conditions using a fixed support surface and a slowly rotating support surface (plantar flexion-dorsiflexion and inversion-eversion). Postural control was measured by the net location of COP with respect to the foot and the amount of movement around the mean COP location. Alterations were seen in the mean COP location during both the fixed and moving support-surface conditions: a lateral adjustment during the fixed-surface condition and a medial adjustment during the rotating-surface condition after anesthesia. Movement around the mean COP location was not significant under either of the conditions. The authors suggested that an adaptive mechanism occurred after anesthesia to compensate for the loss of afferent inputs from the lateral ankle.

Using a more dynamic approach, the effect of anterior talofibular ligament anesthesia on multiaxial-platform stability was considered by DeCarlo and Talbot.70 The study consisted of a pretest, anesthetic injection, and posttest. Stability was significantly increased after anesthesia. The authors attributed the increased stability to a learning effect based on the repeated exposures. It is important to note that the methods used to measure platform stability were not sensitive, as they were based solely on whether the platform fell completely out of balance and contacted the underlying support bracket.

As extensions to the 2 investigations above, investigators at the Neuromuscular Research Laboratory (University of Pittsburgh, Pittsburgh, PA) recently concluded a series of investigations to identify the role of the lateral ankle-ligament mechanoreceptors in postural control during static, reflexive, and functional tasks. In addition to incorporating a wide variety of tasks, postural control was considered from a multivariate perspective by using electromyographic, kinematic, and force-plate measurements. Preliminary results of these studies are briefly presented below.

The first investigation was focused on the contribution of lateral ankle-ligament inputs to single-leg postural control.71 Postural control was measured during stance on fixed- and multiaxial-support surfaces (eyes open and closed), and a single-leg landing task. Fourteen healthy subjects underwent 2 treatment conditions (control, lateral ankle-ligament anesthesia) in a counterbalanced order (48-hour intertest interval). During the treatment condition, an anesthetic solution was injected directly into the anterior talofibular and calcaneofibular ligaments. Initial statistical analyses were focused on the means and variances of the electromyographic, kinematic, and forceplate data collected during each task. Analyses across all variables failed to demonstrate significant alterations in postural control between the 2 conditions.

The subsequent investigation involved 13 healthy subjects (7 men, 6 women) attending 2 testing sessions.72 At each testing session, subjects were injected bilaterally with either an anesthetic solution or a placebo solution into the anterior talofibular and calcaneofibular ligament. Before and after the injections, anterior tibialis, peroneus longus, peroneus brevis, and gluteus medius muscle electromyographic activity was collected following a high-speed standing inversion perturbation, treadmill walking, and jogging. Significantly decreased muscle function occurred after both the anesthetic and placebo conditions; however, there was no significant difference between the 2 solutions.

Based on these investigations, it would appear that isolated losses of articular mechanoreceptor input alone do not explain the postural alterations in CAI patients reported in the literature. Yet this should not be interpreted as a definitive declaration that lateral ankle-ligament mechanoreceptors do not have a role in postural control. Animal studies documenting the effects of mechanoreceptor stimulation on γ-MNs and the findings of suppressed activity of the dynamic ankle restraints after ligamentous distention suggest that articular receptors contribute to the process of maintaining postural control. It may be that their isolated role is very subtle (ie, influencing muscle-spindle sensitivity via γ-MNs) and goes undetected by currently available measurement tools and techniques. Further research is needed in this area. Again, the pertinent concept is that isolated articular deafferentation accompanying repetitive ankle trauma does not appear to be the cause of the postural alterations reported in patients with CAI.

OTHER POTENTIAL FACTORS LINKING POSTURAL-CONTROL DEFICITS TO CHRONIC ANKLE INSTABILITY

Accepting the idea that reduced mechanoreceptor input does not account for the postural alterations in patients with CAI naturally leads one to ponder the question: What is the cause of the postural-control alterations demonstrated in CAI patients? In answering this question, one has to revert to the composition and mechanisms involved in maintaining postural
control. In other words, to understand the relationship between postural alterations and CAI, athletic trainers must broaden their traditional perspective and consider the effects of injury upon each of the PCS components.

During an ankle-joint sprain, disruptions to the mechanoreceptors are believed to accompany the ligamentous and joint capsule tearing. Also, potentially occurring at the time of injury are tensile or compressive (or both) loading of the afferent fibers and nerves conveying the mechanoreceptive information to the central nervous system. Both of these events can lead to an immediate reduction in afferent input arising from the joint (ie, deafferentation). To date, experimental research has only considered the effect of isolated mechanoreceptor reduction on postural control. It may be that infliction of external loads by repetitive inversion injury on the afferent fibers adversely affects the conveyed inputs arising from populations of mechanoreceptors located in adjacent tissues. An additional explanation might be that damage to the muscle mechanoreceptors or their associated afferent fibers also occurs. Furthermore, sensory and tissue damage can affect the joints distal (ie, subtalar) or proximal (ie, knee) to the talocrural joint.

After acute injury, patients often present with voluntary guarding and inhibition, which may be attributed to pain or fear of reinjury. Over repeated injury episodes, such as in patients with CAI, the voluntary avoidance strategies may become more permanent and automatic elements of their motor programs. This may explain the bilateral deficits demonstrated in patients with unilateral ankle instability by Tropp 41 and the bilateral training responses reported by Gauffin et al. 52 In addition, reorganization of the central afferent pathways may occur after anterior cruciate ligament rupture. 73 Although the clinical significance of this finding and whether a similar change occurs after ankle-ligament injuries has yet to be determined, it could potentially explain postural alterations in CAI patients.

Analogous to the inversion-injury mechanism’s effect on the sensory nerve fibers, a similar situation appears to occur with motor neurons. Several investigators 74–76 have demonstrated decreased nerve-conduction velocities and nerve injury after inversion injury. Although the results of the studies can only be directly applied to subjects with acute injuries, one could reasonably speculate that repeated trauma to the motor nerves might lead to permanent neural disruptions and, therefore, an inhibited ability to control the temporal and spatial characteristics of muscle activation. Moreover, although no direct supportive evidence exists, it is a sensible conjecture that this idea in isolation could explain the shift toward increased hip strategies demonstrated by CAI patients.

Although deficits in muscle strength and endurance as contributory factors in CAI remain a controversial topic, it is important to recognize that these deficits affect the ability of the PCS to execute motor commands involving the ankle musculature. Finally, several of the biomechanical and physiologic characteristics appear to be altered in CAI. Many people with CAI (but not all) appear to have deficits in the mechanical stability of the ankle joint as revealed by excessive joint laxity during clinical stress tests and stress radiography. 8 The effect of decreased mechanical ankle-joint stability might require higher levels of ankle-muscle coactivation to maintain the joint in optimal alignment, thereby increasing reliance on corrective action at the hip joint. Additionally, many patients present with altered ankle range of motion, which also could influence the execution of motor strategies concerned with maintaining equilibrium.

**CLINICAL SIGNIFICANCE**

The clinical significance of the information presented in this manuscript can be focused on 2 major points. First, it remains unknown if postural control is disrupted in patients with CAI. The number of investigators reporting alterations is matched with investigators failing to find significant differences. The wide disparity in subject-inclusion criteria, assessment tasks, and variables tested makes drawing a consensus difficult. In addition to different experimental methods, one possibility to potentially explain the varied results is the altered strategies demonstrated in subjects with CAI. Depending upon the effectiveness of a particular strategy, deficiencies in the PCS may not be revealed in the absence of challenging tasks and environmental conditions. In other words, based on the investigations that revealed increased hip strategies, it is possible that the altered strategies enable patients to demonstrate normal equilibrium as measured by forceplate variables (especially COP), leading investigators to conclude that no differences exist. Several researchers have noted the large influence of ankle function on forceplate measures of postural control. 51,77,78 Future researchers should consider measuring postural control through multivariate measures, including electromyographic, kinematic, and forceplate variables under a variety of tasks and environmental conditions.

The second major clinically relevant detail is that reduced mechanoreceptor input in isolation does not appear to explain the postural alterations reported in the literature. Common to the investigations using isolated injections into the lateral ankle ligaments were no significant differences that could be attributed to mechanoreceptor anesthesia. Thus, other areas within the PCS must be explored as potential causes. It is very likely that the source of postural deficits in CAI patients is unique to each individual. In some patients, decreased mechanical stability may account for alterations, while in other patients, damaged afferent or efferent (or both) neural pathways might be responsible. Thus, clinicians need to evaluate patients individually to design customized rehabilitation strategies. Using the guidelines presented in the “Assessment of Postural Control” section, clinicians could design a progressive battery of tasks to target, challenge, and evaluate the various components of the PCS. During evaluations in the optimal setting, instrumented measures can be used to determine whether a postural-control deficiency exists and whether altered strategies are being used. Clinicians without access to sophisticated instrumentation may want to consider using the various noninstrumented measures available. It is important that the final stages of the evaluative and rehabilitation process involve functional tasks of increasing complexity to ensure synchronization of the individual PCS components to the overall motor system. Clinical activities need to be included that simulate the demands imposed by functional movements to determine the capability of the PCS to control posture in a “natural” context.

In conclusion, potentially more important than the issue of whether postural control becomes disrupted as a result of ankle injury is the effect on the selection of sensory and motor strategies. Given the documented and potentially related sensory, central nervous system, and motor alterations associated with CAI, it follows that the manner in which postural equilibrium
is maintained or restored would naturally become altered. Several immediate questions naturally follow acceptance of this idea: (1) When a strategy is not available because of the effects of injury, how is postural equilibrium maintained when that strategy is most appropriate? (2) Does a reliance on different motor strategies cause a predisposition to other injuries? (3) In the case of athletes, do altered strategies adversely affect performance? Thus, while research in this area began more than 30 years ago, a plethora of avenues is available for future investigation.

REFERENCES

Factors Contributing to Chronic Ankle Instability: A Strength Perspective

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Objective: To examine the concept of dynamic ankle stability and closely critique the relevant research over the past 50+ years focusing on strength as it relates to those with chronic ankle instability (CAI).

Data Sources: We reviewed the literature regarding the assessment of strength related to CAI. We searched MEDLINE and ISI Web of Science from 1950 through 2001 using the key words functional ankle instability, chronic ankle instability, strength, ankle stability, chronic ankle dysfunction, and isokinetics.

Data Synthesis: An overview of dynamic stability in the ankle is established, followed by a comprehensive discussion involving the variables used to assess ankle strength. Additionally, a historical look at deficits in muscular stability leading to CAI is provided, and a compilation of numerous contemporary approaches examining strength as it relates to CAI is presented.

Conclusions/Recommendations: Although strength is an important consideration during ankle rehabilitation, deficits in ankle strength are not highly correlated with CAI. More contemporary approaches involving the examination of reciprocal muscle-group ratios as a measure of strength have recently been investigated and offer an insightful, albeit different, avenue for future exploration. Evidence pertaining to the effects of strength training on those afflicted with CAI is lacking, including what, if any, implication strength training has on the various measures of ankle strength.

Key Words: isokinetics, lateral ankle sprain, chronic ankle dysfunction, functional ankle instability, mechanical instability, reciprocal muscle group ratios, E:I ratios, concentric, eccentric, dynamic ankle stability

Individuals who have experienced ankle sprains account for a substantial percentage of clinician referrals and emergency room visits annually. Injury to the lateral ligamentous complex results in more time lost from participation than any other single sport-related injury. Almost one half of patients with these injuries continue to exhibit a common and serious residual disability now referred to as functional ankle instability (FAI). The concept of FAI was first described by Freeman et al.² to classify patients with ongoing complaints of "giving way" of the ankle. Not to be confused with mechanical instability, FAI is characterized as joint motion that does not normally exceed a person's normal range of motion but is beyond volitional control. Functional instability can also exist in the absence of mechanical instability. Giving rise to chronic complaints of pain and swelling, recurrent injury and degenerative joint changes, chronic ankle instability (CAI) has been shown to be independent of the severity of the original injury and treatment received. Wilkerson et al described this as the enigmatic nature of CAI, in which no relationship between the method of initial treatment and the prolonged residual symptoms is apparent.

In spite of the comprehensive research efforts thus far, the primary mechanism underlying chronic ankle instability or dysfunction remains unclear. Identified contributing factors include ligamentous laxity, subtalar instability, syndesmosis instability, bony deformity, proprioceptive deficits, and (peroneal) muscle weakness. Consequently, CAI has become a complex phenomenon that is difficult to qualify and quantify.

Strength training has typically been an integral part of the rehabilitation process after lateral ankle sprains (LASs). In fact, strength-training exercises are often initiated as soon as pain-free range of motion is achieved and resistive forces can be tolerated. The primary goal of rehabilitation is to return the athlete to participation as quickly as possible. However, some athletes continue to suffer from the effects of repeated sprains despite clinical efforts to prevent these injuries from recurring. Our goal is to examine the concept of ankle stability and critique the relevant research that has occurred over the past 50+ years focusing on strength as it relates to CAI.

Dynamic Muscular Stability in the Ankle

The ankle-foot complex challenges the clinician. Movements at the foot and ankle occur at numerous articulations, including the talocrural, subtalar, and transverse tarsal articulations, rendering the biomechanics of this region quite complicated. Muscles that control the movements of these joints must also work around the changing axes of motion associated with the biomechanics of this region. As a result of this integrated movement, limitation at one joint may greatly affect surrounding structures. The challenge in understanding dy-
dynamic stabilization and its contribution to CAI will continue to plague, but at the same time intrigue, the clinician.

Dynamic joint stabilization is achieved by cocontraction of the muscles surrounding a joint. During activities that involve the lower limb, such as running, cutting, and jumping, the athlete relies on muscular cocontraction, in particular eccentric control, to minimize forces between the ground and the ankle-foot complex. As a result, athletes who are lacking or imbalanced in this muscular cocontraction ability may be susceptible to injury because they do not have the muscular ability to smoothly dissipate these forces in a coordinated manner. The excessive stress on the surrounding joint tissues often predisposes the athlete to injury.

Even with recognition of the important role of dynamic stability at a joint, little work has been done on the clinical applicability afforded by dynamic strength, particularly with the extensive use of isokinetic testing since the 1980s. This is surprising given the high incidence of ankle injuries and the increasing awareness of the ramifications of CAI. Perhaps researchers and clinicians have avoided testing and evaluating the ankle due to the intricate articulations and short polyarticularized segment, difficulty in evaluating the separate contributions of the numerous muscles operating at the ankle, mechanics of limb and joint stabilization, and subsequent alignment of joint axes of motion and their movements. Avoidance may also be due to disagreements among biomechanists regarding where ankle motion is actually occurring and differences in definitions of pronation-supination and inversion-eversion. Despite these constraints, clinicians and researchers are attempting to resolve the issue of dynamic strength and CAI using the talocrural (plantar flexion and dorsiflexion) and subtalar (inversion and eversion) joints.

Assessing Dynamic Ankle Stability

The capacity of muscles to produce force (strength) and afford stabilization to the joint can be assessed using either static (isometric) or dynamic (isotonic or isokinetic) contractions. Traditionally, strength-training exercises incorporated into CAI protocols follow a normal progression from isometric to isotonic activities, occasionally concluding with an introduction to isokinetic techniques. Similarly, stability in the ankle has been assessed using each of these types of strength measurements.

Isometric Assessment. Static, or isometric, activity is produced when muscle tension is created without change in the muscle’s length. The maximum amount of tension that one can create in a brief period of time (<5 seconds) is often referred to as the maximum voluntary contraction (MVC). As the maximal effort is sustained past 5 seconds, tension in the muscle progressively decreases because of fatigue. Isometric assessment offers the clinician a simple and inexpensive method to monitor strength. However, it has disadvantages when used in a research environment. Traditionally, the same muscle-strength grades used with manual muscle testing are also used to assess isometric strength. However, the measurements may be susceptible to error because of subjective grading. In addition, differences in testing position and the amount of resistance applied and variations in testing angles can all lead to measurement discrepancies. Isometric strength measurements can also be performed with the use of special testing equipment that can lessen the subjectiveness associated with the traditional grading schemes. These specialized devices include cable tensiometers, handheld dynamometers, handgrip dynamometers, pinch dynamometers, isokinetic dynamometers, and pressure algometers. Each of these devices is capable of measuring force output in a quantifiable term, whether it is in pounds, newtons, or radians. Handgrip and pinch dynamometers are typically used for assessing upper extremity isometric strength, while pressure algometers have been used extensively in the assessment of pain. Several types of handheld dynamometers have been employed to measure isometric ankle strength. It would also appear that the manual muscle techniques described in Daniels and Worthingham’s Muscle Testing35 textbook are the most common isometric test positions instituted.

Docherty et al34 used a MicroFET2 handheld dynamometer (MicroFET, Draper, UT) to measure dorsiflexion and eversion strength to the nearest 0.1 N. Similarly, Paris and Sullivan35 used a Nicholas hand-held dynamometer (Lafayette Instruments Co, Lafayette, IN) to examine isometric force generated during rearfoot inversion and eversion. This device is capable of measuring force output to the nearest 1.0 N. Furthermore, isokinetic dynamometers set at a velocity of 0 s–1 can be used to assess isometric strength. Holme et al36 used a Cybex 6000 isokinetic dynamometer (Henley Health Care, Sugarland, TX) to examine inversion, eversion, plantar flexion, and dorsiflexion isometric strength in their training subjects. The Kin Com dynamometer (Chattanooga Group, Hixson, TN) has similarly been used to examine isometric strength in the ankle. Other noncommercial dynamometers have also been employed to assess dynamic isometrically, usually consisting of a load cell to measure torque production and some laboratory-manufactured test apparatus. Geboers et al37 recently measured the effects of immobilization on ankle-dorsiflexion strength with such a device. Typically, 3 to 5 maximal isometric test repetitions are performed with each trial, which lasts 5 seconds. Rest periods of approximately 1 minute allow local circulation to be reestablished and fatigue due to lactic acid production to decrease.

Some experts believe that isometric training improves strength at a particular joint angle, while others believe that isometric training at one angle joint may have carryover to adjacent angles. Specificity is a critical issue, but the extremes to which it prevails remain controversial. Regardless, clinical isometric testing requires testing at numerous angles if detailed information is to be gained concerning the dynamic strength of the ankle muscles involved in CAI.

Isotonic Assessment. Evaluation of dynamic ankle strength is possible using isotonic methods. Isotonic activity is dynamic, involving a change in the muscle’s length. Isotonic strength testing requires testing at numerous angles. Both concentric (shortening) and eccentric (lengthening) muscle actions can be assessed with isotonic strength testing. However, isotonic measurement is the least used of the 3 different strength-testing techniques at the ankle. While isotonic exercises (rubber tubing, toe exercises, body-resistance exercises, and commercial equipment) are commonly prescribed during ankle rehabilitation, the use of the one-repetition maximum (1RM) isotonic test of ankle strength is relatively nonexistent. Recent reports have examined the force-elongation properties of rubber tubing in an attempt to quantify resistive force during a variety of exercise routines with these tubes; however, we found no published reports of using rubber bands to quantify isotonic strength.
muscle actions involving the ankle-foot complex is the lack of devices used for testing. Although the 1RM test is ordinarily used to assess the strength of large muscle groups, it is not typically used for the smaller muscle groups of the ankle region. Some of the newer isokinetic dynamometers also offer the availability of isotonic modes. These devices lend themselves to a more accurate assessment of isotonic strength, especially with smaller joints, such as the ankle, where isolation of specific muscle groups is difficult. Recently, Nadeau et al\(^{41}\) evaluated ankle plantar-flexion strength in the isotonic mode on a Biodex isokinetic dynamometer (Biodex Medical Systems, Inc, Shirley, NY). Isokinetic assessment of plantar-flexion strength provided different values of torque, velocity, and power depending on testing conditions (preload and range of motion) used. Furthermore, they suggested that in a clinical setting, it would be important to control for these conditions. Perhaps this is why isotonic testing of the ankle using these dynamometers is rarely performed. The need for further studies using isotonic test protocols is evident.

**Isokinetic Assessment.** The concept of isokinetic strength was first introduced by Hislop and Perrine in 1967.\(^{42}\) Isokinetic strength testing offers resistance at a constant speed (velocity), so the amount of resistance varies through the range of motion.\(^{29,31}\) For a movement to be considered truly isokinetic, the patient must provide maximal effort throughout the entire range of motion. Isokinetic dynamometers are safe to use and provide a very accurate assessment of strength throughout the available joint range of motion. Perhaps the greatest disadvantages to isokinetic testing are the expensive initial cost and maintenance. However, from a research perspective, the useful results derived from these isokinetic devices are considered the standard for strength measurement.

With the introduction of isokinetic dynamometry, the manner in which clinicians can quantify strength has vastly improved. Over time, numerous modifications have occurred, but the dynamometers continue to remain a reliable and valid way of assessing muscle performance.\(^{29}\) Their development has also permitted the attainment and control of velocity during maximal concentric and eccentric contractions.\(^{43}\)

While we may be experiencing a decline in the clinical use of isokinetic dynamometry and a reduction in the number of available manufacturers, research investigations continue. Having the ability to assess both concentric and eccentric actions of muscle gives the clinician the tools to evaluate strength deficits and monitor strength changes more closely as the rehabilitation program progresses. Contemporary evidence also supports the use of isokinetic dynamometry to examine reciprocal muscle-group ratios.\(^{25,44,45}\) Perhaps Perrin\(^{29}\) was right when he stated, less than a decade ago, that the arrival of active isokinetic dynamometry would potentially bring increased reports of concentric-to-eccentric ratios to the scientific literature.

One of the greatest challenges for the clinician and researcher involving the examination of isokinetic strength values relates to the vast disparity in how these values are reported. Clinicians and researchers need to use similar sets of values and language, which will make comparisons across studies easier and more applicable. Both peak and average torque values have been reported. Perrin\(^{29}\) reported high reliability with both measures. In addition, several other studies\(^{46-51}\) have established the reliability of isokinetic muscle testing of the ankle joint. It is important to remember that average torque values require a standardization of range of motion through which the test was performed, because force production at each point in the range of motion is necessary for determining the average. Expressing peak and average torque as a percentage of body mass enables comparisons among subjects despite body-size differences. Wilkerson et al\(^{15}\) advocated using average power data because the rate at which muscular tension is developed is as important as the magnitude of that tension. However, care must be taken to ensure that the units of expression are similar and that torque (force) production data are expressed using le Système International d'Unités (SI). Most isokinetic dynamometers and the computers with which they are interfaced can be programmed to report SI base units. In summary, the use of isokinetic dynamometry in the assessment of ankle strength has thus far proven to be objective, quantifiable, and reliable.

With such a complex series of integrated articulations, it is difficult to separate the effects of different muscles and joints working across the many angles of ankle-joint motion. This is particularly true for dynamic isometric-strength testing because different muscles are likely to be recruited at different parts of the range, but the use of isokinetics for dynamically evaluating strength is becoming more popular. Increased use may be attributed to the accommodating resistance, ability to use higher velocities or speeds of contraction, and closer approximation of functional speeds than other methods of strength evaluation. However, human muscle performance is not characterized by a constant speed of movement but by a continuous interplay of acceleration and deceleration. Functionally, muscle groups work together synergistically in particular activation patterns that vary from task to task. Although isokinetics may be a less-than-perfect simulation of human muscle performance, they are still considered by many to be the best indicator for quantifying functional performance, providing useful values to determine injury and rehabilitation status, and as a discharge criterion.

**Dynamic Stability Interpretation**

Once the method of evaluating human muscle performance has been selected, the clinician must decide how to interpret and use the information gained. Opportunities for interpretation and usefulness vary according to the evaluation method selected. A comparative standard is needed to distinguish between “normal” and “abnormal.”\(^{30}\) Yet this is difficult, because the normative data previously reported tend to be dynamometer or method specific and not directly applicable to other systems. The lack of direct application may be the result of differences in instrumentation, testing protocols, data reduction, and output.\(^{30}\) Furthermore, muscle performance varies substantially with age, sex, body mass, and activity level.

**Measurement Units.** Absolute values are often measured as maximal peak torques or force.\(^{6,15,22,35,46,49,52,53}\) The data are a useful comparison for a given subject from session to session but are not useful when making comparisons among subjects (general population, healthy or otherwise). When reporting the absolute torque values, typically a comparison is made with the same muscle or muscle group in the contralateral extremity. As the “gold standard” of measurement, a discrepancy of 10% or less is considered within acceptable limits.\(^{23,30}\) However, this method does not consider that an individual may have or have had a bilateral injury, causing the gold standard to be inaccurate.

Comparisons among subjects require a common baseline,
such that issues of body size and sex, for example, are not factors. Reporting isokinetic strength relative to body mass enables comparison and useful interpretation. Furthermore, the conversion of (isokinetic) absolute values to ratios permits such comparisons to be made with normative data and from any measurement system. Being able to clinically identify a muscle imbalance may enhance the clinician’s understanding of a patient’s problem and improve subsequent rehabilitation.

**Agonist-Antagonist Ratios.** Agonist-antagonist ratios were advocated to answer the dilemma of more objectively evaluating and comparing the muscle balance (or imbalance) around a joint. This ratio has permitted comparisons of dynamic strength values to be made between and within subjects or patients. Acceptable agonist-antagonist ratios for various muscle groups in both the upper and lower extremities have been developed, and at one time, they became an improved gold standard for evaluation. However, the major drawback is that the agonist-antagonist absolute values used to calculate the ratio may still be weaker than normal when contrasted with the absolute values obtained from the uninjured side, and yet, the ratio may be equivocal. A muscle imbalance would still exist, predisposing the patient to (re)injury.

Benefits to isotonic (fixed load, changing angular velocity) and isokinetic (fixed angular velocity, changing load) evaluation include selecting concentric or eccentric (or both) muscle actions. Concentric muscle actions involve shortening of the muscle-tendon unit, while eccentric actions involve lengthening of the muscle while attempting to resist the force. Although most of the early isokinetic reporting has focused on concentric actions, the benefits of eccentric actions are being more widely recognized. However, it is not advisable to draw comparisons between concentric and eccentric values. For example, maximal moment developed concentrically by the muscle decreases concurrently with increments in test velocity, whereas for eccentric actions, the tension generated by the muscle remains similar, regardless of test velocity. For the same test velocity, eccentric strength is greater than concentric strength, and the order of strength depends on contraction mode (eccentric > isometric > concentric). In order to achieve a certain force, lower levels of motor-unit activity are required with eccentric actions. Consequently, additional units not being used are available and can provide higher increments than with concentric contractions. Eccentric actions are less resistant to fatigue, generate more mechanical muscle tension, and maintain lower oxygen needs as a consequence of the muscle physiology.

During normal movements, human muscles follow a stretch-shortening cycle in which the eccentric-stretching phase of the muscle-tendon unit is followed by a concentric contraction. This well-established phenomenon is based primarily on the mechanical behavior of the series elastic element found in contractile tissue and tendons to generate maximum force production. Eccentric-concentric coupling uses the stimulation of various types of proprioceptors to facilitate an increase in muscle recruitment over a minimal amount of time, which may provide insight into an individual’s neuromuscular performance. The isokinetic determination of this maximal eccentric moment/maximal concentric moment, or E/C ratio, may indicate the coordination of the muscle groups involved, which would lead to greater net-force production and efficiency and reduced risk of injury. The E/C ratio also indicates how the nervous system is reacting with maximum speed to the lengthening muscle. Because the magnitude of the moments generated in both contraction modes is velocity dependent (yet less so in the eccentric mode), the E/C ratio is velocity dependent and increases proportionately with test velocity.

The reciprocal contraction-mode ratios may provide important clinical information, especially in the ankle, with regard to the capacity of the opposite muscle group to restarting the prime mover. Reciprocal-mode contraction ratios in the ankle may be expressed as concentric/eccentric (C/E) and eccentric/concentric (E/C) for both the inverters and evertors separately. Hartwell and Spaulding examined E/C ratios for the inverter and evertor muscles at various isokinetic velocities (60°·s⁻¹, 120°·s⁻¹, 180°·s⁻¹, and 240°·s⁻¹) in subjects with healthy and chronically unstable ankles using a Cybex isokinetic dynamometer (Cybex, Inc, Ronkonkoma, NY). The E/C ratios increased as velocity increased but leveled off (plateaued) at 180°·s⁻¹ and 240°·s⁻¹. They concluded that adequate E/C ratios in the chronically unstable ankle might exist in the absence of normal strength.

Now that it is possible to evaluate dynamic strength of a muscle using concentric and eccentric muscle actions, the co-contraction of muscle can be determined. Knowing the E/C ratio for a subject and how it compares with an individual’s contralateral extremity or with other individuals may imply an abnormal condition or a predisposition to injury. The clinical benefits of the E/C ratio are now recognized. For example, assume that isokinetic evaluation demonstrates weaker-than-normal evertor muscles, particularly at the higher velocities considered to be a better representation of functional performance. Ligamentous injury typically occurs when the peroneal muscles are called upon to work eccentrically in response to high-velocity movements. However, if the ability of the evertor muscles to work eccentrically is reduced, as would be reflected in the E/C ratio, functional muscle activity around the ankle is impaired under eccentric and high-velocity conditions, and CAI could result. Current knowledge regarding the range of these ratios refers mostly to the low-medium range of the velocity spectrum, because using high velocities to study eccentric muscle performance is not risk free. The upper limit for this ratio has remained at 2.0, with a lower end range of 0.8 to 0.9.

**Reciprocal Muscle-Group Ratios.** In determining return-to-play status and establishing rehabilitation goals, especially in the knee and shoulder regions, physicians and other clinicians frequently use reciprocal muscle-group ratios. In the ankle region, these ratios are typically expressed as EV/INV and EV/EV. The more traditional expression of the muscle action-mode ratios is that of EV/CON (EV evertor/CON invertor). Perhaps this ratio expresses our “traditional” viewpoint of the inverters acting eccentrically to slow the lateral displacement of the tibia in a closed kinetic chain. It also gives some credence to the need to examine inverter strength deficits in those with CAI. The opposite ratio expression involving EV/INT (EV evertor/CON invertor) has also recently been explored. This more “functional” expression of the ratio describes how the peroneal muscles may react eccentrically to slow the rate of inversion in an open kinetic chain. There has been some interest lately in functional ratio expressions using the thigh musculature. Aagaard et al recently reported on the use of functional reciprocal muscle-group ratios involving the hamstring and quadriceps muscles. Use of these ratios in the ankle region is in the developmental stages, and acceptable values
still need to be defined. However, we do know that the values are velocity dependent, such that with increasing test velocity, the CON \textsubscript{evertor}/ECC \textsubscript{inverter} ratio decreases and the ECC \textsubscript{evertor}/CON \textsubscript{inverter} ratio increases. Until more specific ratios have been defined in the literature, the clinician should use the ratios from the uninjured extremity as the gold standard for comparison.

Evidence involving reciprocal muscle-group ratios is limited. Results involving the shoulder rotators \cite{58} indicated that the range of reciprocal contraction-mode ratios for CON \textsubscript{external rotators}/ECC \textsubscript{internal rotators} was 0.48 to 0.34 (as velocity increased), and for ECC \textsubscript{external rotators}/CON \textsubscript{internal rotators} was 0.69 to 0.84 (as velocity increased). Whether these ranges are indicative of reciprocal contraction-mode ratios at smaller joints, such as the foot and ankle, remains to be determined. Recent works by Buckley et al. \cite{45} and Kaminski et al. \cite{44} involved the use of reciprocal muscle-group ratios for ankle isokinetic-strength measurements. Buckley et al. \cite{45} examined differences in eversion (E)-to-inversion (I) strength ratios between the injured and uninjured ankles of subjects with unilateral CAI. \cite{45} Maximal peak torque (PT) and average torque (AT) values normalized for body mass (kg) were used to calculate the EV \textsubscript{CON}/INV \textsubscript{ECC} and EV \textsubscript{ECC}/INV \textsubscript{CON} strength ratios. PT EV \textsubscript{CON}/INV \textsubscript{ECC} ratios ranged from 0.34 to 2.38 Nm/kg, while PT EV \textsubscript{ECC}/INV \textsubscript{CON} ratios ranged from 0.62 to 3.77 Nm/kg. The AT EV \textsubscript{CON}/INV \textsubscript{ECC} ratios ranged from 0.25 to 2.54 Nm/kg, while the AT EV \textsubscript{ECC}/INV \textsubscript{CON} ratios ranged from 0.65 to 3.53 Nm/kg. On closer examination of the mean values, it is apparent that the EV \textsubscript{CON}/INV \textsubscript{ECC} ratios for both PT and AT were below 1.0. Ratios at 30°-s\textsuperscript{-1} were consistently higher than those at 120°-s\textsuperscript{-1}. Conversely, the EV \textsubscript{ECC}/INV \textsubscript{CON} ratios for both PT and AT were all higher than 1.0. Here again, the ratios derived at 30°-s\textsuperscript{-1} were higher than those at 120°-s\textsuperscript{-1}. The ratio values of more than 1 are to be expected whenever the ECC values are placed over the CON value in the ratio equation because more force (torque) is generated eccentrically according to the isokinetic force-velocity relationship for the ankle. \cite{61} Interestingly, no differences in strength as measured by the E:I ratios were found between the 2 ankles in these subjects. Another study by Hartsell involving the ankle demonstrated that the CON \textsubscript{evertor}/ECC \textsubscript{inverter} ratios ranged from 0.45 to 0.76, whereas the ECC \textsubscript{evertor}/CON \textsubscript{inverter} ratios ranged from 1.11 to 1.83 with increasing velocities (H. D. Hartsell, unpublished data, 2001). For the group with CAI, these ratios were 0.37 to 0.66 and 0.81 to 1.16 for the reciprocal contraction-mode ratios identified, respectively. Recent work by Kaminski et al. \cite{44} focused on the differences among the ratios established with the FAI group and a group of healthy individuals serving as controls. Until a database of normative isokinetic-strength ratios for the ankle-group and a group of healthy individuals serving as controls. The analysis and practical use of multijoint motion are of considerable interest in rehabilitation because of the increasing awareness of the need to integrate motion and emphasize the whole as opposed to the part. Although the total moment output may be isokinetically measurable, the individual contributions of the muscle and muscle groups responsible for executing the motion may not be directly determined. However, isokinetic evaluation is still the best approximation of functional human muscle performance to indicate the individual's dynamic limitations. The advantages and limitations must be clearly recognized and understood.

**Ankle Force-Velocity Relationships.** Muscle fibers shorten at a specific speed or velocity while concurrently developing a force used to move a segment or external load. \cite{62} Hill's \cite{63} classic work provided a model to explain the mechanical behavior of muscle. From his work, the study of muscle force-velocity relationship (FVR) began.

Muscles create an active force to match the load in shortening. The active force continuously adjusts to the speed at which the contractile system moves. \cite{64} With low-load conditions, the active force is adjusted by increasing the speed of contraction, while under high loads, the muscle adjusts the active force by decreasing the speed of shortening. Knowing the mechanical properties of muscle may provide us with a better understanding of how the motor act is performed, and ultimately, lead to improved performance.

The function of muscle is to produce force. It performs this in 1 of 3 ways. The muscle can shorten (concentric action), lengthen (eccentric action) and develop force while being elongated by an external force, or maintain a constant length (isometric action). A considerable amount of research has been done to examine the FVRs of muscles both in vitro and in vivo.

The concentric FVR follows a hyperbolic pattern that was initially proposed by Hill. \cite{63} with little alteration since (Figure 1). \cite{65} As the velocity of contraction decreases, the force produced increases. In human experiments, a neural-inhibiting mechanism is activated at very low velocities to limit the amount of force production, \cite{63} which appears to prevents injury to the contracting muscle.

Most FVR studies before the mid 1980s were primarily focused on the shortening (concentric) action and to some extent on the isometric action of muscle. However, it is important to remember that a muscle can produce force while lengthening, commonly referred to as eccentric action. In eccentric action, the muscle lengthens while it works. The net muscle moment is in the opposite direction from the change in joint angle; the mechanical work is negative. \cite{66} Experimentally, it is difficult...
to conduct research involving eccentric exercises because an external device must be available to do work on human muscle and to overcome the strength of the subject. The motor must provide an external force exceeding that of the muscle. Isokinetic dynamometers are now available to help the clinician and researcher study these events. Generally, the FVR produced during an eccentric muscle action is opposite to that seen in the shortening or concentric muscle action (see Figure 1). With eccentric actions, the muscle resists stretch with a force greater than it produces during concentric actions. A closer look at the muscle cross-bridge structure helps to explain this phenomenon. The force required to break the cross-bridge protein links within the sarcomere is greater than that required to hold them together. Each of these attachment-separation reactions produces a recorded tension (resistance to stretch) by the muscle but with no apparent energy consumption. This occurs because the cross-bridge has not cycled but continues to remain in the high-energy state. Additionally, the elastic properties and the stiffness of the muscles that are stretched provide other sources of force generation. Increased extensibility and depressed inhibition of the Golgi tendon organs may also assist in generating the larger force production. This increase in extensibility allows for a more efficient transfer of muscle tension to the connective tissue-tendon complex.

During the initial stages of lengthening, when the load is slightly greater than the isometric maximum, the speed of lengthening and the length changes in the sarcomere are small. As the loads approach 50% or more of the isometric maximum, the muscle elongates at a very high velocity. Tension increases with speed of lengthening because the muscle is stretching as it is acting eccentrically. The eccentric force-velocity curve ends abruptly at some lengthening velocity when the muscle can no longer control the movement of the load.

In 1997, Kaminski et al examined the FVRs for ankle eversion and plotted the results using trend analyses. This is the only study known to plot FVRs of the ankle evertors using both concentric and eccentric data. The major finding involving the concentric data was that a linear relationship best described the concentric FVR (Figure 2). In fact, the linear trend accounted for approximately 84% of the variance for concentric force. This supports the theory that, as the velocity of muscle shortening increases, the force production decreases.
closed-chain stance and movement. Further research is needed to examine this theory more closely.

Promotor weakness, evertor weakness, and calf dysfunction were all terms used to describe the cause of CAI. Regardless of the label, peroneal weakness and the need for strengthening have received considerable attention in the literature as a leading cause of CAI. Bonnin was the first to mention that the frequency of ankle sprains depended on muscular control. In the untrained, a false step may catch the weak muscles “off guard” or simply overcome their resistance. Bonnin added that additional leverage, possibly due to the rotation away from the midline, puts excess strain on the ligaments, resulting in frequent sprains. He encouraged the development of muscular control by the peroneal muscles. In a follow-up study of 133 ankle sprains, Boscin et al. reported that peroneal weakness was the most significant factor contributing to recurrent ankle sprains. Fifty-one percent of the patients had some form of rehabilitation postinjury. Manual muscle tests revealed peroneal weakness in 22% of the ankles examined, and of the 35 injuries associated with both residual changes (increased mobility and decreased strength) and ankle symptoms (recurrent sprains, instability, and pain), 66% had peroneal weakness. They theorized that the weakness was the result of overstretching of the peroneal muscles, disuse atrophy, or both. Staples published a 15-year follow-up on 73 major lateral-ligament injuries, including 51 ankles. Manual muscle tests were again performed on the peroneal muscles, and some degree of weakness (although never severe) was found in 43% of the symptomatic ankles. Although the numbers were small, he concluded that peroneal weakness was one causal factor that could easily be treated, with obvious symptomatic improvements ensuing. Staples later studied 27 ankles having immediate surgical treatment for ruptures of the fibular collateral ligaments. All cases involved serious athletes, with an average age of 19.7 years. On follow-up, peroneal muscle weakness and some form of functional instability were present in 3 patients several months after surgery. All 3 patients recovered fully between 10 and 19 months after injury, following a period of continued manual-resistance exercise intended to strengthen the peroneal muscles. Perhaps the greatest pitfall with the conclusions of these early studies examining CAI and strength was the fact that highly subjective measures were used to evaluate muscle strength (ie, manual muscle tests). Manual muscle tests provide a less accurate measure and do not reflect the true dynamic nature of inversion-eversion subtalar joint motion.

Kamper and Malone indicated that the evertor and pronator muscles play a major role in preventing ligamentous injury to the ankle. Cyriax offered a diagnostic examination to determine peroneal involvement in the ankle that turns over easily. If the strain can be easily reproduced and an audible click is heard as varus stress is applied to the heel, the fibular collateral ligament has obviously been overstretched. If this sign is absent, the cause would appear to be related to the delayed contraction of the peroneal muscles. He further added that if the peroneal muscles are weak, often the first complaint from a lower motor-neuron lesion is recurrent sprain at the ankle. Arneheim and Prentice stated that the peroneal muscles, mainly the peroneus longus muscle, must be exercised to provide eversion strength and prevent the foot from being forced into inversion.

Tropp was the first to examine isokinetic strength and CAI as he measured peak torque with a Cybex isokinetic dynamometer. He assessed strength of dorsiflexion and pronation ankle motions at 30°·s⁻¹ and 120°·s⁻¹. Although the sample was small, each subject had unilateral functional ankle instability. A significant difference in peak torque for pronation was evident between ankles with and without functional instability. He concluded, however, that the muscular impairment was due to inadequate rehabilitation and secondary muscle atrophy and not true FAI, as his subjects had reported.

Several investigations have contradicted the premise that peroneal muscle weakness is associated with chronic ankle instability. Lentell et al. despite having hypothesized that differences would exist, did not find evertor weakness to be associated with CAI. Ankle inversion and eversion testing was done on the Cybex II isokinetic dynamometer at speeds of 0°·s⁻¹ and 30°·s⁻¹. A total of 33 subjects (17 men, 16 women) participated in the study. Interestingly, 4 subjects (12%) demonstrated deficient evertor strength in the injured ankle of 20% or greater when compared with the opposite, uninjured limb. They suggested that a progressive resistive-exercise program to strengthen the evertors may be beneficial for a minority of subjects with significant deficits in evertor strength. The authors tested only concentric and isometric strength and encouraged future study to examine the muscular activity of the evertors under eccentric and high-velocity conditions. In a follow-up study, an additional 42 subjects were tested isokinetically at speeds of 30°·s⁻¹, 90°·s⁻¹, 150°·s⁻¹, and 210°·s⁻¹, and once again, no significant differences were found between the involved and uninjured ankles.

Schraeder investigated concentric and eccentric muscle function in subjects with chronically sprained ankles. After 40 subjects were divided into 2 groups (healthy versus chronically sprained), eversion and dorsiflexion strength was assessed isokinetically on the Kin Com dynamometer. He concluded that lack of concentric muscle strength was not a factor contributing to chronic ankle sprains. As speed increased from 60°·s⁻¹ to 180°·s⁻¹, eccentric torque values increased regardless of group assignment. Interestingly, a significant difference existed eccentrically in that the chronic-sprain group was stronger than the never-sprained group. The author stated that, for this particular group of subjects with chronic sprains, the restoration of muscular strength postinjury resulted in higher torque production.

Ryan tested concentric eversion strength in 45 subjects with unilateral CAI using a Cybex dynamometer at a velocity of 30°·s⁻¹. Finding no differences in eversion strength between the CAI ankle and the opposite uninjured ankle, he concluded that evertor weakness was not a dominant factor in those with CAI. Quite surprisingly was his finding of differences in inversion peak torque between the ankles. He theorized that the inversion deficits might have resulted from selective inhibition or deep peroneal nerve dysfunction as a result of overstretching the peroneal nerve. Nitz et al. have provided evidence that the deep peroneal nerve may be compressed after LAS. Ryan speculated that LAS renders the inverter motor-neuron pool less excitable, while the evertor motor-neuron pool is not affected as much. The examination of inversion strength and CAI is an area ripe for further research.

Bernier et al. assessed eccentric ankle inversion and eversion strength in subjects with unilateral functional instability. Peak torque was measured isokinetically at 90°·s⁻¹. No differences were seen in either inversion or eversion strength between the healthy and functionally unstable ankles.

McKnight and Armstrong were interested in strength as a
factor in the criteria for return to play after LAS. They measured eversion and dorsiflexion strength at 30°-s⁻¹ and 240°-s⁻¹ and found no differences in strength between those with uninjured ankles and those with unilateral CAI. They suggested that return-to-play criteria be based on factors other than strength.

Wilkerson et al.¹⁵ set out to examine inversion and eversion strength in 30 physically active subjects who had either acute ankle injuries or symptoms of CAI. Isokinetic strength was assessed at velocities of 30°-s⁻¹ and 120°-s⁻¹. No differences in eversion strength were noted between the ankles, but inversion-strength deficits were found. They stressed the importance of eccentric inversion in the control of lateral displacement of the lower leg, especially during the LAS injury. Additionally, they suggested that, despite the widespread focus on strengthening of the evectors in ankle rehabilitation, the latest evidence suggests a relationship between deficits in invertor strength and lateral ligament injury.

In a later study, Kaminski et al.²² compared concentric and eccentric isokinetic and isometric eversion ankle-strength measurements among subjects with unilateral CAI and subjects with no history of LAS. They assessed eversion peak torque at 7 velocities and found no significant differences in strength between the groups, concluding that those with unilateral CAI did not appear to have eversion-strength deficits and that, unless evidence of clear weakness exists, clinicians may find eversion-strength training exercises unnecessary.

A clinically important question remains to be addressed: Why are there no eversion-strength deficits between healthy and chronically unstable ankles? Glick et al.⁸⁷ observed that those with unilateral CAI exhibited an increased amount of inversion just before heel strike. Tropp et al.⁸⁸ later presented evidence that the ankle is inverted before heel strike and that an inversion lever is created through the subtalar joint, resulting in a varus thrust if the peroneal muscles do not counter, with the end result being an ankle sprain. Thus, the theory suggests that the peroneal muscles are active to counteract this motion (varus thrust), preventing excessive inversion from occurring with each step during the gait cycle. Bernier et al.⁹⁰ noted that this is somewhat of a compensatory mechanism, with the peroneal muscles called upon to stabilize the ankle with every step. Another interesting phenomenon is that most of the studies examining CAI involved subjects who have previously undergone strength training as part of their rehabilitation yet still experience episodes of instability. This supports the contention by several authors⁶⁻²²,²₃,⁵₃,⁸₅ that lack of strengthening may lead to further ankle instability, but that strength rehabilitation may counteract future episodes of instability due solely to eversion weakness. It can be said that strength rehabilitation can improve the functional disability that muscle weakness purportedly contributes to CAI.

Testing of motions other than eversion has also been performed while trying to link strength deficits to CAI. Each of the 3 remaining ankle motions (inversion, plantar flexion, and dorsiflexion) has been studied using isokinetic strength assessments. Ryan⁸ and Wilkerson et al.¹⁵ reported inversion-strength deficits in those with CAI or after lateral ankle sprain. Reflexive inhibition of the muscle producing the motion (inversion) that caused the initial injury may occur after the ankle-joint injury.⁸,⁸¹ The fact that inversion deficits may exist in those with CAI has led to the more recent examination of eversion-to-inversion (E/I) reciprocal muscle-group ratios. Porter et al.⁸⁹ examined eversion and dorsiflexion strength (PT/body weight ratios) and time-to-peak torque values between a group of 15 FAI subjects and matched controls. Time to PT was measured in dorsiflexion using a simulated stretch-shortening cycle protocol on the Kin Com isokinetic dynamometer. An eccentric muscle action immediately preceded a concentric counteraction for the ankle dorsiflexors. Interestingly, no differences in strength or time to PT existed between the groups. The authors had expected differences, particularly relating to the time to PT between the groups. This was based on the premise that amortization time in a stretch-shortening cycle movement would be significantly increased (longer time to concentric contraction) in a group of subjects with unilateral FAI. One limitation was that the Kin Com dynamometer used in that study can only calculate time to the nearest 0.01 second. The stretch-shortening cycle phenomenon involves very quick and precise transition periods most likely translated in more diminutive timing phases. Further research in this area is definitively warranted.

Lastly, and perhaps most important is the challenge proposed to researchers concerning the actual presence of FAI in subjects recruited for research investigations. No universally accepted definition of FAI exists, nor is there any requirement as to how often distortions need to be sustained or to what degree external provocation needs to be carried out. Konradsen et al.⁹⁰ suggested that in defining functional instability, it is of great importance that the inversion injuries and the giving-way episodes are experienced in situations in which ankle-stable subjects would not normally sustain injuries. The subjective nature of determining FAI and the lack of a consistent set of criteria for FAI may not be providing us with the true subject pool needed to study this phenomenon further.⁹⁰ The recent release of a standardized set of criteria for establishing FAI is an attempt to combat this problem.⁹¹,⁹²

Until the research community settles on a standardized set of criteria for classifying FAI, difficulties in trying to compare and contrast the research evidence will persist. Further research is also needed to examine the relationship between mechanical and functional instability and ways in which the mechanical instability can be ruled out in those with “true” FAI.

Chronic instability of the ankle is a complex syndrome in which different functional, mechanical, and neuromuscular factors are probably involved.³,³ McConkey³⁴ added that it is a complex subjective complaint resulting from several of the aforementioned factors. Difficulty develops in identifying one specific factor when mechanical instability, proprioceptive defects, and peroneal weakness can occur simultaneously in the same patient.

**MUSCLE STRENGTHENING AFTER LATERAL ANKLE SPRAIN**

Peroneal muscle weakness and the need for strengthening has been reported as a potential concern in the management of CAI.¹³,¹⁹,⁸²,⁸⁷,⁹⁵ Strength of the peroneus longus, brevis, and tertiatus is highly important in absorbing stress and providing additional support to the lateral-ligament complex. Staples¹⁹ advocated peroneal-muscle strengthening as an integral part of any therapy program after inversion sprain. With the discovery of isokinetic dynamometry, peroneal-muscle weakness can now be quantified, and the progress and results of peroneal-muscle-strengthening programs can be monitored. In addition, with the more recent evidence suggesting that inver-
sion-strength deficits may exist in those with CAI, isokinetic dynamometry can assist the clinician in monitoring strength deficits and developing strength objectives for the rehabilitation program. The literature is void of studies examining the eccentric action of the peroneal muscles and the ankle inverters (tibialis anterior, tibialis posterior) and their importance in ankle stability, both in normal and chronically unstable ankles.

Strength exercises have been advocated for many years in the rehabilitation of both acute and chronic ankle sprains. Exercises focusing on the eccentric action of muscle have become popular, especially in the muscles of the thigh. Curwin and Stanish\(^9\) indicated that eccentric muscle actions play an important role in the treatment of knee pain associated with tendinitis. Eccentric actions of both the quadriceps and hamstring muscle groups have long been known to provide deceleration and stability during many sport-related activities. Eccentric exercises for the treatment and rehabilitation of ankle injuries are gaining more popularity and acceptance. Fiore and Leard\(^9\) and Tomaszewski\(^9\) advocated eccentric tubing exercises in the rehabilitation of LAS to strengthen the stabilizing effect of the peroneal muscles. Eccentric muscle actions create greater tension levels than concentric or isometric actions at the same angle.\(^70,71\) Cyriax\(^8\) identified the peroneal muscles as the cause of recurrent ankle sprains, stating that when the ankle starts turning over, the peroneal muscles are merely brought into play too slowly to prevent the sprain. He recommended strength-training exercises. Peroneal reflex and resultant contraction are considered the first dynamic joint-protection mechanism in the case of sudden inversion.\(^9\) Electromyographic activity demonstrates that the peroneal muscles are quite active during the stance phase of walking and running.\(^100,101\) The contraction of these muscles shifts the weight-bearing area to the medial structures of the foot, which appears to be an important consideration in the prevention of inversion sprains. One could argue that to stimulate maximal strength gains, one should incorporate eccentric training sessions into the rehabilitation program.

**STUDIES INVOLVING STRENGTH TRAINING AND CHRONIC ANKLE INSTABILITY**

The effect of balance training on those with CAI has been studied much more extensively than has the effect of strength training on this same population. Several researchers\(^102-105\) have reported on the effects of balance and proprioception training on those with CAI. Very few studies have examined the effects of some type of strength-training program on those with CAI.\(^34,44\)

Using a protocol similar to the one employed in the study by Kaminski et al,\(^44\) Docherty et al\(^34\) reported improvements in eversion and dorsiflexion strength after 6 weeks of progressive-resistance strength training. Their 20 subjects with a history of unilateral functional instability demonstrated improvements in joint position—sense measures, a finding they attributed to enhancements in muscle—spindle activity.\(^34\)

Kaminski et al\(^44\) recently reported the effects of strength and proprioception training on measures of isokinetic strength. Thirty-eight subjects were randomly assigned to one of 4 treatment groups (strength training, proprioception training, strength + proprioception training, and control). Subjects were pretested and posttested for peak isokinetic torque. Ankle—eversion and —inversion motions were tested both concentrically and eccentrically through a range of motion involving 40°. Six weeks of combined strength and proprioception training influenced E/I isokinetic strength ratios in a group of subjects with CAI, providing evidence for combined strength and proprioception training in the rehabilitation of those with CAI. Further research is needed to more closely examine the effects of these strength-training interventions on those with CAI.

**KINETIC CHAIN DYNAMIC EFFECTS ON CHRONIC ANKLE INSTABILITY**

Joints of the lower extremity do not work in isolation. Consequently, function or dysfunction at one level has multiple effects throughout the kinetic chain. Numerous factors have been identified as contributing to CAI, but the contribution of dynamic strength imbalances to CAI is still controversial.\(^8,15,16,22,25,26,45,53\) Consequently, concern is growing that dynamic strength may still be a causal factor, but it may occur at the more proximally related joints in the lower kinetic chain.

No investigations were found relating the dynamic strength values of the knee to those of the chronically stable or unstable ankle. While we do not have flexor—extensor strength values at the knee for those with CAI, Calmels et al\(^106\) offered a graphic representation of these torque ratios for healthy subjects. The maximal eccentric moment/maximal concentric moment ratios were not provided, nor was the issue of reciprocal—contraction mode ratios addressed. The belief that there may be a relationship between the dynamic strength at the knee and CAI was indirectly reported by Lentell et al\(^52\) in 1988. Investigating the influence of knee position (10° versus 70° flexion) on the peak torques for the invertors and evertors and action potentials for the hamstrings, they showed that both sets of measurements were less when the knee position was in 10° of flexion. It is possible that the effects of tibial rotation are less protective and the ankle musculature weaker in this position. In a recent, yet—unpublished study, a trend was beginning to develop between the rotational dynamic strength of the hip in those individuals with healthy ankles and in those with functionally unstable ankles (H. D. Hartsell, unpublished data, 2001). Although the sample size was small (n = 16), the rotational torques for the ankle (inversion—eversion) and hip (internal—external rotation) were determined using slow (ankle = 60°·s\(^{-1}\), hip = 60°·s\(^{-1}\)), medium (ankle = 120°·s\(^{-1}\), hip = 150°·s\(^{-1}\)) and fast (ankle = 180°·s\(^{-1}\), hip = 240°·s\(^{-1}\)) comparable velocities\(^28\) tested on an isokinetic dynamometer. The E/C ratios for the ankle invertors were lower for the CAI group at all velocities. However, for the ankle evertors, similar E/C ratios were observed for both groups, except for the fast velocity, at which the E/C ratio was lower for the CAI group. The E/C ratios for the hip internal and external rotators were similar between the groups. It was interesting to note that, at the higher velocity, both groups had difficulty performing isokinetics, particularly eccentrically.

While absolute values are no longer strongly supported as the only means of dynamic strength evaluation, they are useful when interpreting the numerous ratios developed. The E/C ratios would imply that the CAI group was stronger both eccentrically and concentrically for ankle inversion strength, whereas the groups were similar for absolute eversion concentric and eccentric torque values. An imbalance existed and, when calculated as the E/C ratio, the evertors did not appear to have the ability to react appropriately at the higher velocity to simulate activities of daily living.

The reciprocal ratios for the ankle demonstrated that as
velocity increased, the $\text{ECC}_{\text{evertor}}/\text{CON}_{\text{inverted}}$ increased, and the CAI group produced lower ratios. As velocity increased, $\text{CON}_{\text{external rotator}}/\text{ECC}_{\text{internal rotator}}$ decreased for each group, and although the groups were similar, the ratios for the CAI group were generally lower. For the hip, $\text{ECC}_{\text{external rotator}}/\text{CON}_{\text{internal rotator}}$ increased as velocity increased, as did the ratio for both groups. Although similarities were observed between the groups, the CAI group generally produced lower ratios. As velocity increased, $\text{CON}_{\text{external rotator}}/\text{ECC}_{\text{internal rotator}}$ decreased for both groups and, again, although similar, the ratios were lower for the CAI group. The ratios should either have been similar between the groups or higher for the healthy group. Given the lower ratios for the CAI group on selected variables, muscle imbalance is recognized.

**SUMMARY**

Our purpose was to provide an overview of the dynamic stability of the ankle and to examine the relationship between strength and CAI. Clinicians need to understand that the ankle-joint complex constitutes a very complicated and dynamic biomechanical structure. The connection between strength deficits and those with CAI has not been clearly delineated in the recent literature. Evidence supports inversion deficits in those with CAI. Contemporary research involving agonist-antagonist muscle-group ratios and reciprocal-mode strength ratios holds promise for future links between strength deficits and CAI. Researchers must be cognizant of the more proximal joints in the lower extremity kinetic chain and determine if strength deficits at these nearby joints may be contributing to a mechanism affecting those with CAI. A normative strength database is needed, consisting of values that will allow the clinician and researcher to make comparisons among studies and to develop rehabilitation goals and objectives. Lastly, it is imperative that a widely accepted set of criteria be established to accurately identify those with CAI. We hope that this article will serve as a foundation for clinicians and researchers wanting to develop and explore new pathways into the CAI mystery.

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Assessment of the Injured Ankle in the Athlete

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Objective: To present appropriate tools to assist in the assessment and evaluation of ankle injuries in athletes.

Data Sources: A MEDLINE search was performed for the years 1980–2001 using the terms ankle injuries and ankle sprains.

Data Synthesis: Ankle sprains are the most common injuries in the Athlete, accounting for 10% to 15% of sport-related injuries, and are responsible for 7% to 10% of all emergency room visits. Most of these injuries occur in persons under 35 years of age. Findings from a recent study suggested that women are more at risk for minor ankle sprains than men. Injuries to the lateral-ligament complex caused by ankle inversion are the most common ankle sprains.

Isolated lateral ankle sprains must be differentiated from other sprains. Subtalar-joint sprains often occur with lateral ankle-ligament sprains but can occur as isolated injuries. Isolated subtalar sprains are difficult to diagnose but usually respond well to nonoperative treatment.

Isolated medial ankle sprains are relatively uncommon, with most deltoid injuries occurring in combination with lateral malleolus fractures or syndesmosis injuries. However, isolated injury to the deltoid ligament can occur during an inversion injury in which the body rolls over an everted foot. The anterior fibers of the deltoid are most commonly injured.

Isolated syndesmosis injuries, often referred to as “high” ankle sprains, are also relatively uncommon, although they are probably underreported in the literature. More often, syndesmosis injuries are associated with an injury to the anterior part of the deltoid ligament or fractures of the medial or lateral malleoli (or both). The mechanism of injury is combined forced external rotation, dorsiflexion, and axial loading of the ankle. The anterior tibiofibular ligament is the usual site of injury in isolated sprains. Isolated partial tears can be treated nonoperatively, but complete syndesmosis ruptures carry a high risk for chronic pain, arthrosis, or ankle instability and are best treated surgically.

LATERAL ANKLE-LIGAMENT SPRAINS AND INSTABILITY

The main lateral soft tissue stabilizers of the ankle are the ligaments of the lateral ligamentous complex: the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL). In the neutral position, especially when coupled with compressive loads during weight bearing, the bony architecture of the ankle joint greatly assists with stability. As the foot goes into plantar flexion, thereby dissociating the bony talus from talocrural stability, the ligamentous structures assume a greater role in providing stability and are more susceptible to injury.

The ATFL is a small thickening of the tibial capsule. When the foot is in plantar flexion, the ligament courses parallel to the axis of the leg. Because most sprains occur when the foot is in plantar flexion, this ligament is most frequently injured in inversion sprains. The CFL and PTFL are less commonly injured. Rupture of these ligaments typically occurs in more severe injuries, as the inversion force continues posteriorly around the ankle after the ATFL is sprained. Isolated injuries of the CFL can occur when the ligament is under maximum strain with the foot in dorsiflexion but are infrequent. Isolated injuries of the PTFL are extremely rare. Most injuries to the PTFL occur with very severe ankle sprains in which both the ATFL and CFL have been torn, and the forces continue around the lateral aspect of the ankle. Brostrom found that isolated, complete rupture of the ATFL was present in 65% of all ankle sprains. A combined injury involving the ATFL and the CFL occurred in 20% of his patients.

The extent of tissue damage that occurs during an injury depends on the direction and magnitude of the forces and the position of the foot and ankle during the trauma. Ankle sprains...
occur significantly more often in athletes who have had previous ankle sprains. Pes cavus, rearfoot varus, tibial varus, and previous trauma are factors that may contribute to ankle-inversion injury, although none of these have been scientifically verified as contributing factors.

**Evaluation**

The most common mechanism of injury is an athlete who “rolled” over the outside of his or her ankle (Figure 1). This usually occurs as either a noncontact injury or when the athlete lands from a step or jumps onto an opponent’s foot with an inverted foot. The foot is usually plantar flexed at the time of the injury. Many patients state that they have heard something “snap” during the trauma; however, feeling a tearing sensation or hearing a snap does not appear to correlate with the severity of the injury. The main site of pain and swelling is usually localized to the lateral side of the ankle over the ATFL. Several hours after the injury, generalized swelling and pain can make the evaluation more difficult and less reliable. Most patients have pain and discomfort when trying to ambulate on the injured extremity. Ecchymosis can occur 24 to 48 hours after the injury. The discoloration is usually worst along the lateral side but can also occur in the retrocalcaneal bursal area and along the heel because of the potential space available for swelling and the pooling effect of gravity. It is important that the entire leg, ankle, and foot be examined to ensure that no other injuries have occurred. With tenderness over the midshaft of the fibula or medial-side tenderness and swelling, the examiner should be suspicious of fracture or more significant injury.

Clinical stability tests for ligamentous disruption are best performed between 4 and 7 days after the injury, when the acute pain and swelling are diminished and the patient is able to relax during the examination. The anterior drawer test is more specific for assessing the integrity of the ATFL, and the talar tilt test is more specific for detecting injury to the CFL. These findings are best recorded as differences between the ankles (assuming the opposite ankle is uninjured), but the tests can still be difficult to interpret, and the results often vary greatly among examiners. Caution must be exercised in interpreting these tests, but a positive test can help to confirm the diagnosis in a patient with a suspicious history.

The anterior drawer test evaluates ATFL integrity by the amount of anterior-talar displacement that can be produced in the sagittal plane. To perform this test, the patient should be sitting with the knee flexed to relax the calf muscles and prevent the patient from actively guarding against the examiner. The examiner grasps the heel firmly in one hand and pulls forward while holding the anterior aspect of the distal tibia stable with the other hand (Figure 2). The sensitivity of the test can be improved by placing the ankle in 10° of plantar flexion. Increased anterior translation of the talus with respect to the tibia is a positive sign and indicates a tear of the ATFL, particularly if the translation is significantly different from the opposite side. However, how much translation is physiologically normal is the subject of disagreement; it has been reported to be anywhere from 2 mm to 9 mm. Therefore, it is better to compare the amount of pathologic anterior laxity with the normal side. This analysis by the examiner is subjective, and agreement among observers varies.

The talar tilt test is defined as the angle produced by the tibial plafond and the dome of the talus in response to forceful inversion of the hindfoot. The talar tilt test is performed with the ankle in the neutral position. The examiner holds the heel stable while trying to invert the heel with respect to the tibia (Figure 3). It is important to try to grasp the talus and calcaneum...
neus as a unit to limit subtalar motion during the test. As in the anterior drawer examination, the results from the talar tilt test are difficult to interpret, with reports indicating normal values between 5° and 23°, but as a general rule, more than 10° difference from the normal side is considered abnormal.

A new testing device developed by Kirk et al applies standardized loads for both the anterior drawer and talar tilt tests. At an anterior force of 111 N (25 lbs) and a torque of 16 Nm, the mean anterior-drawer translation was 5.9 mm, and the mean talar-tilt translation was 51°. The device has not yet been adopted into widespread use.

**Radiographic Analysis**

Clinical guidelines for determining the necessity of radiographs have been developed to limit the number of radiographs. These guidelines carry tremendous potential for cost savings. The Ottawa Ankle Rules (OAR) are the commonly used criteria for predicting which patients require radiographic images. Radiographs are only required for those patients with (1) tenderness at the posterior edge or tip of the medial or lateral malleolus; (2) inability to bear weight (4 steps) either immediately after the injury or in the emergency room; or (3) pain at the base of the fifth metatarsal. Following these rules provided nearly 100% sensitivity for detecting fractures while significantly reducing the number of unnecessary radiographs. Standard radiographs, if necessary, should include anteroposterior (AP), lateral, and mortise views. The mortise view is an AP view with the tibia internally rotated by 15° to 20°. This position allows evaluation of the syndesmosis and assessment of mortise disruption. In the mortise view, the talus should be equidistant from both malleoli.

Stress radiography for acute injuries will not change the treatment protocol and is generally not indicated. These techniques are more often used for research purposes or to differentiate between mechanical instability and functional instability in patients with chronic ankle problems. Specialized instruments have been developed to apply standardized loads during the stress radiographs. The anterior-drawer stress radiograph is more sensitive for ATFL insufficiency, and the talar-tilt stress radiograph is more sensitive for CFL integrity. However, the amount of displacement that represents a pathologic condition is variable. The most commonly used criteria for the anterior-drawer stress test are those of Karlsson, who defined abnormal laxity as an absolute anterior displacement of 10 mm or a side-to-side difference of more than 3 mm (Figure 4). Abnormal talar tilt is even more controversial due to the large variation in “normal” talar tilt, which is reported to be from 0° to 27°. A talar tilt of 15° more than the normal side correlated with a complete double-ligament rupture (ATFL and CFL). As a general rule, a finding of more than 10° greater than the normal side is considered abnormal (Figure 5).

If the results of the 2 stress-radiographic images are combined, the sensitivity of the tests increases to 68%, but the specificity falls to 71%; therefore, it is difficult to recommend routine use of stress radiography.

Ankle-joint arthrography is a sensitive and specific diagnostic test for ligament ruptures, as shown by Lahde et al, who studied 7000 ankle arthrographies performed over a 15-year period. But they also found limitations of arthrography: it is reliable only within the first 24 to 48 hours, cannot
quantify the severity of ligament damage, and is an invasive procedure. Proper interpretation of arthrographic images requires a full understanding of the variant and natural leakage of contrast. Arthrography is a valuable research tool, but it is rarely indicated for clinical use because it does not change the treatment protocol.

Similarly, magnetic resonance imaging (MRI) and computed tomography (CT) scanning are rarely necessary for typical acute ankle sprains because the results do not affect the treatment protocol. Gaebler et al. compared intraoperative findings with MRI results in 25 patients who had a talar tilt greater than 15° and found that MRI was reliable in diagnosing lateral-ligament injuries. Magnetic resonance imaging and CT scanning have been useful for identifying osteochondral injuries that may mimic, or occur in conjunction with, chronic lateral ankle instability.

Grading Lateral Ankle-Ligament Sprains

Several lateral ankle-ligament grading systems have been used. This makes comparison in the literature difficult, as many authors did not state which grading system they used. The traditional grading system for ligament injuries focuses on a single ligament, with a grade I injury representing a microscopic injury without stretching of the ligament on a microscopic level. A grade II injury has macroscopic stretching, but the ligament remains intact. A grade III injury is a complete rupture of the ligament. Applying this grading system to lateral ankle-ligament sprains addresses only the status of the ATFL and ignores injury to either the CFL or PTFL. Some authors have thus resorted to grading lateral ankle-ligament sprains by the number of ligaments injured. The major drawback to this system is that, unless the injury is treated surgically, objective evidence of injury to each ligament is lacking. Finally, because of the problems of these grading systems, a classification based on clinical severity has been used. This system has 3 clinical grades: grade I (mild), grade II (moderate), and grade III (severe). A grade I injury involves little swelling and tenderness, minimal or no functional loss, and no mechanical joint instability. A grade II injury has moderate pain, swelling, and tenderness over the involved structures; some joint motion is lost, and joint instability is mild to moderate. A grade III injury is a complete ligament rupture with marked swelling, hemorrhage, and tenderness; function is lost, and joint motion and instability are markedly abnormal. Grading of ankle sprains remains a largely subjective interpretation, and agreement among independent observers varies.

Differential Diagnosis

Other problems can mimic, or be coupled with, lateral ankle-ligament sprains. Fractures of the ankle are often associated with ankle-ligament injuries. In particular, the examination should focus on potential fractures of the lateral, medial, and posterior malleolus; proximal fibula; lateral or posterior process of the talus; anterior process of the calcaneus; fifth metatarsal; navicular or other midtarsal bones; and children's epiphyseal separations.

Patients with stress fractures about the ankle joint may present with a different type of history but similar symptoms. In particular, a transverse, proximal diaphyseal fracture of the fifth metatarsal bone (Jones fracture) can mimic an acute lateral ankle sprain. This is particularly true when an acute fracture occurs through an area of previous stress reaction that may have had minimal or no symptoms. The distal fibula, medial malleolus, calcaneus, navicular, and metatarsals are also prone to stress fracture.

Osteochondral fractures or osteochondritis dissecans of the talus or the tibial plafond can occur with lateral ankle-ligament sprains. These fractures can become chronic problems, with continued pain and recurrent instability episodes. If plain radiographs are negative despite continued pain, a bone scan, CT scan, or MRI may be helpful to evaluate for this lesion. Arthroscopy is the definitive test for the diagnosis and treatment of these fractures.

Athletes with sprains of the subtalar joint or midfoot ligaments can present with a similar history. In particular, the dorsal calcaneocuboid ligament, bifurcate ligament, cervical ligament, and interosseous talocalcaneal ligament are prone to injury. Subluxation or dislocation of the peroneal tendons can mimic an ankle sprain. However, these injuries typically occur by a violent dorsiflexion and pronation moment of the ankle instead of the typical inversion injury of lateral-ligament injuries.

SUBTALAR-JOINT SPRAINS AND INSTABILITY

The incidence of subtalar sprains is unknown, mainly due to the difficulty of assessing these injuries and the common association with lateral ankle-ligament sprains. They are probably more common than appreciated. Meyer et al. studied subtalar arthograms in 40 patients with acute ankle sprains and found that 17 (43%) had subtalar-ligament injury. Fortu-
nately, the incidence of chronic ankle problems is low, with subtalar instability present in only about 10% of patients who present with chronic lateral ankle-ligament instability. Patients with acute subtalar sprains seem to do well with nonoperative treatment similar to that used for acute lateral ankle-ligament sprains. However, since the definition and diagnosis of subtalar sprains are not agreed upon in the literature, this is difficult to prove.

Acute symptoms of subtalar sprains are similar to, and can occur with or be masked by, lateral ankle-ligament sprains. Tenderness over the subtalar joint is characteristic but can be difficult to differentiate from the tibiotalar joint because of the close proximity and the swelling that obscures the anatomy.

Clinical evaluation of subtalar instability is very difficult and unreliable. An evaluation of the change in angle between the heel and the tibia with passive inversion and eversion of the heel can be made by comparing this angle with that on the uninjured side, but the sensitivity and specificity of this test is unknown.

Radiographs should be obtained as per the Ottawa ankle rules. Subtalar stress radiographs, subtalar arthrography, or stress tomography can show increased motion and differentiate between subtalar and talocrural motion; however, most of these injuries can be effectively treated by rehabilitation, so specialized studies are usually unnecessary. If surgery is considered, stress radiographs may be helpful in planning the surgery.

**Classification of Subtalar-Joint Sprains**

Subtalar-joint sprains are classified by the injury mechanism and the degree of ligamentous damage. The injury can occur in either plantar flexion or dorsiflexion. Forceful supination with the foot in plantar flexion tears the ATFL (and possibly the cervical ligament), followed by either disruption of the CFL and lateral capsule (type 1) or tearing of the interosseous talocalcaneal ligament (type 2). When the ankle is in dorsiflexion, the ATFL is not under tension and remains uninjured. This type of injury tears the CFL, the cervical ligament, and the interosseous talocalcaneal ligament (type 3). A type 4 subtalar sprain is a rupture of all lateral and medial capsuloligamentous components of the posterior tarsus. This injury occurs as the foot moves from dorsiflexion to plantar flexion while forceful hindfoot supination occurs.

**DELTOID LIGAMENT TEARS**

In Broström's series of 281 acute ankle sprains, medial-side ankle sprains constituted only 3%. Nearly all of the medial-side injuries were partial ligament tears. Complete deltoid ligament ruptures most often occur in combination with ankle fractures. In Harper's review of 42 patients with complete deltoid ligament ruptures, all had other injuries. In the ankle-fracture classification described by Lauge-Hansen, a deltoid ligament tear or medial malleolar fracture occurs as the injury pattern continues around the ankle in a circular fashion. The 3 most characteristic mechanisms of injury of the deltoid ligament are pronation-abduction, pronation-external rotation, and supination-external rotation of the foot. The first component describes the position of a planted foot, and the second term indicates the relative motion of the foot as the leg rotates about the planted foot. So, in the pronation-abduction injury, the foot is planted in pronation as the upper body falls to the lateral side of the foot, placing a large abduction force onto the ankle and deltoid ligament. Because the forces required to injure the strong deltoid ligament are so great, the injury usually continues through the syndesmosis by the strong lever action of the lateral malleolus on the lateral aspect of the talus.

**Evaluation**

Deltoid ligament injuries cause pain, tenderness, and swelling on the medial side of the ankle. A defect may be palpable below the medial malleolus in complete ruptures. If a deltoid ligament injury is present, it is extremely important to evaluate the ankle for a syndesmosis sprain or fracture. The entire fibula, including the proximal third and proximal tibiofibular joint, must also be palpated to rule out complete syndesmosis disruption.

For medial-side injuries, radiographs are necessary to evaluate the bony structures and syndesmosis. The minimum radiographic series includes AP, lateral, and mortise views. If there is any suspicion for a proximal fibular fracture, AP and lateral radiographs of the entire tibia and fibula should be taken. If the deltoid ligament and syndesmosis are both completely disrupted, the medial clear space between the medial talus...
and the lateral border of the medial malleolus will be widened to 4 mm or more (Figure 6). However, isolated deltoid ruptures do not cause widening of the medial clear space because the lateral malleolus holds the talus in position. Similarly, syndesmosis injuries without deltoid tears do not have medial joint-space widening. In this case, the inferior tibiofibular joint must be carefully evaluated for syndesmosis injury. Eversion-stress radiographs, arthrography, or MRI may be helpful in difficult cases, but the diagnosis can most often be made with clinical examination and plain radiographs.

**TIBIOFIBULAR SYNDESMOSIS TEARS: “HIGH” ANKLE SPRAINS**

Partial or complete rupture of the syndesmosis ligament complex can cause diastasis of the inferior tibiofibular joint. Isolated complete syndesmosis injuries are rare, and relatively little information exists in the literature about ankle diastasis in the absence of fracture. Fritschy reported only 12 cases of complete isolated syndesmosis ruptures in a series of more than 400 ankle-ligament ruptures. All 12 injuries were caused by a sudden external rotation of the ankle that caused the talus to pry the fibula laterally, thus opening the distal tibiofibular articulation.

Isolated partial syndesmosis injuries occur with some frequency, and their incidence is probably underestimated in the literature. It is important to recognize that syndesmosis involvement generally increases recovery time 2- or 3-fold over that for a lateral ankle-ligament sprain. Early diagnosis of the syndesmosis sprain can help to give the athlete and coaches realistic expectations of return to play. Nussbaum et al suggested that the expanse of the syndesmosis tenderness was predictive of recovery time, with more syndesmosis tenderness correlating with more playing days missed. However, it is much more common for the injury to be associated with a fracture or deltoid ligament injury (or both). With ankle fractures, the frequency of syndesmosis ruptures is related to the type and level of associated fibular fractures. Syndesmosis injuries are more common as the level of the fibular fracture rises above the level of the ankle joint, as predicted by the Lauge-Hansen injury-mechanism classification of ankle fractures. In this classification scheme, ligamentous injuries or fractures occur as the rotatory forces continue around the ankle in a circular fashion.

**Evaluation**

Pain and tenderness are located primarily on the anterior aspect of the syndesmosis and interosseous membrane. Active and passive external rotation of the foot is painful. The external-rotation test is performed by externally rotating the foot with the ankle in dorsiflexion (Figure 7), which stresses the syndesmosis by levering the talus against the lateral malleolus. Patients with a syndesmosis injury have pain over the anterior inferior tibiofibular ligament and joint. The squeeze test is performed by compressing the midshaft of the tibia and fibula together. If a syndesmosis injury is present, the patient has pain at the inferior tibiofibular joint. Biomechanical studies have confirmed distal tibiofibular motion during the squeeze test.

Radiographs should be taken according to the Ottawa ankle rules as outlined in the previous sections. Anteroposterior, lateral, and mortise views may be needed to exclude fractures and osseous avulsions and to evaluate syndesmosis widening. In athletes with possible syndesmosis widening or proximal fibular tenderness, AP and lateral films of the entire tibia and fibula are necessary to rule out a Maisonneuve fracture. Acceptable radiographic guidelines that indicate syndesmosis diastasis are controversial, and measurements can be affected greatly by the amount of tibial rotation. The most commonly used guidelines are a joint-space widening of greater than 5 mm or a tibiofibular overlap of less than 10 mm, both as measured on the AP view. Other authors prefer to use the ratio of measurements to the fibular width. Ninety percent predictive intervals for a normal relationship were a tibiofibular overlap-to-fibular width ratio greater than 24% and a tibiofibular clear space-to-fibular width ratio of less than 44%, both as measured on the AP radiograph. Stress radiographs with the foot in external rotation in both dorsiflexion and plantar flexion may demonstrate the diastasis. Magnetic resonance imaging has now become the test of choice for evaluating the syndesmosis in difficult cases.

**CONCLUSIONS**

In order to provide appropriate treatment after an athlete sprains an ankle, a thorough evaluation is necessary. This should include the mechanism of injury, physical examination, and appropriate radiographic studies and special tests. The injury can affect the lateral ankle-ligament complex, the subtalar joint, the deltoid ligament, or the syndesmosis or any combination of these structures simultaneously. Defining the extent of injury allows the clinician to institute the proper treatment regimen in preparation for the athlete's safe return to sport.

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Rehabilitation of the Ankle After Acute Sprain or Chronic Instability

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Objective: To outline rehabilitation concepts that are applicable to acute and chronic injury of the ankle, to provide evidence for current techniques used in the rehabilitation of the ankle, and to describe a functional rehabilitation program that progresses from basic to advanced, while taking into consideration empirical data from the literature and clinical practice.

Background: Important considerations in the rehabilitation of ankle injuries include controlling the acute inflammatory process, regaining full ankle range of motion, increasing muscle strength and power, and improving proprioceptive abilities. These goals can be achieved through various modalities, flexibility exercises, and progressive strength- and balance-training exercises. In this article, we discuss the deleterious effects of ankle injury on ankle-joint proprioception and muscular strength and how these variables can be quantifiably measured to follow progress through a rehabilitation program. Evidence to support the effectiveness of applying orthotics and ankle braces during the acute and subacute phases of ankle rehabilitation is provided, along with recommendations for functional rehabilitation of ankle injuries, including a structured progression of exercises.

Recommendations: Early functional rehabilitation of the ankle should include range-of-motion exercises and isometric and isotonic strength-training exercises. In the intermediate stage of rehabilitation, a progression of proprioception-training exercises should be incorporated. Advanced rehabilitation should focus on sport-specific activities to prepare the athlete for return to competition. Although it is important to individualize each rehabilitation program, this well-structured template for ankle rehabilitation can be adapted as needed.

Key Words: ankle sprain, neuromuscular rehabilitation, proprioception, functional ankle instability

Rehabilitation of athletic injuries requires the prescription of sport-specific exercise and activities that challenge the recovering tendons, ligaments, bones, and muscle fibers without overstressing them. The goal of rehabilitation is to return an athlete to the same or higher level of competition as before the injury. Rehabilitation must take into consideration normal tissue size, flexibility, muscular strength, power, and endurance. Control of swelling and effusion must be accomplished with frequent application of external pressure, modalities such as cryotherapy, and active range of motion (ROM).

The effectiveness of the rehabilitation program after injury (Figure 1) or surgery often determines the success of future function and athletic performance. An understanding of the body’s response to injury is paramount to designing a rehabilitation approach. Ligamentous and soft tissue injury results in biochemical changes similar to those seen after an injury. Injury results in bleeding and damage to tissue, which produces pain. After the initial insult, the inflammatory response is initiated, followed by the proliferative phase and the maturation phase (Figure 2).

Stress to collagen fibers results in fiber orientation along these specific lines of stress. Specifically, rehabilitation during days 1 through 5 should focus on protection of the injured tissue, then supervised and protected stress may be applied from days 6 to 42. The goal of athletic rehabilitation is to return the athlete to participation as quickly as possible, while allowing the injured tissue to heal without compromising it by further injury.

The following goals are important for any rehabilitation program: decreased swelling, pain, and initial inflammatory response and protection of the joint so that a secondary inflammatory response does not develop from overly aggressive rehabilitation. Similarly, ROM, muscular strength, power, and endurance must be returned to preinjury levels so that full, asymptomatic functional activities may be performed to the preinjury level and beyond.

The application of specific functional exercises is important to stress the healing tissue. The specific adaptation to imposed demand (SAID) principle is helpful when designing functional progression. The activities and stresses placed on the tissue must be specific to those of the activities at hand. Nonetheless, development of the higher levels of the rehabilitation spectrum must incorporate a working knowledge of the specific activity. If the athletic trainer’s knowledge of the specific activity is vague, incorporating the aid of a member of the coaching staff often results in a welcome collaboration and improved therapy.

Chronic instability (CAI) is thought to be the result of neural (proprioception, reflexes, muscular reaction time), muscular (strength, power, and endurance), and mechanical mechanisms (ligamentous laxity). Therefore, we will address each of these areas in this manuscript.
The multifaceted musculoskeletal system offers various ways that proprioception can be affected. Deficits in proprioception have been demonstrated after injury and with articular disease and increasing age. As a joint moves, impulses must arise from muscular, fascial, tendon, and articular receptors. Injury to any or all of these receptors can result in a sensory deficit.

Evaluating balance or postural stability is one method of assessing sensory deficits after injury. Postural stability is commonly measured as postural sway, the degree or amplitude that a person sways away from his or her center of balance. After injury, a patient must be able to maintain posture against gravity before progressing to more complicated functional activities. Therefore, it is essential that evaluation and rehabilitation for deficits in postural sway be used more frequently after musculoskeletal injuries.

Freeman et al were the first to report that exercises on a wobble board could reduce the incidence of instability after ankle sprain as measured with a modified Romberg test. Since then, various methods have been used to assess the function of postural stability before and after ankle injury. Tropp et al compared 127 soccer players with CAI with 30 normally active individuals. Players showing abnormal stabilometric values were at higher risk for sustaining an ankle injury during the next season. Specifically, they found that the overall incidence of ankle injury was 18% whether the player had suffered a previous injury or not. Twenty-three players sustained an ankle joint injury; 12 of 29 (42%) of those had a pathologic stabilometry value, while 11 of 98 (11%) of those players who had normal values suffered an ankle-joint injury. Therefore, the risk of sustaining an ankle injury was significantly lower if stabilometric recordings were within normal limits.

Specifically, deficits in postural stability have been reported in the unstable ankle and after an acute ankle sprain. However, when subjects with chronically unstable and uninvolved ankles were compared with subjects with chronically unstable ankles and controls, no statistical difference was reported.

Injury to the ankle and CAI may result in deficits in postural stability. Assessment of postural stability using rela-

Figure 1. Three grades of an ankle injury. A, The grade I sprain is characterized by stretching of the anterior talofibular and calcaneofibular ligaments. B, In the grade II sprain, the anterior talofibular ligament tears partially, and the calcaneofibular ligament stretches. C, The grade III sprain is characterized by rupture of the anterior talofibular and calcaneofibular ligaments, with partial tearing of the posterior talofibular and tibiofibular ligaments.
tively inexpensive balance devices and equipment that is more sophisticated should be a standard part of the ankle-rehabilitation program. Documentation of progress and accurate assessment throughout the process makes setting goals for the athlete easier to document while providing quantitative data for the supporting athletic staff and insurance companies.

One goal of rehabilitation is to develop strength and neuromuscular control so that the ankle and foot are better controlled and protected during stance and impact. Injury to the ankle may result in neuromuscular compromise. Nitz et al demonstrated electromyographic abnormalities of the peripheral nerves in the legs of patients with acute grade II and III ankle sprains 2 weeks after injury. The possible causes of nerve injury after ankle sprain include compartment syndrome, epineural hematoma, and nerve traction.

Peroneal nerve-conduction velocities may be reduced 4 to 22 days after inversion trauma. Kleinrensink et al showed that superficial and deep peroneal motor nerve-conduction velocity was reduced for 4 to 8 days after inversion trauma. Careful attention must be given to protecting the ankle while progressing the patient through ROM, proprioceptive neuromuscular facilitation, and functional exercise during the acute phase of injury. Atrophy and compromised performance resulting from nerve injury should be considered.

Adequate strength is necessary for normal movement patterns. The importance of developing correct motor patterns while subjects perform flexibility and strength exercises cannot be overemphasized. The ability or inability to perform multiple tasks depends on our conscious awareness unless the tasks are automated. Regaining strength bilaterally is accepted clinical practice and is thought to be important for the prevention of ligamentous injuries at the ankle; however, agreement on which strength factors are most important is still lacking. While some authors reported peroneal weakness as a factor in ankle sprains, others have noted no measurable difference.

Wilkerson et al and Baumhauer et al have shown that eversion-to-inversion strength ratios are often different in subjects with ankle instability when compared with normal subjects. An eversion-inversion strength ratio of >1.0 is consid-
**Table 1. Recommended Guidelines for Early Functional Rehabilitation**

<table>
<thead>
<tr>
<th>Component</th>
<th>Procedure</th>
<th>Frequency, Duration</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of Motion</td>
<td></td>
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</tr>
<tr>
<td>Passive range of motion</td>
<td>Clinician applies light pressure to facilitate stretch</td>
<td>Pain-free stretch for 15–30 s (\times) 10 repetitions, 3–5 (\times)/d</td>
<td>Maintain extremity in a non-gravity position with compression</td>
</tr>
<tr>
<td>Achilles tendon, stretch, non-</td>
<td>Use towel to pull foot toward face</td>
<td>Pain-free stretch for 15–30 s (\times) 10 repetitions, 3–5 (\times)/day</td>
<td></td>
</tr>
<tr>
<td>weight bearing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Achilles tendon stretch</td>
<td>Stand with heel on the floor and bend at the knees</td>
<td>Pain-free stretch for 15–30 s, 3–5 (\times)/day</td>
<td>Can be performed in conjunction with heat or cold therapy</td>
</tr>
<tr>
<td>weight bearing</td>
<td>Move the ankle in multiple planes of motion by drawing the alphabet in lowercase and uppercase motions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alphabet exercises</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength Training (Isometric)</td>
<td>Resistance can be provided by an immovable object (eg, wall or floor) or the contralateral foot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantar flexion</td>
<td>Push foot downward (away from the head)</td>
<td>Hold muscle contraction for 5–10 s</td>
<td>Strengthening can be accomplished in a pain-free range of motion</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td>Pull foot upward (toward the head)</td>
<td>5–10 repetitions per direction</td>
<td></td>
</tr>
<tr>
<td>Inversion</td>
<td>Push foot inward (toward the midline of the body)</td>
<td>Repeat 3–5 (\times)/day</td>
<td></td>
</tr>
<tr>
<td>Eversion</td>
<td>Push foot outward (away from the midline of the body)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength Training (Isotonic)</td>
<td>Resistance can be provided by the contralateral foot, rubber tubing, weights, or the clinician</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantar flexion</td>
<td>Push foot downward (away from the head)</td>
<td>Maintain muscle contraction for 4–10 s for concentric and eccentric components</td>
<td>Strengthening can be accomplished in full range of motion and incorporate concentric and eccentric contractions in non-weight-bearing position</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td>Pull foot upward (toward the head)</td>
<td>2 sets of 10 repetitions per direction</td>
<td></td>
</tr>
<tr>
<td>Inversion</td>
<td>Push foot inward (toward the midline of the body)</td>
<td>Repeat 3–5 (\times)/day</td>
<td></td>
</tr>
<tr>
<td>Eversion</td>
<td>Push foot outward (away from the midline of the body)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toe curls and marble pick-ups</td>
<td>1. Place foot on a towel. Curl toes, moving the towel toward the body.</td>
<td>2 sets of 10 repetitions, 3–5 (\times)/day</td>
<td>Strengthening can be accomplished throughout the day at work or at home</td>
</tr>
<tr>
<td>2. Use toes to pick up marbles or other small objects.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toe raises, heel walks, toe</td>
<td>Lift the body by rising up on the toes</td>
<td>3 sets of 10 repetitions, progress walking as tolerated</td>
<td>Strengthening can be accomplished using the body as resistance in a weight-bearing position</td>
</tr>
<tr>
<td>walks</td>
<td>Walk forward and backward on the toes and heels</td>
<td></td>
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</tr>
</tbody>
</table>

*Athlete can perform activities with varying external support to stimulate sensory and proprioceptive feedback. Use of a semirigid orthotic may provide somatosensory benefits and neutral alignment for proper muscle activation and reduce unnecessary strain on already stressed soft tissue.

PROPHYLACTIC ANKLE BRACING AND ORTHOTIC INTERVENTION

A prophylactic ankle brace is used to provide mechanical stability. Advantages include ease of use, no need for professional assistance with application, and cost effectiveness when compared with tape over an extended period of time. Ankle braces can be classified as lace-up, stirrup, or elastic type of configuration. In addition to providing mechanical stabilization, an ankle brace offers proprioceptive stimulation. Jerosch et al\(^2^9\) found improvement in single-leg stance, single-leg jumping, and angle reproduction when stirrup and lace-up brace conditions were compared with a no-brace condition. Interestingly, angle-reproduction error was better in the uninjured ankle than the injured ankle for the no-brace condition but better in the injured ankle when braced with a stirrup, lace-up, or tape brace. This implies that the application of
the brace improved proprioceptive and sensory feedback such that accuracy was better in the injured ankle than the uninjured ankle with no external application.\textsuperscript{30}

Friden et al\textsuperscript{14} examined 14 patients with unilateral injury to the lateral ligaments of the ankle and compared them with a group of 55 healthy individuals.\textsuperscript{14} Subjects were tested in single-leg stance for 25.6 seconds. They recorded movement in the frontal plane with the following variables: mean value of the distance between the center of pressure and the reference line, its standard deviation, average speed in frontal-sway

**Table 2. Strength-Training Progression**

<table>
<thead>
<tr>
<th></th>
<th>1st Set: 10 Repetitions</th>
<th>2nd Set: 10 Repetitions</th>
<th>3rd Set: 10 Repetitions</th>
<th>4th Set: 10 Repetitions†</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs (0 kg)</td>
<td>.5 lbs (.23 kg)</td>
<td>1 lb (.45 kg)</td>
<td>1.5 lbs (.68 kg)</td>
<td></td>
</tr>
<tr>
<td>1 (.45)</td>
<td>1.5 (.68)</td>
<td>2 (.91)</td>
<td>3 (1.36)</td>
<td></td>
</tr>
<tr>
<td>2 (.91)</td>
<td>3 (1.36)</td>
<td>4 (1.81)</td>
<td>5 (2.27)</td>
<td></td>
</tr>
<tr>
<td>3 (1.36)</td>
<td>4.5 (2.04)</td>
<td>6 (2.72)</td>
<td>8 (3.63)</td>
<td></td>
</tr>
<tr>
<td>4 (1.81)</td>
<td>6 (2.72)</td>
<td>8 (3.63)</td>
<td>10 (4.54)</td>
<td></td>
</tr>
<tr>
<td>5 (2.27)</td>
<td>7.5 (3.40)</td>
<td>10 (4.54)</td>
<td>15 (6.80)</td>
<td></td>
</tr>
<tr>
<td>7.5 (3.40)</td>
<td>11.25 (5.10)</td>
<td>15 (6.80)</td>
<td>20 (9.07)</td>
<td></td>
</tr>
<tr>
<td>10 (4.54)</td>
<td>15 (6.80)</td>
<td>20 (9.07)</td>
<td>25 (11.34)</td>
<td></td>
</tr>
<tr>
<td>12.5 (5.67)</td>
<td>18.75 (8.51)</td>
<td>25 (11.34)</td>
<td>30 (13.61)</td>
<td></td>
</tr>
<tr>
<td>15 (6.80)</td>
<td>22.5 (10.21)</td>
<td>30 (13.61)</td>
<td>35 (15.88)</td>
<td></td>
</tr>
<tr>
<td>17.5 (7.94)</td>
<td>26.25 (11.91)</td>
<td>35 (15.88)</td>
<td>40 (18.14)</td>
<td></td>
</tr>
<tr>
<td>20 (9.07)</td>
<td>30 (13.61)</td>
<td>40 (18.14)</td>
<td>45 (20.41)</td>
<td></td>
</tr>
<tr>
<td>22.5 (10.21)</td>
<td>33.75 (15.31)</td>
<td>45 (20.41)</td>
<td>50 (22.68)</td>
<td></td>
</tr>
<tr>
<td>25 (11.34)</td>
<td>37.5 (17.01)</td>
<td>50 (22.68)</td>
<td>55 (24.95)</td>
<td></td>
</tr>
<tr>
<td>27.5 (12.47)</td>
<td>41.25 (18.71)</td>
<td>55 (24.95)</td>
<td>60 (27.22)</td>
<td></td>
</tr>
<tr>
<td>30 (13.61)</td>
<td>45 (20.41)</td>
<td>60 (27.22)</td>
<td>65 (29.48)</td>
<td></td>
</tr>
<tr>
<td>32.5 (14.74)</td>
<td>48.75 (22.11)</td>
<td>65 (29.48)</td>
<td>70 (31.75)</td>
<td></td>
</tr>
</tbody>
</table>

*This strength-training program is a modification of Knight’s DAPRE program\textsuperscript{67} as revised by Perrin and Gieck.\textsuperscript{68}
†Patient should proceed to next line when he or she can lock out (complete with correct form) the 4th set 10 times.
movements, mean sway amplitude, and number of movements exceeding defined amplitude levels of 5 mm and 10 mm. The standard deviation was significantly higher in the injured group measured without braces when compared with the reference group, the injured group with brace, and the uninjured side. A significant difference was also noted between the uninjured side in the braced group and the reference group. Fri- 

den et al made a significant contribution by demonstrating that postural-sway values were sensitive enough to distinguish differences between subjects with the injured leg and a reference group. They found that when the injured legs were tested without a brace, they were significantly different than the reference group for the following variables: number of sway movements exceeding 5 mm and 10 mm, mean sway amplitude, and standard deviation of center of pressure.

Baier and Hopf evaluated the effect of a rigid or flexible ankle orthosis on postural sway in subjects with CAI. They tested 22 subjects with CAI and 22 normal subjects. CAI was defined as more than 5 ankle sprains per year and feelings of giving way. In athletes with CAI, both rigid and flexible ankle orthoses significantly reduced mediolateral sway velocity, an effect that was not apparent for the control group. While not significant, there was a trend toward decreased mediolateral sway in the control group when wearing the rigid orthosis versus no orthosis. Subjects were tested in single-leg stance for 25 seconds. Baier and Hopf speculated that the differences in the ankle-brace group were due not just to mechanical instability but also to a proprioceptive effect.

The study of braces to prevent injuries has been undertaken by Garrick and Requa, Sitler et al, and Sitler et al. Sitler et al demonstrated a 3-fold decrease in ankle injuries among braced cadets when compared with nonbraced controls, and Surve et al reported a 5-fold reduction in ankle sprains when braced athletes were compared with nonbraced athletes who had previous ankle injuries. Therefore, the use of ankle taping and bracing has proprioceptive, mechanical, and injury-protection benefits and causes minimal to no performance decrements.

Because the application of an ankle brace has been shown to increase joint position sense, it may be suggested that after an acute ankle sprain, initial exercises and ROM should be performed with some prophylactic support in an attempt to...
### Table 3. Proprioceptive Training Components of Intermediate Functional Rehabilitation*

<table>
<thead>
<tr>
<th>Component</th>
<th>Procedure</th>
<th>Frequency, Duration</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular wobble board</td>
<td>Rotate board in clockwise and counterclockwise directions nonweight-bearing and weight-bearing for bilateral and unilateral stance</td>
<td>5–10 repetitions, 2–3×/d</td>
<td>Exercises can be performed with eyes open or closed and with or without resistance</td>
</tr>
<tr>
<td>Walking on different surfaces</td>
<td>Walk in normal or heel-to-toe fashion over various surfaces (eg, hard floor, uneven carpet, different foam pads)</td>
<td>20–60 ft (6.10–15.24 m), 5–10×/d</td>
<td>Exercises can be performed with eyes open or closed and with or without resistance</td>
</tr>
<tr>
<td>Manual proprioceptive neuromuscular facilitation exercises</td>
<td>Clinician provides degrees of resistance and random perturbations as athlete moves the foot through functional patterns</td>
<td>5–20 repetitions 1–2×/day</td>
<td>Velocity and resistance can be varied to stimulate sensory feedback</td>
</tr>
</tbody>
</table>

*Manual strengthening program is progressed with modified Daily Adjustable Resistance Exercise technique.

### Table 4. Return to Activity Components of Advanced Functional Rehabilitation

<table>
<thead>
<tr>
<th>Component</th>
<th>Procedure</th>
<th>Frequency, Duration</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wobble-board exercises</td>
<td>Athlete balances on wobble board with rubber-tubing resistance or after light perturbations from the clinician</td>
<td>5–20 repetitions, 1–2×/d</td>
<td>Increase difficulty by varying surfaces and alternating eyes open and eyes closed</td>
</tr>
<tr>
<td>Functional exercise on different surfaces and with resistance</td>
<td>Athlete performs functional activities on variable surfaces, eg, trampoline, foam, in water with resistance</td>
<td>5–20 repetitions, 1–2×/d</td>
<td>Increase difficulty by performing skills on unstable surfaces and with varied velocity of movement</td>
</tr>
<tr>
<td>Walk-jog</td>
<td>50% walking and 50% jogging in straight direction, forward, backward, and pattern running</td>
<td>Increase distance by ¼-mile (0.2-km) increments</td>
<td>Increase intensity and incorporate activity-specific training</td>
</tr>
<tr>
<td>Jog-run</td>
<td>50% jogging and 50% running in straight direction, forward, backward and pattern running</td>
<td>Increase distance by ¼-mile (0.2-km) increments</td>
<td>Increase intensity and incorporate activity-specific training</td>
</tr>
</tbody>
</table>
improve sensory and proprioceptive feedback. While this is common when preparing an athlete to return home or before competition, we recommend using a prophylactic stabilizer (neoprene, softshell, or hardshell) intermittently during functional rehabilitation to provide feedback, compression, and support (Figure 3). The presumed efficacy of this technique is based on clinical interpretation of the literature, and justification of rehabilitation outcomes needs further investigation.

The use of orthotics shows promise in the treatment of ankle instability, particularly in response to improving balance after injury or fatigue, when rearfoot motion is altered, and in normal subjects. In the clinical setting, orthotics are com-
monly prescribed for many reasons: to alter the rearfoot motion in the gait cycle, assist in shock absorption, and provide proprioceptive benefits. Recently, some authors have suggested that orthotics can be used clinically as an aid to postural stability. Guskiewicz and Perrin evaluated the use of orthotics after an acute ankle sprain. Orthotics significantly reduced postural sway between the orthotic and nonorthotic conditions during anteroposterior and mediolateral sway. Ortega et al. assessed the effects of molded and unmolded orthotics on balance and pain after an inversion ankle sprain. Subjects reported significantly less pain during jogging while wearing molded orthotics compared with unmolded orthotics and no orthotics. Similarly, Oehsendorf et al. reported a significant reduction in postural sway after orthotic intervention. The authors fatigued the plantar-flexor and dorsiflexor muscle groups and noted that postural-stability values for the orthotic conditions (prefatigue and postfatigue) were less (better) than for the nonorthotic conditions (prefatigue and postfatigue). Miller et al. studied control subjects and subjects with malaligned rearfoot motion (>5° of rearfoot motion) for changes in postural sway during a 6-week period. Postural sway in the malaligned group with orthotics was initially worse than in the control group with orthotics. However, the use of orthotics improved bilateral (eyes-closed) postural sway in the malaligned group when values from baseline were compared with weeks 2, 4, and 6 ($P < .05$).

Therefore, we recommend the use of orthotics during the acute and subacute phases for subjects after an ankle sprain. The use of orthotics provides somatosensory benefits because cutaneous afferents contribute to human balance control and may provide neutral alignment for proper muscle activation and reduce unnecessary strain on already stressed soft tissue. If the athlete has abnormal rearfoot or forefoot alignment, the use of orthotics is justified for all activities. There is a paucity of information describing the use of orthotics for CAI and limited information describing long-term effectiveness in normal individuals and individuals with malalignment. This area needs further study to document functional outcome after an intervention.

**FUNCTIONAL REHABILITATION**

Many researchers have examined the effects of various training regimens on the characteristics of CAI and the symptoms of acute ankle sprains (Appendix). The available research regarding rehabilitation of ankle injuries and CAI ankle instability focuses on a wide variety of exercises and programs. Many experts have succeeded using a type of balance board to improve strength and balance measures in subjects with acute injury and CAI. Others have found that incorporating a variety of coordination-training exercises produces significant improvements in measures of strength and proprioception. And still others have found that strength training can be helpful in increasing not only ankle strength but also ankle-joint proprioception. While various investigators have shown that strength and balance training can be effective, a definitive series of outcome studies that document the number of treatments, the combination, and the volume of exercise necessary to return athletes to full function is lacking. The implications of such research are paramount as evidence for the effectiveness of management.

A secondary purpose of this manuscript was to present a functional-rehabilitation program drawing on concepts from the available literature. A rehabilitation program must be in-
Figure 10. Exercise in water reduces compressive forces and supports injured tissue. A and B, Exercises can be initiated without resistance and then progressed, C, to resistance until D, functional exercises can be performed.
individualized to meet the needs of each athlete. While the importance of creating an individualized rehabilitation program cannot be overstressed, it is our opinion that an individualized rehabilitation program cannot be instituted without prior experience with a structured and well-designed rehabilitation program. Although the educational aims of many undergraduate and graduate programs are to develop clinicians who can be critical thinkers and decision makers, a health care professional can only design an individualized program for a particular patient after gaining substantial experience with a variety of well-structured, progressive rehabilitation programs. Therefore, we provide a structured rehabilitation program that is based on previous experience and empirical evidence. In addition, we supply some alternative concepts that are based on a review of the neuromuscular literature dealing with ankle rehabilitation, bracing, and postural control.

The significance of proper rehabilitation after an ankle sprain cannot be overemphasized, especially when considering the debilitating consequences of decreased ankle ROM, persistent pain, swelling, and CAI. Neglecting appropriate therapy may also precipitate the loss of work hours. In one study, a lack of rehabilitation resulted in several months’ delay in return to military duty. A regimen of Achilles tendon stretching, progressive muscle strengthening, and proprioceptive training after acute treatment plays a pivotal role in hastening return to activity and preventing CAI.

Prolonged immobilization of ankle sprains is a common treatment error. Kerkhoffs et al recently examined the variation of practice with respect to the treatment of the acutely sprained ankle. They performed a formal, systematic review of the literature to scrutinize evidence-based management strategies for the treatment of the acute ankle sprain. Inclusion of the potential studies was independently assessed by 2 reviewers and, when appropriate, results of comparable studies were pooled. They found that immobilization alone should not be used to manage acute lateral ankle-ligament injuries. Kerkhoffs et al reported statistically significant differences for the following outcomes when treatment with immobilization was compared with a functional treatment (based on the available literature): higher percentage of patients returned to work, the length of time elapsed before returning to work was shorter, fewer patients suffered from persistent swelling, fewer patients suffered from objective instability at follow-up, ROM was limited in fewer patients, and subjective satisfaction was higher.

Functional stress stimulates the incorporation of stronger replacement collagen. Functional rehabilitation begins on the day of injury and continues until pain-free gait and activities are attained. Functional rehabilitation has 4 aspects: ROM, strengthening, proprioception, and activity-specific training. Ankle-joint stability is a prerequisite to the institution of functional rehabilitation. Since grade I and grade II injuries are considered stable, functional rehabilitation should begin immediately.

**RANGE-OF-MOTION AND STRENGTHENING EXERCISES**

Range of motion must be regained before functional rehabilitation is initiated (Table 1). Achilles tendon stretching should be instituted within 48 to 72 hours of injury, regardless of weight-bearing capacity, in light of the tissue’s tendency to contract after trauma (Figure 4). Once ROM is achieved and swelling and pain are controlled, the patient is ready to progress to the strengthening phase of rehabilitation. Strengthening of weakened muscles is essential to rapid recovery and is a preventive measure against reinjury. Exercises should focus on the conditioning of the peroneal muscles because insufficient strength in this group has been associated with CAI and recurrent injury. However, all muscles of the ankle should be targeted and all exercises performed bilaterally. If the training is performed bilaterally, we would expect substantial strength gains in both extremities, while the cross-over effect of training only 1 limb may equal only 1.5% to 3.5%. Strengthening begins with isometric exercises performed against an immovable object in 4 directions of ankle movement and progresses to dynamic resistive exercises using ankle weights, surgical tubing, or resistance bands.

Our opinion is that the strength components of many exercise programs would be more effective if performed with clinician-assisted manual resistance. It is common to see athletes perform hundreds of repetitions with various grades of exercise tubing, yet the targeted musculature is hardly fatigued (Figure 5). We recommend that manual resistance be applied for 3 to 5 seconds for 10 to 12 repetitions in each cardinal plane. While controlling the time that a maximal contraction is maintained, the clinician can be assured that the targeted musculature is being maximally loaded in a pain-free arc. Advanced exercises include asking the athlete to maximally resist randomly applied perturbations (Figure 6).

If time is an issue and clinician-assisted manual resistance is not feasible, we recommend a progressive resistive program with weights rather than tubing. Table 2 provides a Daily Adjustable Progressive Resistance Exercise (DAPRE) strength progression for the ankle that was originally described by Knight and later modified by Perrin and Gieck. In this progression, the athlete performs 4 sets of 10 repetitions while increasing the applied weight for each set. The athlete can advance to the next level when he or she can lock out (complete with correct form) the 4th set 10 times. With a structured progression, the athlete can create continuous goals and more easily appreciate improvements. These exercises should be performed with an emphasis on the eccentric component. Patients should be instructed to pause 1 second between the concentric and eccentric phases of exercise and perform the eccentric component over a 4-second period. Concentric contraction refers to the active shortening of muscle with resultant lengthening of the resistance band, while eccentric contraction involves the passive lengthening of the muscle by the elastic pull of the band. Resistive exercises should be performed (2 to 3 sets of 10 to 12 repetitions) in all 4 directions twice a day. Toe raises, heel walks, and toe walks may also be attempted to regain strength and coordination (Figure 7). Continual monitoring of strength is important. Isokinetic strength testing is an accepted method of assessing ankle strength. Less expensive, yet often overlooked, is the use of hand-held dynamometry for consistent monitoring of strength performance.

**PROPRIOCEPTIVE AND BALANCE TRAINING**

As the patient achieves full weight bearing without pain, proprioceptive training is initiated for the recovery of balance and postural control (Table 3). Various devices have been specifically designed for this phase of rehabilitation, and their use in concert with a series of progressive drills has effectively returned patients to a high functional level. The simplest device for proprioceptive training is the wobble board, a small
RETURN TO ACTIVITY-SPECIFIC TRAINING

When the distance walked by the patient is no longer limited by pain, he or she may progress to a regimen of 50% walking and 50% jogging (see Table 4). Using the same criteria, jogging eventually progresses to running, backward running, and pattern running. Circles and figures of 8 are commonly employed patterns. The final phase of the rehabilitation process is documentation that the athlete can perform sport-specific exercises pain free and at a level consistent with preinjury status. Although time consuming, these routines represent the final phase of ankle-joint rehabilitation, and completion of this program is essential for the recovery of ankle stability. In short, clinicians need to create exercises and movement patterns that will increasingly challenge the neuromuscular coordination of the injured athlete.

CONCLUSIONS

Rehabilitation of ankle injuries should be structured and individualized. In the acute phase, the focus should be on controlling inflammation, reestablishing full range of motion, and gaining strength. Once pain-free range of motion and weight bearing have been established, balance-training exercises should be incorporated to normalize neuromuscular control. Advanced-phase rehabilitation activities should focus on regaining normal function. This includes exercises specific to those that will be performed during sport. While having a basic template to follow for the rehabilitation of ankle injuries is important, clinicians must remember that individuals respond differently to exercises. Therefore, each program needs to be modified to fit the individual’s needs.

Appendix. Rehabilitation Articles on Acute and Chronic Ankle Instability

<table>
<thead>
<tr>
<th>Authors (Year)</th>
<th>Title</th>
<th>Specific Training Protocol</th>
<th>Results</th>
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<tr>
<td>Tropp et al (1984)</td>
<td>“Factors affecting stabilometry recordings of single limb stance”</td>
<td>Balance training: Single-leg stance for 15 min, each leg, 1 x/d</td>
<td>No significant differences between acute and nonacute, tape and no tape. Significant changes in pre-post results. Results stabilized and subjective “giving-way” feeling improved with ankle-disk coordination training.</td>
</tr>
<tr>
<td>Gauffin et al (1988)</td>
<td>“Effect of ankle disk training on postural control in patients with functional instability of the ankle joint”</td>
<td>Strength training Ankle-disk training on unstable ankle only, 10 min, 5 x/wk for 8 wk</td>
<td>Proprioceptive ankle-disk training (10 wk) decreased postural sway in healthy subjects.</td>
</tr>
<tr>
<td>Hoffman and Payne (1995)</td>
<td>“The effects of proprioceptive ankle disk training on healthy subjects”</td>
<td>Balance training Biomechanical Ankle Platform System (Spectrum Therapy Products, Jasper, MI): 3 x/wk for 10 wk, 10-min length, 5 trials/session: 40 s long, change clockwise to counterclockwise every 10 s</td>
<td>Fewer recurrent sprains and chronic instability episodes in training group versus control group. No differences in time to return to activities of daily living pain free, no differences in speed of reduction of hematoma and edema.</td>
</tr>
<tr>
<td>Wester et al (1996)</td>
<td>“Wobble board training after partial sprains of the lateral ligaments of the ankle: a prospective randomized study”</td>
<td>Balance training Weeks 1–3: 15 min/d Wobble board: move front to back 10 x, board not touching floor, for 15 s, rest 10 s; Wobble board: move left to right 10 x, board not touching floor, for 15 s, rest 10 s; Wobble board move in circle 5 x, 60 s, rest 20 s</td>
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<td>Authors (Year)</td>
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<td>Specific Training Protocol</td>
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<tr>
<td>Mattacola and Lloyd (1997)</td>
<td>“Effects of a 6-week strength and proprioception training program on measures of dynamic balance: a single-case design”</td>
<td>Weeks 4–6: 15 min/d&lt;br&gt;Wobble board: knees flexed, repeat exercises from wk 1–3 for 30 s, rest 20 s, × 5;&lt;br&gt;Wobble board: single-leg stance for 7 s × 5;&lt;br&gt;Wobble board: single-leg stance, eyes closed, for 4 s × 5;&lt;br&gt;Said training was for 12 wk but only gave 6 wk?</td>
<td>Strength and proprioception training (6 wk) effective in improving dynamic balance abilities assessed on a single-plane balance device.</td>
</tr>
<tr>
<td>Bernier and Perrin (1998)</td>
<td>“Effect of coordination training on proprioception of the functionally unstable ankle”</td>
<td>Balance and strength training: 3×/wk for 6 wk&lt;br&gt;Strength training: 3 sets of 10, isotonic contractions for ankle PF, DF, EV, INV: manual resistance for 3 s&lt;br&gt;Proprioception training 3 sets × 25 reps, single-leg stance on KAB (Kinesthetic Ankle Board), counterclockwise, clockwise, bilateral</td>
<td>Equilibrium balance scores (anteroposterior, mediolateral) improved after 6-week coordination-training program. No effect on sway index or joint position sense.</td>
</tr>
<tr>
<td>Docherty et al (1998)</td>
<td>“Effects of strength training on strength development and joint position sense in functionally unstable ankles”</td>
<td>Week 1: 15 s each, 45-s rest&lt;br&gt;Fixed surface, eyes open&lt;br&gt;Fixed surface, eyes closed&lt;br&gt;Tilt board, DF, PF, eyes open&lt;br&gt;Tilt board, DF, PF, eyes closed&lt;br&gt;Tilt board, INV, EV, eyes open&lt;br&gt;Tilt board, INV, EV, eyes closed&lt;br&gt;Tilt board, diagonal, eyes open&lt;br&gt;Tilt board, diagonal, eyes closed&lt;br&gt;Week 2: 20 s, 40-s rest&lt;br&gt;Same as week 1&lt;br&gt;Add wobble board, eyes open, × 2&lt;br&gt;Week 3: 25 s, 35-s rest&lt;br&gt;Same as week 2&lt;br&gt;Add wobble board, PF, DF, eyes closed&lt;br&gt;Remove tilt board diagonal, eyes open and eyes closed&lt;br&gt;Week 4: 30 s, 30-s rest&lt;br&gt;Fixed surface, eyes closed&lt;br&gt;Fixed surface, pick up objects&lt;br&gt;Tilt board, PF, DF, eyes open&lt;br&gt;Tilt board, PF, DF, eyes closed&lt;br&gt;Wobble board, eyes open, × 2&lt;br&gt;Wobble board, eyes closed, × 2&lt;br&gt;Week 5: 30 s, 30-s rest&lt;br&gt;Same as week 4&lt;br&gt;Add wobble board, eyes closed, × 2&lt;br&gt;Functional hop, eyes open, × 2&lt;br&gt;Week 6: 30 s, 30-s rest&lt;br&gt;Fixed surface, eyes closed&lt;br&gt;Fixed surface, pick up objects&lt;br&gt;Tilt board, PF, DF, eyes open&lt;br&gt;Tilt board, PF, DF, eyes closed&lt;br&gt;Wobble board, eyes open&lt;br&gt;Wobble board, eyes closed&lt;br&gt;Functional hop, eyes open, × 2&lt;br&gt;Functional hop, eyes closed, × 2</td>
<td>Ankle strength-training exercises (6 wk) improved DF and eversion strength and INV and PF joint position sense.</td>
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<td>Authors (Year)</td>
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<tr>
<td>Holme et al (1999)</td>
<td>“The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain”</td>
<td>Week 4: 3/wk for 10 min, black tubing (special heavy), 4×10, PF, DF, EV, INV&lt;br&gt;Week 5: 3/wk for 10 min; silver tubing (super heavy), 3×10 reps, PF, DF, EV, INV&lt;br&gt;Week 6: 3/wk for 10 min; silver tubing (super heavy), 4×10, PF, DF, EV, INV&lt;br&gt;Coordination training: 1 h, 2×/week; ~6 wk includes comprehensive balance exercises, both legs; figure-of-8 running; standing on outside of feet, eyes open, eyes closed; standing on inside of feet, eyes open, eyes closed&lt;br&gt;Session 1:&lt;br&gt;Bilateral squat: 3×3 min, 1-min rest @ 20% BW&lt;br&gt;Heel raise: 3×3 min, 1-min rest @ 21% BW&lt;br&gt;Unilateral hop: 5×30, 1-min rest @ 17% BW&lt;br&gt;Walk/run: 2.0 m/s, 15 min @ 80% BW&lt;br&gt;Shuffle: 0.9 m/s, 4 sets × 1 min @ 77% BW&lt;br&gt;Stretching: 4×15 s, 15-s rest&lt;br&gt;Unilateral squat: 5×30, 1-min rest @ 77% BW&lt;br&gt;Session 2:&lt;br&gt;Bilateral squat: same&lt;br&gt;Heel raise: same&lt;br&gt;Unilateral hop: same&lt;br&gt;Walk/run: 3.4 m/s for 15 min @ 82% BW&lt;br&gt;Shuffle: 1.3 m/s, 4 sets × 1 min @ 87% BW&lt;br&gt;Stretching: same&lt;br&gt;Unilateral squat: 5×30, 1-min rest @ 82% BW&lt;br&gt;Session 3:&lt;br&gt;Bilateral squat: same&lt;br&gt;Heel raise: same&lt;br&gt;Unilateral hop: same but @ 21% BW&lt;br&gt;Walk/run: 3.6 m/s for 15 min @ 82% BW&lt;br&gt;Shuffle: 1.3 m/s, 4 sets × 1 min @ 89% BW&lt;br&gt;Stretching: same&lt;br&gt;Unilateral squat: 5×30, 1-min rest @ 94% BW&lt;br&gt;Session 4:&lt;br&gt;Bilateral squat: same&lt;br&gt;Heel raise: 3×3 min, 1-min rest @ 21% BW&lt;br&gt;Unilateral hop: same but @ 26% BW&lt;br&gt;Walk/run: 4.0 m/s for 15 min @ 81% BW&lt;br&gt;Shuffle: 1.8 m/s, 4 sets × 1 min @ 100% BW&lt;br&gt;Stretching: same&lt;br&gt;Unilateral squat: 5×30, 1-min rest @ 103% BW&lt;br&gt;Session 5:&lt;br&gt;Bilateral squat: same but @ 26% BW&lt;br&gt;Heel raise: same as session 4&lt;br&gt;Unilateral hop: same but @ 31% BW&lt;br&gt;Walk/run: 3.6 m/s for 15 min @ 89% BW&lt;br&gt;Shuffle: 2.0 m/s, 4 sets × 1 min @ 100% BW&lt;br&gt;Stretching: same&lt;br&gt;Unilateral squat: same as session 4</td>
<td>After injury (6 wk), side-to-side differences in isometric strength and postural control. After 4 mos, both variables normalized in both the training and control group. After 12 mos, training group had fewer reinjuries. Improved active range of motion, pain-free isometric strength, average unilateral peak vertical force production, unilateral hop test performance. Return to full activity, pain free.</td>
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<tr>
<td>Authors (Year)</td>
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<td>Specific Training Protocol</td>
<td>Results</td>
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|               | Bilateral squat: same as session 5  
|               | Heel raise: same as session 5  
|               | Unilateral hop: same as session 5  
|               | Walk/run: 4.0 m/s for 15 min @ 100% BW  
|               | Shuffle: same as session 5  
|               | Stretching: same  
|               | Unilateral squat: same as session 5  | No significant differences in static balance measures. Significant differences in semidynamic and dynamic balance for all training groups versus control group. No one training program more effective in improving healthy subjects' balance. |
|               | Gray Theraband (Hygenic Corp, Akron, OH): 3×10 reps, PF, DF, EV, INV  
|               | Free weights: 3×10 reps  
|               | Standing calf raises: 3×10 reps  
|               | Proprioception Training  
|               | Theraband kicks: 50 reps, 4 positions  
|               | 4-square hops: 4 patterns, 1 rep, 20 s  
|               | Single-leg stance (with ball): 3×20 s  
|               | Biomechanical Ankle Platform System (BAPS) (Spectrum Therapy Products, Inc, Jasper, MI) (level 3): single-leg stance, 3×20 s  
|               | Combination training  
|               | BAPS: single-leg stance, clockwise 10 s, counterclockwise 10 s  
|               | 4-square hops: 4 patterns, 1 rep, 20 s  
|               | Standing calf raises: 3×10  
|               | Gray Theraband: 3×10, PF, DF, INV, EV  
|               | Balance training: 3×15 s each leg, each exercise, 10–15 min/d × 30 d, then 3×/wk for rest of season | No significant differences between groups as to number, incidence, type of traumatic lower extremity injuries. Incidence rate of “major” injuries higher in the intervention group. More anterior cruciate ligament injuries, so knee injury not prevented with balance-board training. Of athletes with prior injury, more control-group subjects with reinjuries or new injuries. |
|               | 4-wk training using the ABC Agility Ladder (MF Athletic Co, Cranston, RI), 3×/wk for 20 min/session; 3–5-min warm-up followed by series of 7 drills, separated by 15-s rest  
|               | Seven drills included  
|               | Forward: 2 feet in  
|               | Lateral: 2 feet in  
|               | Forward shuffle  
|               | One-foot-in-Ali shuffle  
|               | Forward slalom jumps  
|               | Forward cross-steps, 90° ankle  
|               | Balance training  
|               | Single-leg stance on ankle disc, remaining upright for as long as possible, 10 min/d, 5×/wk for 10 wk; one group taped from the lateral malleolus to the sole of the foot, other group untaped  
|               | Balance training  
|               | Ankle-disk training × 15 min/d for 8 wk, injured side only | Agility training (4 wk) using ABC Agility Ladder did not significantly affect postural sway in subjects with chronic ankle instability. Conversely, trained subjects reported more stability and better able to perform activities. |
| Matsusaka et al (2001) | “Effect of ankle disk training combined with tactile stimulation to the leg and foot on functional instability of the ankle” | Improved postural sway in all subjects who trained using ankle disk; taped subjects improved 2 weeks earlier, perhaps due to increased afferent input. |

*PF indicates plantar flexion; DF, dorsiflexion; EV, eversion; INV, inversion; BW, body weight; rep, repetition.
REFERENCES


Can Chronic Ankle Instability Be Prevented? Rethinking Management of Lateral Ankle Sprains

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Objective: To pose the question, “Can chronic ankle instability be prevented?” The evaluation and treatment of chronic ankle instability is a significant challenge in athletic health care. The condition affects large numbers of athletes and is associated with reinjury and impaired performance. The management of acute injuries varies widely but in athletic training has traditionally focused on initial symptom management and rapid return to activity. A review of practice strategies and philosophies suggests that a more detailed evaluation of all joints affected by the injury, correction of hypomobility, and protection of healing structures may lead to a more optimal long-term outcome.

Background: Sprains to the lateral ankle are common in athletes, and the reinjury rate is high. These injuries are often perceived as being isolated to the anterior talofibular and calcaneofibular ligaments. It is, however, becoming apparent that a lateral ankle sprain can injure other tissues and result in joint dysfunction throughout the ankle complex.

Description: We begin by addressing the relationship between mechanical and functional instability. We then discuss normal ankle mechanics, sequelae to lateral ankle sprains, and abnormal ankle mechanics. Finally, tissue healing, joint dysfunction, and the management of acute lateral ankle sprain are reviewed, with an emphasis on restoring normal mechanics of the ankle-joint complex. A treatment model based on assessment of joint function, treatment of hypomobile segments, and protection of healing tissues at hypermobile segments is described.

Key Words: joint mobilization, injury prevention

Ankle sprains are among the most common injuries suffered during athletic activities. The reinjury rate after lateral ankle sprain has been reported to be as high as 80% among athletes. Previous injury has been identified as a strong predictor of reinjury, although little is known about the specific anatomical and biomechanical factors predicting reinjury. The treatment of acutely injured ankles consists of initial efforts to control pain and swelling followed by range-of-motion exercises, stretching of musculotendinous tissues, efforts to improve neuromuscular control, and strengthening exercises. Stability of the ankle is not improved by immobilization. Improved functional abilities, however, are seen with early mobilization, which has led to early return to activities. Athletes are often allowed to weight bear, ambulate, and return to functional activities soon after injury. Despite the quick return of athletes to functional activities, the reinjury rate and incidence of chronic instability are high. What are we missing? Through a review of the clinical and research literature, we have reexamined the treatment of acute ankle sprains.

Our review has led us to focus on the resolution of altered joint mechanics after lateral ankle sprains. Altered joint mechanics during the tissue-repair phase of the healing process may force tissues to heal in elongated positions (producing laxity), expose tissues to excessive forces, create altered feedback to the neuromuscular control system, or result in chronic losses of motion. We begin by addressing the relationship between mechanical and functional instability. We then discuss normal ankle mechanics, sequelae to lateral ankle sprains, and abnormal ankle mechanics. Finally, tissue healing, joint dysfunction, and the management of acute lateral ankle sprain are reviewed, with an emphasis on the restoration of normal mechanics of the ankle joint complex. Unfortunately, limited data exist to permit assessment of the effects of the treatment approach we propose. The treatment of chronic ankle instability (CAI), however, has proven to be difficult. Thus, we believe that treatment of the acutely injured ankle must be reviewed in an effort to prevent reinjury and CAI.

THE RELATIONSHIP BETWEEN MECHANICAL AND FUNCTIONAL INSTABILITY

The relationships between alterations in joint mechanics and functional instability have not been fully elucidated. Some have claimed that mechanical and functional instability are relatively unique entities. For example, Hess et al, citing the works of Bernier et al and Tropp et al, stated that “anatomic laxity is not considered a primary cause” of CAI. Our review of these articles suggests a need to reconsider the relationship between laxity and chronic instability.

Bernier et al reported that 7 of 9 subjects with functional ankle instability demonstrated laxity in the anterior talofibular ligament. Consistent with Bernier et al, Hertel et al found that 75% of subjects with a history of ankle sprain demon-
strated laxity of the talocrural joint on stress fluoroscopy, but two thirds of those with talocrural laxity also demonstrated laxity at the subtalar joint. Similarly, Meyer et al. noted subtalar injury in 80% of 40 patients who suffered an acute lateral ankle sprain.

Although these reports suggest a link between mechanical and functional ankle instability, only laxity of the talocrural and subtalar joints was considered. Little consideration has been given to the role of the distal and proximal tibiofibular joints or the effect of hypomobility at any of the joints of the ankle complex on the incidence of CAI. In order to appreciate the potential for these sources to contribute to CAI and reinjury after lateral ankle sprain, a review of normal ankle mechanics is needed.

NORMAL ANKLE MECHANICS

The talocrural (ankle) joint is one of the most congruent joints in the body. It consists of the articulation between the talus and the mortise created by the distal tibiofibular joint. The talocrural joint is a synovial joint that is usually described as having a single oblique axis, allowing plantar flexion and dorsiflexion. Some medial and lateral rotation and talar tilt have, however, also been documented in healthy ankles.10-11

The talus is wedge shaped, wider anteriorly than posteriorly. The medial facet of the talus, which articulates with the tibial malleolus, is shorter in the anterior-posterior dimension than the lateral facet of the talus, which articulates with the fibular malleolus. Therefore, the distal fibula must travel farther than the distal tibia on the talus during ankle dorsiflexion and plantar flexion. The shape of the talus results in external rotation of the talus during dorsiflexion and internal rotation during plantar flexion.11,12

The proximal and distal tibiofibular joints are dynamic entities that facilitate movement during normal functional activities. The proximal tibiofibular joint is a synovial joint with slight convexity to the tibial facet and slight concavity to the fibular facet. The distal tibiofibular joint is a syndesmosis, with a concave tibial facet and a convex fibular facet.11

During ankle dorsiflexion (physiologic motion), the talus glides posteriorly (accessory motion) and externally rotates in relation to the mortise.13-15 Calcaneal eversion also causes the talus to tilt laterally.14 These motions of the talus in relation to the mortise produce a superior-posterior glide and lateral displacement of the distal fibula in relation to the tibia.13 At the same time, at the proximal tibiofibular joint, the fibula glides anterolaterally and superiorly on the tibia, fixing the fibula to the tibia.15 In addition, the fibula demonstrates a small amount of rotation during dorsiflexion.11,14 Impaction of the proximal tibiofibular joint, along with increased tension in the crural intersosseous tibiofibular ligament and intersosseous membrane, creates a stable base from which attached muscles can function. From this stable base, the peroneus longus and brevis muscles contract. The peroneus longus plantar flexes the first ray, and both facilitate weight transfer from lateral to medial across the metatarsals during the stance phase of gait.11 During ankle plantar flexion, the opposite motions occur at these articulations.11,14 In addition, the fibula glides superoposteromedially and inferoanterolaterally at the proximal tibiofibular joint with the rotational movements of pronation and supination, respectively.15

The subtalar joint has 2 separate articulating surfaces that function together. In the anterior portion of the joint, the articular surface of the calcaneus is concave and the articular surface of the talus is convex. In the posterior portion of the joint, the articular surface of the calcaneus is convex and the articular surface of the talus is concave. At the subtalar joint, the talus glides in an anterior and medial direction in relation to the calcaneus from heel strike to the foot-flat position. This movement tenses the intersosseous ligament of the subtalar joint and pulls the calcaneus into eversion. Eversion of the calcaneus is also facilitated by loading of the calcaneus at the posterolateral tubercle during heel strike and the mitered hinge created by the axis of the subtalar joint. Eversion of the subtalar joint, in combination with plantar flexion and adduction of the talus on the calcaneus, constitutes the pronation observed at the subtalar joint from the foot-flat position to midstance. Eversion at the subtalar joint is accompanied by a lateral glide of the calcaneus on the talus in the anterior joint and a medial glide and lateral roll at the posterior joint. From midstance to toe-off, the opposite sequence of motions occurs, constituting supination of the subtalar joint. The subtalar joint inverts, and the talus dorsiflexes and abducts on the calcaneus. From midstance to toe-off, the calcaneus is pulled into inversion by contraction of the posterior tibial muscle and the gastrocnemius-soleus complex in combination with the heel rise. As the calcaneus inverts, the talus moves in a posterior and lateral direction in relation to the calcaneus.11

SEQUELAE TO LATERAL ANKLE SPRAIN

The most common mechanism of ankle injury involves excessive inversion or supination of the foot and ankle complex, resulting in injury to the lateral ligaments of the ankle.2,16-18 At end range, inversion and supination are limited by the lateral joint capsule of the ankle and the ligaments supporting the lateral talocrural, subtalar, and distal and proximal tibiofibular joints. Overload of these structures results in disruption of the fibrous integrity of the ligaments and dysfunction (hypermobility or hypomobility) of one or more joints in the ankle complex.

Tissue injury results in pain, swelling, and joint dysfunction. Pain and swelling, while the focus of initial intervention, resolve with time. Altered joint mobility, involving either hypermobility or hypomobility, however, may be more long lasting and indicate residual dysfunction of the joints of the ankle complex.

ABNORMAL ANKLE MECHANICS

Joint dysfunction, whether due to hypermobility or hypomobility, is commonly found in patients suffering from functional instability. A familiar concept is ligamentous laxity, or mechanical instability, after lateral ankle sprain. Hypermobility is usually associated with mechanical instability. Mechanical instability, by definition, is an increase in the accessory movements that the individual cannot voluntarily produce, such as glide and roll of the talus in the mortise. Increased accessory movement at a joint indicates an enlargement of the neutral zone of the joint.19-21 The neutral zone is defined as the area of joint accessory movement available without ligamentous tensioning.19,20 Increased accessory movements also produce an abnormal pattern of movement of the instantaneous axis of rotation (IAR) of the joint with physiologic movement.22,23 Residual mechanical instability usually results from
a tear or lengthening of one of the ligamentous structures supporting the joint and suggests a nonoptimal healing process after injury.

Cadaveric study of the ligaments of the ankle has demonstrated the existence of mechanoreceptors. The observed alterations in proprioception in mechanically and functionally unstable ankles are likely due, at least in part, to the altered or disrupted input from these sensory receptors. Moreover, the abnormal movement of the IAR likely results in altered proprioceptive input from tissues that are abnormally stressed and forces the athlete to alter motor-control programs to compensate if function is to be maintained. If the motor-control system adapts and new motor programs and preprogrammed reflexes are well learned, then deficits in gross function are not evident without detailed kinesiologic studies.

Several authors have reported that sprain of the anterior talofibular and calcaneofibular ligaments can result in increased laxity with anterior drawer and inversion talar tilt testing. The interosseous and cervical ligaments of the subtalar joint and the inferior tibiofibular interosseous ligaments are also commonly involved in lateral ankle sprains; damage can result in excessive pronation or an unstable mortise, respectively.

Residual laxity in the subtalar joint strongly suggests that the cervical and interosseous ligaments were damaged in a lateral ankle sprain. While the function of these structures has not been fully elucidated, Viladot et al described these structures as the cruciates of the subtalar joint. If this is the case, these ligaments limit end-range pronation and supination. Loading of injured cervical and interosseous ligaments may occur with early return to full weight bearing after injury. Early loading and stress to these ligaments may compromise the healing process and cause the ligaments to heal in a lengthened state. This hypothesis is consistent with the observation of subtalar laxity after lateral ankle sprain and reports of improved function when pronation is constrained by an orthotic device after ankle injury. In theory, if the subtalar ligaments are involved in the injury and if these ligaments limit end-range pronation and supination as proposed by Viladot et al, then orthotic intervention limits the stresses applied to the healing subtalar ligaments and allows repair to occur at a more optimal length. The high incidence of CAI and evidence of residual laxity of the subtalar complex after an inversion injury suggest the need for further study of the effects of orthotics in this population.

A less familiar concept is the role of hypomobility in producing ankle instability. Hypomobility at any joint in the lower extremity kinetic chain can challenge the motor-control mechanisms of the athlete and lead to joint instability. Joint hypomobility can be physiologic or arthrokinematic (accessory motions) in nature. Limited range of motion of the joint can be intra-articular or extra-articular in nature. Intra-articular sources of limited mobility usually alter the arthrokinematics of the joint, producing limitations of the accessory movements of roll and glide between the joint surfaces. The abnormal restrictive barrier to accessory movement changes the normal pattern of movement of the IAR of the joint by becoming the axis of rotation of the joint when engaged. Again, movement around an abnormal axis of rotation abnormally stresses tissues and produces altered proprioceptive input to the central nervous system. The motor-control system must adapt to maintain function.

It has been suggested that after an ankle sprain, hypomobility may occur at the subtalar joint, talocrural joint, distal tibiofibular joint, proximal tibiofibular joint. The need to restore ankle dorsiflexion after injury is commonly addressed in rehabilitation guidelines. Limited dorsiflexion after lateral ankle sprain has been attributed to tightness in the gastrocnemius-soleus complex, capsular adhesions developed during immobilization, or both. Subluxation has also been suggested as a source of hypomobility at the ankle-joint complex after lateral ankle sprain. Limited dorsiflexion after lateral ankle sprain can result in limited physiologic motion (eg, ankle dorsiflexion); however, it is also important to note that due to compensatory movements at adjacent joints, physiologic motion can be restored and maintained despite restricted arthrokinematic motion. For example, limited talocrural joint dorsiflexion may initially produce a vertical limp during gait. This compensation maintains forward movement of the lower leg over the foot during midstance. Later, hypermobility of the subtalar joint into eversion and the midfoot into abduction may be seen as the adaptive ability of the tissues of these joints is overcome by the excessive pronation required to maintain forward gait.

Denegar et al reported limitations in posterior talar glide in a group of collegiate athletes who had returned to sport after ankle sprain. Green et al noted accelerated restoration of dorsiflexion and normal gait patterns after anterior-to-posterior mobilizations of the talus in the mortise. Dananberg et al suggested that hypomobility at the proximal tibiofibular joint can also limit ankle dorsiflexion.

In addition to the works cited above, the manual-therapy literature is replete with references to hypomobility about the ankle-joint complex. While data to support some of the assertions regarding hypomobility are limited, some research and case study reports substantiate these claims. Mulligan claimed that anterior subluxation of the fibula on the tibia at the distal tibiofibular joint may be the cause of painfully limited inversion after ankle sprain. Kavanagh supported this assertion by demonstrating differences in mobility at the tibiotalar joint between subjects with and without ankle sprains. The precise link between ligamentous sprain and the resultant joint dysfunctions is not fully understood and is likely to differ among individual patients. Although the relationship between hypermobility and ankle instability is often discussed, little attention has been paid to the relationships among hypomobility, ankle injury, and CAI. Tabrizi et al reported that limited dorsiflexion predisposed children to ankle injury. They attributed limited dorsiflexion to the extra-articular structures, principally tightness of the calf muscles. Dananberg et al demonstrated that one session of manipulation directed at the talocrural and proximal tibiofibular joints produced twice the dorsiflexion range-of-motion gains of a 6-month regimen of calf stretching. These findings suggest that limitations in accessory joint motion have a profound effect on ankle-joint mechanics and may predispose the ankle to injury.

**Tissue Healing and Joint Dysfunction**

The link between hypermobility and hypomobility may lie in the loss of normal bony alignment (subluxation) or restrict-
ed joint mobility resulting from forced inversion. Limitations in talocrural-joint dorsiflexion and lateral ligamentous laxity have been reported after inversion ankle sprains. Unaddressed hypomobility at the injured joint may result in compromised tissue repair and compensatory motions at other joints. For example, the talus may be subluxed or malpositioned within the mortise as a result of the sudden plantar flexion-inversion stress produced by the inversion ankle sprain. The anteriorly displaced talus lacks the normal restraint to anterior displacement and talar tilt provided by the anterior talofibular and calcaneofibular ligaments, yet it does not glide posteriorly, resulting in restricted dorsiflexion range of motion (hypomobility). Such subluxation results in a firm end feel with grossly restricted dorsiflexion and the associated accessory movement of posterior glide of the talus within the mortise. If the talus remains subluxed anteriorly after an inversion ankle sprain, the torn anterior talofibular ligament heals in an elongated position, thereby compromising its role in providing mechanical stability to the ankle and proprioceptive input to the central nervous system.

Restriction of normal arthrokinematic motion at the proximal or distal tibiofibular joint can also restrict dorsiflexion. As previously mentioned, the fibula must be able to glide superiority and displace laterally with dorsiflexion. Subluxation of the fibula anteriorly and inferiorly at the proximal or distal tibiofibular joint prevents the normal excursion of the fibula and limits posterior translation of the talus in relation to the mortise during dorsiflexion. If the fibula remains subluxed anteriorly and inferiorly during healing, the inferior tibiofibular intersosseous ligament may be stressed during healing, thereby compromising mortise stability. If the talus is subluxed anteriorly along with the fibula, the anterior talofibular ligament and the tibiofibular intersosseous ligament may heal in elongated positions.

The superior tibiofibular joints can also become dysfunctional after the common inversion ankle sprain, contributing to functional instability. Myre suggested that the fibula subluxes anteriorly at the superior tibiofibular joint with an inversion ankle sprain. The restriction of normal fibular translation may lead to diminished talocrural-joint dorsiflexion mobility. The inability of the fibula to move may also compromise the stable base from which the peroneus longus and brevis muscles act to plantar flex the first ray, transfer weight across the metatarsals, and dynamically stabilize the ankle.

The subtalar joint can also sublux during the inversion ankle sprain, resulting in limited eversion and compromise of the joint’s ability to pronate during gait. If the interosseous and cervical ligaments are damaged and the subluxation is maintained during tissue healing, the ligaments may heal in an elongated state and compromise joint stability and function.

Clinical observation and the research literature strongly suggest that residual joint dysfunction is common and underappreciated. Residual laxity at the knee or shoulder can result in re-injury, persistent pain and swelling, and functional disability. Hypomobility at the knee, such as a loss of terminal extension, is also associated with these symptoms. These phenomena also occur at the ankle complex. Because management practices can affect the integrity of healing ligaments at the knee, it is reasonable to believe that they can also affect the integrity of healing ligaments and joint mechanics at the ankle.

INJURY AND MANAGEMENT: REPAIR AND MOBILITY

The talocrural joint neither functions nor is injured in isolation. Each articulation of the ankle-joint complex should be evaluated and addressed after a lateral ankle sprain. While the ligaments supporting the joints of the ankle complex are similar histologically to the collateral ligaments of the knee, the contemporary management of knee and ankle sprains demonstrates a distinct contrast. After a second- or third-degree medial collateral liga...
Techniques that apply forces to unload, rather than stress, injured tissues while correcting subluxation are indicated in the early management of an ankle sprain. Thus, we believe that joint mobilization should be incorporated into the early management of the injured ankle if accessory joint motion is limited. The mobilization should be performed to correct anterior talar and fibular subluxation while avoiding stress to the injured ligaments. Motion restrictions at the subtalar and proximal tibiotalar joints must also be identified and addressed.

Once joint-mobility restrictions are corrected, a gradual increase in tissue stress to optimize tensile strength of the repaired tissue, rather than an abrupt increase in load with early, full weight bearing, is required. Initial exercise for the muscles of the ankle should be performed while keeping the healing tissue in a shortened position, typically the beginning to mid-range position of the joint that the ligament crosses. For the anterior talofibular ligament, this means neutral to dorsiflexed positions while avoiding plantar-flexed and inverted positions. As tissue healing allows, exercise can move into ranges in which the tissue is maximally stressed, typically the end ranges of joint mobility. For the anterior talofibular ligament, this means plantar-flexed and inverted positions. Resistance should be low and repetitions high through the first 3 to 4 weeks. Resistance can be increased and repetitions decreased as the tissue-remodeling process progresses.60

The shift from open- to closed-chain activities substantially increases end-range loading of the subtalar joint. During walking, the foot reaches full pronation in midstance. It is quite plausible that the subtalar-joint laxity observed in some patients with chronically unstable ankles resulted from excessive stress applied to the healing subtalar ligaments by an early return to full weight bearing and walking. Orthotic interventions that constrain subtalar-joint pronation have been reported to improve functional and balance performance64,65 and are recommended in the treatment of acute lateral ankle sprains.65

The effect of orthotic intervention on residual laxity has not, however, been reported. Thus, while the healing anterior talofibular and calcaneofibular ligaments are not overly stressed with early weight bearing, the same is not necessarily true of other injured structures. If laxity is detected upon subtalar-joint evaluation, orthotic intervention should be considered before the athlete returns to full weight bearing and gait training. When identified, subluxation of the subtalar joint must be corrected before orthotic intervention is considered.

Once normal joint mobility is restored and the healing ligaments are adequately protected, efforts must be made to restore neuromuscular control and maximize reflexive, dynamic stability surrounding the joints of the ankle complex. Many of the intervention strategies reported in this special issue can be applied in the treatment of the acute lateral ankle sprain. By addressing the spectrum of sequelae to the initial injury rather than focusing solely on the ligaments of the lateral ankle, we believe that the incidence of CAI can be reduced.

SUMMARY

We believe that effective management of the acutely injured ankle requires greater protection from stress to healing tissues than is allowed with rapid return to weight bearing, walking, and functional exercises. The greatest challenge presented by CAI may not be in treatment but in prevention. To expect therapeutic exercises, external supports, or surgical reconstruction to fully restore the structural and functional integrity of the ankle joints is not reasonable. Athletes suffering from CAI miss practices and competitions, require ongoing care to remain active, and often suffer from suboptimal performance.

Can CAI be prevented through appropriate care of the injured ankle? This question is yet to be answered. At present, all we can offer is a treatment approach based upon what is known about the effect of injury on ankle joint-complex mechanics, repair of injured ligaments, and the stresses placed on the ligaments of the ankle complex during daily and athletic activities. This treatment approach requires an understanding of inflammation and lower extremity biomechanics. Through this knowledge, a treatment program that manages the symptoms of inflammation, restores normal joint motion, and gradually applies stress to healing tissues can be offered as a viable alternative to current practices.

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Biomechanical and Neuromuscular Effects of Ankle Taping and Bracing

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Objective: An extensive review of clinically relevant research is provided to assist clinicians in understanding the underlying mechanisms by which various ankle-support systems may provide beneficial effects. Strategies for management of different types of ankle ligament conditions are also discussed.

Background: Much of the literature pertaining to ankle instability and external support has focused on assessment of inward displacement of the hindfoot within the frontal plane. Some researchers have emphasized the importance of (1) pathologic rotary displacement of the talus within the transverse plane, (2) the frequent presence of subtalar joint ligament lesions, and (3) the interrelated effects of ankle support on deceleration of inversion velocity and facilitation of neuromuscular response.

Description: The traditional method for application of adhesive tape to the ankle primarily restricts inward displacement of the hindfoot within the frontal plane. The biomechanical rationale for a method of ankle taping that restricts lower leg rotation and triplanar displacement of the foot associated with subtalar motion is presented.

Clinical Advantages: The lateral subtalar-sling taping procedure may limit strain on the anterior talofibular ligament associated with subtalar inversion, restrain anterolateral rotary subluxation of the talus in the presence of ligament laxity, and protect the subtalar ligaments from excessive loading. The medial subtalar sling may reduce strain on the anterior-inferior tibiofibular syndesmosis and enhance hindfoot-to-forefoot force transfer during the push-off phase of the gait cycle.

Key Words: ankle instability, subtalar joint injury, ankle dysfunction

For more than a century, ankle taping has been advocated as a means to protect the ankle ligaments from excessive strain. Widespread belief in the effectiveness of ankle taping and the extremely high incidence of lateral ankle sprains among athletes resulted in ubiquitous use of the procedure within scholastic and professional athletic organizations for many years. The skillful application of adhesive tape to the ankles of athletes remains strongly associated with the role of the athletic trainer today. One prospective study has documented the effectiveness of ankle taping in reducing sprain incidence, and numerous researchers have evaluated the extent to which tape provides a mechanical restraint to excessive ankle motion. Literature on the subject also contains descriptions of various tape-application procedures for the ankle and critical analyses of the benefits that may be derived from ankle taping. Some researchers have emphasized that ankle taping rapidly loses its initial level of resistance to motion during exercise, but most studies on the mechanical effect of taping have demonstrated some level of motion restriction after exercise. Although tape clearly loosens significantly during exercise, its restraining effect on extreme ankle motion is not eliminated by prolonged athletic activity.

In recent years, a variety of ankle braces have become commercially available as alternatives to ankle taping. Some investigators have studied the mechanical effect of various brace designs on restraint of ankle motion and many such studies have compared the mechanical effects of bracing and taping. Some researchers have found comparable levels of postexercise motion restraint for taping and bracing, whereas others have concluded that ankle bracing is superior to taping on the basis of less exercise-induced increase in ankle motion with bracing. In a recent meta-analysis of 19 studies of the effects of different types of ankle support on ankle motion before and after activity, significantly greater frontal-plane ankle-motion restriction after exercise was found for a semirigid stirrup brace design than for taping or a lace-up type brace. Several prospective studies have documented a beneficial effect of semirigid ankle bracing on sprain incidence and 2 retrospective studies comparing the effects of taping and a lace-up brace on sprain incidence supported the superiority of bracing for injury prevention. Despite these findings, some sports medicine clinicians and athletes believe that taping provides superior benefits related to comfort, perception of greater support, and less interference with normal ankle function.

EFFECTS ON PERFORMANCE CAPABILITIES

A number of authors have evaluated the effects of ankle taping and bracing on the functional performance capabilities of normal and injured subjects. Findings regarding the extent to which ankle support may interfere with normal function have been inconsistent, and no clear conclusions can...
be drawn concerning the relative effects of different brace designs (eg, semirigid versus lace up). For example, some researchers found that various forms of ankle support decreased vertical jump height by 3% to 5%, whereas others did not observe a significant effect. Some investigators observed significantly decreased performance on multidirectional agility tests for uninjured subjects wearing ankle support, whereas others did not find a difference between supported and unsupported conditions. Most of the studies comparing the effects of taping and bracing on performance have not demonstrated significant differences between taping and various types of braces. Some group of researchers has suggested that stirrup-type braces are superior to taping and lace-up braces on the basis of a less adverse effect on sagittal-plane isokinetic strength and range of motion.

Surprisingly, relatively few authors have evaluated the extent to which ankle support may improve the functional capabilities of subjects with ankle dysfunction. None have evaluated different ankle-taping methods or different brace designs, as all 3 of the cited studies evaluated the effect of the same semirigid, stirrup-type brace. Gross et al found no significant beneficial effect on agility test performance for subjects with a history of recurrent ankle sprains, whereas Halset al reported significantly improved agility test performance for subjects with a postacute sprain wearing the brace. Fridén et al observed significant improvement in unilateral postural balance in subjects with a postacute sprain wearing the stirrup-type brace.

Although research evidence supports protected functional use as the most appropriate management of an acute lateral ankle sprain of any degree of severity, relatively little scientific information pertains to the influence of ankle-support characteristics on recovery of optimal ankle function. Athletic trainers have long used the open-basketweave ankle-taping procedure to restrict ankle motion and control edema and stirrup-type ankle braces have been designed to provide the same therapeutic benefits. Two studies of the effects of different brace designs on edema control and the rate of restoration of functional capabilities produced conflicting results. A potentially important area of research that has not been thoroughly investigated is the relationship between specific structural characteristics of various ankle supports and their suitability for achieving different beneficial effects, such as restricting frontal-plane motion and transverse-plane motion, reducing ankle-displacement velocity, controlling edema, reducing load on specific ligaments, and enhancing proprioceptively mediated joint stabilization.

**ALTERNATIVE MECHANISMS OF BENEFICIAL EFFECT**

A number of investigators have provided information about alternative mechanisms by which ankle support may offer protection during a potentially injurious event. The effects of ankle taping and bracing on proprioceptive input to the central nervous system, peroneal muscle activity, and deceleration of ankle motion may be as important as restriction of the range of ankle inversion for sprain prevention.

Feuerbach and Grabiner found that both anteroposterior and mediolateral postural sway were decreased in normal subjects when a semirigid, stirrup-type brace was worn. The possibility that the improvement was due to enhanced proprioceptive input to the central nervous system was evaluated in a subsequent study of the effect of the brace on joint position sense, both with and without ankle-joint anesthesia. Because the presence of the brace improved the accuracy of active replication of reference ankle positions in each of 3 planes, even in the anesthetized condition, the authors concluded that the stirrup-type brace enhanced proprioception from cutaneous mechanoreceptors.

Simoneau et al found that tape straps adhered to the skin significantly improved joint position sense in nonweight-bearing plantar flexion. Heit et al noted that taping and a lace-up brace both significantly improved the ability of subjects to actively reproduce a specific plantar-flexion joint angle. Because taping also significantly enhanced inversion position sense, they suggested that taping may be more effective than bracing for improving ankle joint proprioception. Awareness of ankle-joint position is clearly most important immediately before ground contact in order to avoid landing in an inverted position, whereas peroneal muscle activation is essential to counteract a potentially injurious force after landing.

Glick et al were the first to present evidence of a relationship between peroneal muscle activity and the presence of tape on the ankle. Using electromyography (EMG) and cinematography, they found that the peroneus brevis muscle was active for a longer period of time at the end of the swing phase, just before footstrike, when the ankle was taped. Springers et al also used EMG to assess the effect of taping on peroneal activation, expecting that the tape would relieve strain on the lateral anatomical structures of the ankle and decrease eveter muscle activation during a step-down maneuver and a simulated weight-bearing inversion-sprain motion. Contrary to this expectation, which was derived from the concern that long-term taping might ultimately produce peroneal weakness, taping did not prevent the eveter musculature from being vigorously activated.

Karlsson and Andréasson used EMG to assess the effect of taping on the speed of peroneal response to sudden weight-bearing inversion in subjects with normal and mechanically unstable ankles. Tape on mechanically unstable ankles decreased the response latency of both the peroneus brevis and peroneus longus muscles by 8% (75.2 versus 81.6 milliseconds) and 13% (73.4 versus 84.5 milliseconds), respectively; the greatest improvement in response speed was in ankles with the greatest degree of instability.

Lohrer et al analyzed the effects of taping on both peroneal EMG activity and restraint of weight-bearing lateral ankle displacement. They concluded that reduction in the angular velocity of displacement with tape, combined with restricted displacement amplitude, permitted relatively greater peroneal activation per degree of motion than the untaped condition. The “proprioceptive amplification ratio,” calculated as the integrated peroneal EMG activity divided by the maximum inversion amplitude, was presented as a means of quantifying the interrelated neuromuscular stimulation and motion-restriction effects of taping. Further evidence supporting this concept was presented by Alt et al, who used identical methods to evaluate the effects of ankle taping before and after 30 minutes of exercise. Compared with the untaped condition, ankle taping reduced the postexercise inversion amplitude by 38% and the postexercise integrated EMG activity by only 20%. Thus, taping produced relatively greater integrated peroneal EMG activity within the restricted range of inversion than that ob-
served for the corresponding portion of the range of unrestricted inversion.

Vaes et al17 used radiographic cinematography to assess the effect of ankle bracing on inversion velocity during a weight-bearing sprain simulation that induced 50° of inversion displacement. A stirrup-type brace decreased the distance that stable and mechanically unstable ankles were displaced during a 40-millisecond high-velocity phase of the sprain simulation by approximately 15% to 20%. Approximately 40% of the 50°-inversion displacement of the unbraced ankles occurred during this high-velocity phase, which occurred within the 40- and 80-millisecond intervals after inversion displacement began. Conversion of their reported ankle-displacement data from pixels to degrees of motion yields an estimated velocity of approximately 400°·s⁻¹ to 450°·s⁻¹ for the unbraced ankles, which is consistent with the 400°·s⁻¹ injury velocity estimate of Alt et al3 and the maximum inversion velocity value of 460°·s⁻¹ reported by Pederson et al15 for untaped ankles.

Ricard et al18 reported a maximum inversion velocity of 740°·s⁻¹ for untaped ankles and a corresponding average inversion velocity of about 370°·s⁻¹ for a 37° range of displacement. Taping decreased both the maximum and average postexercise inversion velocities by 31% to velocities of 511°·s⁻¹ and 254°·s⁻¹, respectively. Clarke et al98 and DeClerq70 reported almost identical maximum velocity values of 532°·s⁻¹ and 533°·s⁻¹ for subtalar inversion during running. Although the values for inversion velocity derived from trapdoor platforms are relatively similar to those observed for subtalar eversion during running, the velocity of ankle displacement associated with jump landing may exceed 1000°·s⁻¹. Ricard et al99 suggested that most ankle injuries occur between 30 and 50 milliseconds after ground contact. Vaes et al17 demonstrated that 50° of weight-bearing inversion displacement did not produce harm or discomfort, which suggests that some greater amount of displacement is necessary for lateral ankle-ligament injury. Thus, inversion velocity must be greater than 1000°·s⁻¹ to produce ankle displacement beyond 50° in less than 50 milliseconds.

Konradsen et al100 and Alt et al3 reported a 50- to 65-millisecond delay between the initiation of sudden inversion and the onset of peroneal EMG activity and a total time of at least 120 milliseconds required for generation of an effective muscle force to resist the inversion displacement. The findings of Glick et al96 concerning the facilitatory effect of tape on peroneal activation before footstrike and those of Karlsson and Andréasson9 concerning the facilitatory effect of tape on the speed of peroneal response to sudden weight-bearing inversion suggest that the peroneal muscles may generate an effective restraining force against inversion displacement in less than 120 milliseconds when the ankle is taped.

Assuming that the peroneal muscles are completely relaxed at the start of inversion, a velocity of approximately 300°·s⁻¹ or less would allow for generation of a resisting eversion force before the ankle is displaced beyond 40° of inversion. Ricard et al18 reported that the postexercise average inversion velocity for taped ankles was approximately 250°·s⁻¹. They also presented evidence that high-velocity weight-bearing inversion demonstrated smaller amounts of postexercise support loss in taped ankles than very low-velocity open-chain inversion. This suggests that both the deceleration and motion-restriction effects of taping are rate dependent and are relatively more effective at high velocities of ankle displacement.

The contradictory findings of past research on the relative effects of ankle taping and bracing may be explained by variations in tape-application procedures, variations in the properties of tape and other materials used in the application process, methodologic limitations imposed by the risk of injury to subjects, and the exceedingly complex nature of the integrated biomechanical function of the joints of the foot and ankle. Discussion of the effects of an external ankle-support system necessitates a review of the normal biomechanical function of the foot and ankle, and clear distinctions need to be made among various terms used to describe foot and ankle motion.101,102

PATHOMECHANICAL CONSIDERATIONS

Many authors and clinicians use the coupled terms eversion-inversion to define motion confined to the frontal plane, and the coupled terms pronation-supination to define triplanar motion that occurs around the functional axis of the subtalar joint. Others make the distinction between uniplanar and triplanar motion in an opposite manner, and some use the 2 sets of terms interchangeably. Further complicating the matter, pronation-supination is commonly used to describe triplanar displacement associated with normal gait, and inversion-eversion is commonly used to describe triplanar displacement associated with ankle-injury mechanisms. Regardless of whether the research methods employed to study the effects of ankle support have analyzed isolated frontal-plane motion or triplanar motion, researchers have almost exclusively used the term inversion to define either type of inward displacement of the plantar aspect of the foot. Because this discussion relates to the pathomechanics of ankle injury, the terms frontal-plane inversion and subtalar inversion will be used to differentiate the uniplanar component of the injury-producing motion from the more complex triplanar motion that occurs between the leg and the foot.

INVERSION-EVERSION MECHANICS

The talus is the key structure of the ankle, linking the leg and the foot in a manner similar to a universal joint.103 The leg is hinged to the talus in 1 plane at the talocrural joint; the foot is hinged to the talus in a different plane at the subtalar joint. The function of the subtalar joint is highly integrated with that of the talocrural joint proximally, as well as that of the transverse tarsal and lateral tarsometatarsal joints distally. The configuration of the articular surfaces between the talus and the calcaneus is the primary determinant of the pattern of foot displacement that results from subtalar motion. Because the functional axis of the subtalar joint approximates a 45° orientation in relation to the long axis of the foot in the sagittal plane (Figure 1), it has been compared with a mitered hinge that produces opposite and equal amounts of rotation of the proximal and distal hinged segments.104 Under weight-bearing conditions, the coupling mechanism created by the integrated function of the talocrural, subtalar, and transverse tarsal joints acts like a torque converter between the leg and the foot. Rotation of either segment is associated with rotation of the other segment in the opposite direction. The relative amounts of foot displacement and axial leg rotation associated with subtalar motion vary considerably among individuals and are related to the structure, alignment, and ligamentous integrity of the ankle and foot joints.105

Although subtalar inversion causes the talus to rotate exter-
nally with respect to the calcaneus in the transverse plane, the transfer of inversion torque between the talocural joint and the lower leg is associated with external rotation of the lower leg in relation to the talus after the subtalar joint has reached the limit of its range of motion. If the lateral border of the foot inverts, the lateral tarsometatarsal joints, the transverse tarsal joint, and the subtalar joint each lock when the maximum range of inversion is reached, and the entire foot acts as a rigid lever that rotates inwardly around the subtalar axis while the lower leg rotates externally (Figure 2). If the anterior talofibular ligament (ATFL) is disrupted, the composite axis of talocural-subtalar motion is no longer fixed, and the anterolateral portion of the talus is free to rotate out from beneath the tibiofibular mortise. The term anterolateral rotary instability refers to anterior and internal rotary displacement of the lateral border of the talus in relation to the lower leg.

Figure 1. Approximate orientation of functional axis of the subtalar joint in the sagittal plane for most individuals.

Figure 2. Development of tension within the anterior talofibular ligament as the leg externally rotates in relation to the foot, which resists rotary subluxation of the talus.

CLINICAL EVALUATION AND MANAGEMENT OF ANKLE INSTABILITY

To evaluate the integrity of the ATFL, stress radiography has been used to quantify anterior translation of the talus in relation to the calcaneus within the sagittal plane and varus tilt of the talus in relation to the tibia within the frontal plane. The lack of a consistent relationship between radiographic evidence of talocural joint instability and symptoms of chronic ankle dysfunction after an inversion sprain is largely responsible for widespread acceptance of the idea that mechanical instability and functional instability are distinctively different conditions. Many believe that a deficiency in joint proprioception is responsible for symptoms of functional instability in the absence of mechanical instability, but some authors have suggested that traditional methods of clinical evaluation are inadequate for identification of rotary mechanical instability within the transverse plane.

Because severe damage to the lateral ankle ligaments has been associated with increased talar tilt, prevention of frontal-plane displacement of the calcaneus and talus has been a primary goal guiding the design of ankle-support systems. The notion that talar tilt is the primary component of the mechanism responsible for disruption of the lateral ankle ligaments is refuted by research findings derived from axially loaded cadaver specimens. Cass and Settles found that isolated release of the ATFL was not associated with talar tilt when an axial load was applied to an inverted hindfoot. Unlike other cadaver studies of pathologic ankle displacement, axial rotation of the leg was not constrained. These researchers and others have emphasized the role of the ATFL in restraining external rotation of the leg upon the talus. Much of the research that has evaluated the mechanical effects of ankle support has involved assessment of isolated frontal-plane motion of the foot in relation to the leg, and no study has assessed the effect of ankle taping or bracing on leg rotation.

In recent years, magnetic resonance imaging (MRI) has clearly demonstrated that ligamentous damage can be more severe than associated physical signs and symptoms might suggest. Magnetic resonance imaging has also dramatically increased awareness of various types of soft tissue conditions that were previously unrecognized. Frey et al compared ankle-sprain severity diagnoses made by orthopaedic surgeons with MRI results and concluded that clinicians often underestimate the severity of ligamentous damage in the absence of a complete ligament rupture. Several recent reports have emphasized MRI evidence that the ligaments of the subtalar joint are frequently damaged in patients who experience chronic ankle dysfunction after an inversion sprain.
Joint instability in 75% of subjects with a history of lateral ankle sprain and evidence of talocrural instability (6 of 8 subjects). Tochigi et al found MRI evidence of an ATFL lesion in all but 1 of 24 subjects diagnosed as having sustained either a moderate or severe inversion sprain, and more than 50% (13 of 24 subjects) had an interosseous talocalcaneal ligament lesion in the subtalar joint. Other lesions associated with a history of inversion ankle sprain that are extremely difficult to diagnose without MRI affect the calcaneofibular ligament, the cervical ligament, the lateral talocalcaneal ligament, the posterior talofibular ligament, the deltoid ligament, the peroneus longus tendon, the peroneus brevis tendon, the posterior tibialis tendon, the inferior peroneal retinaculum, and the lateral root of the inferior extensor retinaculum. Johnson and Markolf observed that sectioning of the ATFL in cadaver specimens produced a surprisingly low failure level for the remaining ligaments (3 Nm) and emphasized that an unprotected injured ankle is highly susceptible to further injury. Hertel et al noted that little emphasis has been placed on specifically limiting subtalar motion with ankle braces. A taping procedure for stabilization of the subtalar joint, referred to as the subtalar sling, has previously been reported. A similar technique of tape application, referred to as the inversion brake, was presented by Vaes et al.

**Rationale for Subtalar Taping Procedure**

Although numerous combinations of tape-strip orientations and wrapping patterns have been advocated as superior ankle-taping procedures, the basic components of the application procedure described by Gibney in 1895 are included in almost every contemporary ankle-taping procedure. The Gibney basketweave procedure consists of an interwoven application of stirrup strips, which cover the plantar surface of the hindfoot and extend proximally on both the medial and lateral aspects of the leg, and horseshoe strips, which are applied perpendicular to the stirrup strips on the hindfoot. Most athletic trainers use an ankle-taping procedure that incorporates some variation of the Gibney basketweave in combination with the Louisiana heel-lock and figure-8 wrapping patterns.

Although inward displacement of the hindfoot is generally associated with triplanar rotation around the functional axis of the subtalar joint, external forces can impose a nonfunctional rotation around the long axis of the foot when it is in a neutral or dorsiflexed position. The force vector created by tension within the longitudinal fibers of stirrup strips is perpendicular to an anteroposterior axis of isolated frontal-plane inversion when the talocrural joint is in a neutral position (Figure 3). Thus, stirrup strips are well positioned to provide maximum restraint to inward displacement of the hindfoot within the frontal plane (i.e., varus displacement of the calcaneus and lateral tilting of the talus within the talocrural mortise). The application of heel-lock and figure-8 components further encases the hindfoot, which probably provides additional resistance to lateral distraction of the talocrural and subtalar joints within the frontal plane.

Because torque is transferred through the kinetic chain from the forefoot to the leg and vice versa, efforts to stabilize the talocrural joint should not be limited to restricting inward hindfoot motion within the frontal plane. The subtalar sling consists of 1 or more strips of high-strength, semielastic tape that spans all of the joints between the forefoot and leg (i.e., tarsometatarsal, transverse tarsal, subtalar, and talocrural). The subtalar-sling component is applied after the stirrup and horseshoe strips and before the heel-lock configuration to the hindfoot and overlapping circumferential closure strips on the foot and leg. To resist subtalar inversion, the tape strips are anchored on the plantar aspect of the forefoot, wrapped around the lateral border of the foot, and wrapped around the leg above the malleoli. When viewed in the sagittal plane, the midportion subtalar sling has a 45° orientation that is approximately perpendicular to the orientation of the functional axis of the subtalar joint (Figure 4). The semielastic tape strips are applied with sufficient tension to create a lateral “bowstring effect” when anchored to the leg. Excessive tension may cause discomfort to develop along the lateral border of the foot during activity, whereas insufficient tension fails to restrict the end range of subtalar inversion after exercise-induced loosening. Nonelastic tape covers and secures the subtalar-sling attachment to the plantar aspect of the forefoot, and the lateral bowstringing portion is pulled against the surface of the midfoot through the application of a heel-lock tape configuration.

The incorporation of the lateral subtalar sling with other components of a traditional hindfoot-taping procedure increased residual subtalar inversion restriction after 2 to 3 hours of physical activity by 94% compared with the traditional procedure without the additional component. Compared with the unrestricted range of inversion, the taping procedure that incorporated the lateral subtalar sling provided a residual restriction of 16.5° (41% of 40° unrestricted range), whereas the taping procedure without the subtalar sling provided a residual restriction of 8.5° (21% of 40° unrestricted range).

The vector created by tension within the lateral subtalar sling has a vertical component that resists varus displacement of the forefoot in the frontal plane and an anteroposterior component that resists anterior translation of the talus in the sagittal plane (Figure 5). Probably more important is its effect on torque transmission between the forefoot and leg and restraint of rotary subluxation of the talus in the transverse plane (Figure 6). External rotation of the leg increases tension within the
Figure 4. Lateral subtalar sling. A, Orientation of lateral subtalar sling applied over stirrup strips on the hindfoot. B, Optional second lateral subtalar sling wraps around the lateral aspect of the foot at a more distal position.

Figure 5. Vertical and anteroposterior components of the vector created by tension within the lateral subtalar sling.

tape strips forming the lateral subtalar sling, which tends to lift the lateral border of the foot, thereby reversing the normal effect of external leg rotation on the forefoot and protecting the ATFL from tensile loading.

The point at which the lateral subtalar sling wraps around the border of the foot affects the degree of discomfort experienced by some athletes and is a major factor determining the extent to which the sling achieves the desired effect. The more anterior on the foot the sling is applied, the longer the moment arm is between the functional axis of the subtalar joint and the sling fixation point on the lateral border of the foot. A more posterior position may be more comfortable for the athlete but lacks the mechanical advantage of the more anterior position (Figure 7). Although discomfort is sometimes experienced by athletes who are unaccustomed to the pressure exerted by the tape on the lateral border of the forefoot, those who complain...
generally become more tolerant of the procedure after several applications.51

The subtalar sling can also be applied to the medial aspect of the foot to support the medial longitudinal arch and to control subtalar eversion (Figure 8). Although the mechanism is unclear, MRI evidence of damage to the deltoid ligament and the posterior tibialis tendon has been associated with a history of an inversion ankle sprain and concomitant damage to the lateral structures.120,122 Several investigators have reported a relationship between lateral ankle-ligament injury and a deficiency in the isokinetic performance of the ankle inverters.125-128 This phenomenon is believed to be caused by neural inhibition of the muscles that produce the motion associated with the injury mechanism, and the degree of inhibition after an acute lateral sprain appears to be related to the amount of traumatic edema associated with the injury.130 Stabilization of the talonavicular joint by the posterior tibialis muscle is essential for transfer of the force generated by the gastrocnemius-soleus muscles at their insertion on the calcaneus to the forefoot at push-off. Use of the medial subtalar sling may compensate for deficient posterior tibialis function, thereby facilitating the hindfoot-to-forefoot force transfer that occurs between the midstance and push-off phases of the gait cycle.

Another potentially important clinical application for the medial subtalar sling is the prevention of anterior-inferior tibiofibular syndesmosis sprain. The mechanism of injury associated with the syndesmotic ankle sprain involves external rotation of the foot and internal rotation of the lower leg.131-134 Restriction of subtalar eversion, which is associated with foot and leg rotation in opposite directions, can reduce the amount of stress imposed on the syndesmosis by functional activities. Because susceptibility to an inversion sprain is always a concern, a taping procedure that incorporates the medial subtalar sling should always include application of the lateral subtalar sling.

CONCLUSIONS

Although the relative effectiveness of taping versus bracing for restraint of excessive inversion has not been clearly established, both types of ankle support clearly provide beneficial protective effects. During the acute phase of ankle-sprain management, bracing offers advantages related to ease of repetitive removal and reapplication, adjustability of strap or lace tension, and structural features that may facilitate edema resolution. Research findings suggest that taping may provide superior benefits with regard to deceleration of inversion velocity and facilitation of dynamic neuromuscular protective mechanisms. Furthermore, taping offers a means to address the complex interrelated biomechanical factors that are responsible for subtalar joint injury and rotary instability of the talocrural joint. Future research on the effectiveness of various braces and taping procedures should use methods that assess rotary displacements of both the foot and lower leg within the transverse plane.
REFERENCES


99. Ricard MD, Saret JJ, Schulthies SS. Comparison of the amount and rate


Efficacy of Prophylactic Ankle Support: An Experimental Perspective

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Objective: To provide a comprehensive review of the literature regarding the role of external ankle support on joint kinematics, joint kinetics, sensorimotor function, and functional performance.

Data Sources: We searched MEDLINE and SPORT Discus databases from 1960–2001 for the key words ankle bracing, ankle support, ankle taping, and ankle prophylaxes. We also used personal libraries based on our own research to complement the existing literature.

Data Synthesis: The effects of external ankle support have been studied on a plethora of dependent measures. Here, we specifically discuss the role of external ankle support on joint kinematics, joint kinetics, sensorimotor function, and functional performance and present a general consensus regarding the overall effects of these prophylactic devices.

Conclusions/Recommendations: The effects of ankle support on joint kinematics during static joint assessment and on traditional functional-performance measures (ie, agility, sprint speed, vertical jump height) are well understood. However, the potential effects of ankle support on joint kinetics, joint kinematics during dynamic activity (eg, a cutting maneuver), and various sensorimotor measures are not well known. Future research investigating the role of external ankle bracing needs to focus on these areas.

Key Words: ankle bracing, joint mechanics, sensorimotor function, functional performance

Individuals who participate in athletic activities are particularly susceptible to ankle injuries1–5; of these injuries, approximately 86% are sprains.2 Acute ankle sprains occur during dynamic movement, particularly when rapidly changing directions. The lateral ligaments of the ankle-foot complex, which provide static support, are frequently torn, and the stability provided by the peroneal muscles is insufficient to limit forced inversion.4 It has been suggested that the peroneal muscle group plays a large role in dynamically stabilizing the lateral ankle-foot complex against an injurious inversion moment6–8; however, the extent to which this dynamic defense mechanism can protect the ankle-foot complex from injury is still unclear.

Because of the frequency of ankle injuries, a considerable amount of epidemiologic research has been conducted to examine the causes and effects of various methods used to prevent such injuries.9–12 The high incidence of trauma to the lower extremity, most notably the ankle-foot complex, has contributed to the proliferation of external ankle-stabilizing devices.13,14 Ankle taping, lace-up style braces, and semirigid orthoses are used in an effort to prevent ankle injuries and to stabilize patients who suffer from chronic ankle instability (CAI). Ankle bracing and taping reduce ankle injury9–12 and injury frequency rates,2,3,9–12,15,16 principally due to the mechanical support offered by these devices, although increased sensorimotor function offered by external ankle support may be a contributing factor.17,18

Many comparative studies have evaluated the efficacy of these different types of external ankle support on ankle-foot range of motion (ROM),19–41 functional performance,32,42–48 and various sensorimotor values1,8,17,18,49–64 in subjects with healthy and chronically unstable ankles. Thus, our purpose is to discuss and critically analyze the literature regarding the effects of external ankle support on joint kinematics, joint kinetics, sensorimotor function, and functional performance.

ANKLE PROPHYLAXES AND JOINT KINEMATICS

Most studies classifying the effects of external ankle support on joint kinematics have involved passive ROM evaluation using an isokinetic dynamometer19,22,26–28 or a goniometric device20,24,25,32–34,36,65–67 after some type of exercise. Little consideration has been given to using video32 or film analyses68 to assess the joint restriction provided by an ankle support after exercise consisting of a dynamic movement.

Gross et al.26–28 compared the effects of adhesive tape and selected prophylactic ankle appliances on passive inversion and eversion before and after exercise. The tape condition, a softshell stabilizer, and a semirigid orthosis reduced inversion and eversion before exercise.26–28 After a 10-minute exercise session, tape still offered significant support compared with pre-exercise measures; however, the semirigid orthosis provided greater restriction.26 With a semirigid brace, eversion increased after exercise, although differences between a lace-up style brace and a semirigid stabilizer have not been found.26,27 With respect to inversion ROM, tape and semirigid orthoses28 have demonstrated greater restriction than a softshell or lace-up style brace,27 yet this result has not been supported by other
work. Additionally, the DonJoy Ankle Ligament Protector (dj Orthopedics Inc, Vista, CA) provided greater inversion restraint, comfort, and perceived stability than the Aircast Sport Stirrup (Aircast Inc, Summit, NJ). It is interesting to note that inversion ROM increased after exercise during tape, lace-up, and semirigid conditions, while inversion ROM remained restricted. A plausible explanation may be that the braces are designed with more emphasis on restricting inversion, because that is the common mechanism of injury in ankle sprains; however, it does not appear to be supported or refuted by brace manufacturers.

A few authors have evaluated the effects of adhesive tape and selected ankle appliances on passive ROM after prolonged exercise sessions lasting more than 10 minutes. In as little as 10 minutes of exercise during a squash match, 2 ankle-support conditions (tape and lace-up style appliance) ineffectively supported the ankle. Additionally, after 1 hour of exercise, the adhesive tape lost its restrictive properties, resulting in greater plantar flexion and inversion and combined motions of plantar flexion with inversion and eversion. Similarly, after 20 minutes of exercise, inversion and eversion ROM increased by a lace-up style brace, while the Aircast Sport Stirrup maintained inversion support after 90 minutes of exercise. During the entire 90-minute practice session, the DonJoy Ankle Ligament Protector demonstrated no decrement in support. The authors concluded that the DonJoy Ankle Ligament Protector might be more beneficial than the Aircast Sport Stirrup for people who suffer from CAI. Adhesive tape substantially decreased its restrictive properties after 20 minutes of volleyball practice, while the braced ankles demonstrated diminished eversion restriction after 3 hours of practice, but in the latter group, inversion ROM restriction was maintained. Many of these researchers have concluded that either a lace-up brace or semirigid orthosis may be more effective than athletic tape in restricting subtalar joint ROM after exercise bouts lasting longer than 10 minutes.

Although agreement exists concerning the effectiveness of different ankle prophylactic devices on passive subtalar-joint motion, little research has examined the role of external ankle devices in controlling such motion while running. In comparison with the abundance of published works regarding the role of external ankle supports on passive ankle-foot ROM after exercise, little information is available on the effects of different ankle prophylaxes on subtalar joint motion during dynamic activities such as walking, running, and lateral-cutting maneuvers. It may be evident that these various braces may behave differently when dynamically evaluated. Investigators in 2 ankle-support studies quantitatively measured rearfoot motion during running using motion-analysis technology. In an earlier study, the effectiveness of different types of ankle-tape support on pronation restriction while walking was measured. All ankle-strapping techniques were equally effective in maintaining consistent restriction for 10 minutes of continuous walking on a treadmill. Furthermore, all strapping techniques caused the foot to be excessively supinated before heel strike compared with the barefoot condition. More recently, inversion restraint provided by different ankle support devices was compared before and after walking and running. On subjects walking at 6.44 km/h (4 mph), the Aircast Sport Stirrup permitted the least amount of inversion (7.6° before exercise, 10.7° after exercise) compared with the Swede-O Universal lace-up (10° before exercise, 11.5° after exercise) brace (Swede-O Inc, North Branch, MN) and adhesive tape (10.7° before exercise, 14.8° after exercise). With subjects running at 14.48 km/h (9 m/h), the Aircast Sport Stirrup brace and Swede-O-Universal lace-up brace demonstrated no difference in average maximum inversion before and after exercise. They concluded that athletic tape is ineffective in restricting inversion under a dynamic load, while the Sport Stirrup and lace-up brace were similar in limiting inversion during walking and running.

In an attempt to statistically synthesize the related literature in this area, we used a meta-analysis approach to evaluate ankle-support effects on ankle and foot ROM before and after exercise. We evaluated 253 effects from 19 studies (that met all of the inclusion criteria) published between 1966 and 1997. Standardized effect sizes were calculated to establish the overall restrictive effect of each treatment condition (tape, lace-up braces, and semirigid braces) compared with the control condition within each study. The average ROM restriction in degrees compared with the control condition was calculated from the standardized effect sizes (Table 1). Because we applied a quantitative statistical analysis to published research in this area, the following conclusions can be considered a consensus regarding the effects of external ankle support on ankle-foot ROM:

- Before exercise, semirigid braces restricted inversion ROM 21.3% more than tape and 26.2% more than lace-up braces.
- After exercise, semirigid braces restricted inversion ROM 72.1% more than tape and 59.5% more than lace-up braces.
- No significant difference existed in inversion ROM restriction between the tape and lace-up brace conditions before (15.9° and 14.9°, respectively) or after exercise (7.3° and 10.6°, respectively).
- Semirigid braces provided greater overall inversion ROM restraint compared with the tape and lace-up brace conditions before (19.8° semirigid, 9.5° tape, 14.4° lace-up) and after exercise (24.9° semirigid, 7.1° tape, 8.9° lace-up).
- Lace-up braces provided greater overall inversion ROM restriction (9.8°) than tape (7.2°).
- Dorsiflexion ROM was restricted 38.3% more with taping than with a lace-up brace.
- No significant difference existed between tape (9.1°) and lace-up style braces (9.7°) on overall plantar flexion ROM restriction.

Historically, the assessment of talocrural-talocalcaneal joint displacement has been the primary research focus in understanding the mechanical effects of external ankle support. Surprisingly, little emphasis has been placed on studying the effects of ankle support on other kinematic variables such as angular velocity and angular acceleration. Quantifying talocrural and talocalcaneal angular velocity can provide the scientific community with detailed information regarding the mechanical-restriction properties of external ankle support in addition to angular displacement. The amount of subtalar-joint angular displacement an ankle brace may offer only provides information regarding the change in position of the subtalar joint with respect to time. Angular joint displacement does not measure the rate at which the change in angular position occurs. Often, joint injuries occur due to the rate at which the joint is displaced and not the amount of displacement itself. Each support device (tape, semirigid, or lace-up brace) contains some degree of elasticity. Accordingly, each type of ankle support exhibits viscoelastic properties, and the level of strain (percentage deformation) that each support can undergo depends
on the rate at which the stress is applied. Thus, it is quite possible that 2 different ankle braces offer the same amount of joint-motion restriction but exhibit entirely different strain rates. Quantifying the amount of angular velocity at the ankle-foot complex can provide additional information regarding the mechanical efficacy of external ankle support.

Recently, investigators have quantified rearfoot angular velocity under various ankle-support conditions during a sudden inversion movement using an electrogoniometer and high-speed videography. In both studies, an inversion trapdoor was used to simulate the mechanism of injury of a traditional lateral ankle sprain. Rearfoot inversion average velocity decreased significantly with adhesive tape (40%) and a lace-up brace (38%) compared with a control condition. Additionally, the semirigid brace substantially decreased inversion average velocity (51%) compared with the lace-up style brace. These findings provide critical insight regarding the ability of external ankle support to reduce the rate of rearfoot movement during sudden inversion. Although a direct assessment of joint moments was not performed, these studies offer preliminary data suggesting that external ankle support may reduce the forces that cause subtalar joint motion during a simulated lateral ankle injury. More research is necessary to understand how external ankle support may modify talocrural and talocalcaneal angular velocity and acceleration during dynamic activity.

**ANKLE PROPHYLAXES AND JOINT KINETICS**

Greater evidence exists supporting the application of external ankle support in limiting ankle and foot passive ROM during static or quasistatic conditions. However, whether external ankle support reduces the forces that cause joint motion has been questioned. Because external ankle support reduces joint angular displacement and angular velocity, we may surmise that external ankle support attenuates the external forces that cause angular motion. The moments created at the talocrural and talocalcaneal joints under various ankle-brace conditions when the lower extremity is positioned in the closed kinetic chain have not been directly assessed. Yet isolated joint torque production and ground-reaction force components have been assessed during ankle-support applications (Table 2).

The question of whether external ankle support affects isolated ankle-foot torque production is not new. In one of the earliest studies assessing the influence of ankle taping, traditional application of adhesive tape had no adverse effects on isokinetic plantar-flexion, dorsiflexion, inversion, or eversion torque production. Although no treatment effect was reported, only 7 subjects participated in the study. Based on the data presented, it appears that a type I statistical error influenced the results. In a similar study investigating talocrural joint torque and total work, the Swede-O-Universal brace diminished plantar-flexion and dorsiflexion force production compared with the Aircast Sport Stirrup and Active Ankle Support but not tape at 30° s⁻¹. Also, dorsiflexion peak torque was not affected by the application of an ankle appliance. Further, the no-support condition and the Active Ankle brace were associated with significantly higher plantar-flexion work values than the Swede-O-Universal brace and adhesive tape.

The role of external ankle supports on the ground-reaction forces produced during a dynamic task has not been greatly explored. Developing insight into the pattern, magnitude, and temporal characteristics of the ground-reaction forces that occur in various ankle-support conditions could help to explain some of the kinematic changes affecting the ankle-foot complex. Evaluating the kinetics of movement allows for accurate assessment of the support mechanics used. In the few existing studies, some researchers evaluated the effects of the Aircast Sport Stirrup on ground-reaction forces during running, while another group evaluated these potential effects during a dynamic inversion shuffling movement.

Hamill et al evaluated the 3-dimensional components of ground-reaction force data using 2 common ankle-stabilizing appliances while subjects ran at a controlled speed of 5 m s⁻¹.

### Table 1. Standardized Effect Sizes and Average Range-of-Motion Restriction Using Tape, Lace-Up, and Semirigid Ankle Supports during Pre- and Postexercise Movements

<table>
<thead>
<tr>
<th>Ankle Support</th>
<th>Effect Size (0 ± SE)</th>
<th>Average ROM (degrees)</th>
<th>No. of cases (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preexercise</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape</td>
<td>-2.33 ± 0.38</td>
<td>15.9</td>
<td>13</td>
</tr>
<tr>
<td>Lace-up</td>
<td>-2.18 ± 0.86</td>
<td>14.9</td>
<td>7</td>
</tr>
<tr>
<td>Semirigid</td>
<td>-2.97 ± 0.63</td>
<td>20.2</td>
<td>15</td>
</tr>
<tr>
<td>Eversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape</td>
<td>-1.14 ± 0.24</td>
<td>9.5</td>
<td>8</td>
</tr>
<tr>
<td>Lace-up</td>
<td>-1.73 ± 0.96</td>
<td>14.4</td>
<td>6</td>
</tr>
<tr>
<td>Semirigid</td>
<td>-2.38 ± 0.79</td>
<td>19.8</td>
<td>9</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape</td>
<td>-0.98 ± 0.29</td>
<td>6.6</td>
<td>7</td>
</tr>
<tr>
<td>Lace-up</td>
<td>-0.47 ± 0.29</td>
<td>3.2</td>
<td>6</td>
</tr>
<tr>
<td>Semirigid</td>
<td>-0.13 ± 0.13</td>
<td>0.9</td>
<td>7</td>
</tr>
<tr>
<td>Plantar flexion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape</td>
<td>-1.71 ± 0.33</td>
<td>10.5</td>
<td>10</td>
</tr>
<tr>
<td>Lace-up</td>
<td>-1.51 ± 0.42</td>
<td>9.3</td>
<td>6</td>
</tr>
<tr>
<td>Semirigid</td>
<td>-0.53 ± 0.20</td>
<td>3.3</td>
<td>6</td>
</tr>
<tr>
<td><strong>Postexercise</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape</td>
<td>-1.07 ± 0.20</td>
<td>7.3</td>
<td>22</td>
</tr>
<tr>
<td>Lace-up</td>
<td>-1.56 ± 0.29</td>
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<td>15</td>
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<tr>
<td>Semirigid</td>
<td>-3.85 ± 0.64</td>
<td>26.2</td>
<td>20</td>
</tr>
<tr>
<td>Eversion</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Tape</td>
<td>-0.85 ± 0.32</td>
<td>7.1</td>
<td>16</td>
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<td>Lace-up</td>
<td>-1.07 ± 0.21</td>
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<td>14</td>
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<td>Semirigid</td>
<td>-3.00 ± 0.60</td>
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<td>Dorsiflexion</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tape</td>
<td>-0.89 ± 0.18</td>
<td>6.0</td>
<td>10</td>
</tr>
<tr>
<td>Lace-up</td>
<td>-0.55 ± 0.16</td>
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<td>10</td>
</tr>
<tr>
<td>Semirigid</td>
<td>NA†</td>
<td>NA†</td>
<td>NA†</td>
</tr>
<tr>
<td>Plantar flexion</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tape</td>
<td>-1.24 ± 0.16</td>
<td>7.6</td>
<td>14</td>
</tr>
<tr>
<td>Lace-up</td>
<td>-1.65 ± 0.20</td>
<td>10.1</td>
<td>10</td>
</tr>
<tr>
<td>Semirigid</td>
<td>NA†</td>
<td>NA†</td>
<td>NA†</td>
</tr>
</tbody>
</table>

*SE indicates standard error; ROM, range of motion, NA; that no data were reported for the semirigid brace after exercise, and thus, effect sizes could not be calculated for dorsiflexion and plantar flexion. Negative effect sizes indicate greater restriction in range of motion for each brace compared with the control condition. (Reproduced and modified with permission from Cordova ML, Ingersoll CD, Le Blanc MJ. Influence of ankle support on joint range of motion before and after exercise: a meta-analysis. Journal of Orthopaedic & Sports Physical Therapy. 2000;30:170-182.)
Table 2. Examination of External Ankle Support on Joint Kinetics

<table>
<thead>
<tr>
<th>Study</th>
<th>Ankle Support</th>
<th>Joint Kinetic Measure(s)/Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdenour et al71</td>
<td>Adhesive tape</td>
<td>Plantar flexion torque/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dorsiflexion torque/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inversion torque/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eversion torque/None</td>
</tr>
<tr>
<td>Cordova et al8</td>
<td>Aircast Sport Stirrup</td>
<td>Lateral peak impact force/None</td>
</tr>
<tr>
<td></td>
<td>Active Ankle T2</td>
<td>Lateral maximum loading force/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral propulsion force/None</td>
</tr>
<tr>
<td>Gehlsen et al22</td>
<td>Adhesive tape</td>
<td>Lateral peak impact force/None</td>
</tr>
<tr>
<td></td>
<td>Aircast Air Stirrup</td>
<td>Lateral maximum loading force/None</td>
</tr>
<tr>
<td></td>
<td>Active Ankle</td>
<td>Lateral propulsion force/None</td>
</tr>
<tr>
<td></td>
<td>Swede-O Universal</td>
<td>Plantar flexion torque/Decreased at 30°-s⁻¹ and 120°-s⁻¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dorsiflexion torque/None</td>
</tr>
<tr>
<td>Hamill et al72</td>
<td>Aircast Air Stirrup</td>
<td>Vertical force/None</td>
</tr>
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<td></td>
<td>Adhesive tape</td>
<td>Anteroposterior force/None</td>
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<tr>
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<td>Mediolateral force/None</td>
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<td>Peak lateral force/Increased</td>
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</tbody>
</table>

The time to peak vertical impact force and the time to minimum vertical force were larger for the preexercise tape condition than the ankle-stabilizer conditions. In the anteroposterior (AP) force, the relative time to zero force was larger between the tape and ankle-stabilizer conditions. No difference was reported between ankle-support conditions for the mediolateral (ML) component. Although the external ankle support did not affect the magnitude of the ground-reaction forces, the time in which the forces were produced was slower. This suggests that the external support may attenuate forces at the ankle-foot complex by extending the amount of time in which they act. In a similar study73 of subjects with functionally unstable ankles while running, an Aircast Sport Stirrup brace increased peak medial force compared with the control condition. Additionally, the lateral forces generated in the brace condition decreased compared with those produced during the unbraced treatment. Moreover, the stability offered in the braced ankle reduced the ML velocity at foot contact compared with the control condition. These data suggest that the stiffness offered by the brace does, in fact, allow the forces generated at the ankle-foot complex to be attenuated and, perhaps, controlled.

More recently, the effects of the Active Ankle and Aircast Sport Stirrup semirigid brace on lateral ground-reaction forces were assessed while subjects performed a controlled shuffling movement. This movement was designed to produce a dynamic inversion loading on the ankle-foot complex in the lateral direction.8 Ankle bracing did not alter peak impact force, maximum loading force, or peak propulsion force in the lateral direction compared with the control condition. Thus, ankle bracing may not act as a force bypass when the talocrural and subtalar joints are dynamically loaded in the lateral direction. A significant limitation exists when trying to compare the data presented in the 3 studies previously discussed.8,72,73 Earlier studies72,73 assessing the influence of ankle support on ground-reaction forces were performed on subjects running on a treadmill. External ankle supports are designed to be stressed in the frontal plane; running does not produce frontal-plane motion at the rearfoot and midfoot articulations, and so the devices are not stressed in the intended manner. Thus, the differences found in the Stuessi et al73 study may have been due to individual variability in gait among the 11 subjects. Cordova et al8 imposed a demand on the ankle-foot complex similar to what the external support is intended to control against. Although differences in lateral ground-reaction forces were not found, more work using similar methods is needed to further validate these effects.

It may be argued that assessing ground-reaction force data may not be the most direct method for estimating the forces exerted on the ankle-foot complex. Additional inquiry is required to estimate talocrural and talocalcaneal joint moments, either through inverse dynamics or forward solution modeling, under dynamic loads among various support conditions. Until this direct assessment is performed, researchers can only speculate as to the role external ankle support may have in reducing the forces imposed on the ankle-foot complex under dynamic loads.

ANKLE PROPHYLAXES AND SENSORIMOTOR FUNCTION

The effect of external ankle support on joint kinematics has been widely studied. Evidence is substantial that ankle support, offered through tape or a ready-made stabilizer, provides mechanical stability to the ankle-foot complex.39 To a much lesser degree, the potential effects of external ankle support...
Table 3. Examination of External Ankle Support on Sensorimotor Function

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects*</th>
<th>Ankle Support</th>
<th>Sensorimotor Measure(s)/Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt et al&lt;sup&gt;59&lt;/sup&gt;</td>
<td>U</td>
<td>Adhesive tape</td>
<td>Peroneus longus muscle reflex latency/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peroneus longus muscle reflex integrated electromyography/Decreased</td>
</tr>
<tr>
<td>Bennell et al&lt;sup&gt;53&lt;/sup&gt;</td>
<td>U</td>
<td>Adhesive tape</td>
<td>Mediolateral force deviation/Increased</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mediolateral force deviation/Increased</td>
</tr>
<tr>
<td>Brooks et al&lt;sup&gt;64&lt;/sup&gt;</td>
<td>U</td>
<td>Active Ankle T2</td>
<td>Peroneus longus muscle Hoffmann reflex/None</td>
</tr>
<tr>
<td>Cordova et al&lt;sup&gt;60&lt;/sup&gt;</td>
<td>U</td>
<td>McDavid A 101†</td>
<td>Peroneus longus muscle reflex latency/None for either brace</td>
</tr>
<tr>
<td>Cordova and Ingersoll&lt;sup&gt;81&lt;/sup&gt;</td>
<td>U</td>
<td>McDavid A 101</td>
<td>Peroneus longus muscle reflex amplitude/Immediately increased</td>
</tr>
<tr>
<td>Feuerbach et al&lt;sup&gt;52&lt;/sup&gt;</td>
<td>U</td>
<td>Aircast Air Stirrup</td>
<td>Anteroposterior postural sway/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mediolateral postural sway/Decreased</td>
</tr>
<tr>
<td>Feuerbach et al&lt;sup&gt;116&lt;/sup&gt;</td>
<td>U</td>
<td>Aircast Air Stirrup</td>
<td>Talocrural joint repositioning/Enhanced</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Talocalcaneal joint repositioning/Enhanced</td>
</tr>
<tr>
<td>Heit et al&lt;sup&gt;56&lt;/sup&gt;</td>
<td>U</td>
<td>Adhesive tape</td>
<td>Planar-flexion joint positioning/Enhanced</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inversion joint positioning/Enhanced</td>
</tr>
<tr>
<td>Jerosch et al&lt;sup&gt;55&lt;/sup&gt;</td>
<td>B</td>
<td>Adhesive tape</td>
<td>Planar-flexion joint reposition/Enhanced for all 3 supports</td>
</tr>
<tr>
<td>Karlsson and Andréasson&lt;sup&gt;51&lt;/sup&gt;</td>
<td>I</td>
<td>Adhesive tape</td>
<td>Peroneus longus muscle reflex latency/Enhanced</td>
</tr>
<tr>
<td>Kinzey et al&lt;sup&gt;57&lt;/sup&gt;</td>
<td>U</td>
<td>Active Ankle</td>
<td>Anteroposterior, mediolateral, and total center of pressure/None for any of the 3 braces</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircast Sport Stirrup</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>McDavid A 101</td>
<td></td>
</tr>
<tr>
<td>Lohrer et al&lt;sup&gt;51&lt;/sup&gt;</td>
<td>U</td>
<td>Adhesive tape</td>
<td>Proprioceptive amplification ratio/Increased</td>
</tr>
<tr>
<td>Nishikawa and Grabiner&lt;sup&gt;47&lt;/sup&gt;</td>
<td>U</td>
<td>Aircast Air Stirrup</td>
<td>Peroneus longus muscle Hoffmann reflex/Increased</td>
</tr>
<tr>
<td>Palmieri et al&lt;sup&gt;63&lt;/sup&gt;</td>
<td>U</td>
<td>McDavid A 101</td>
<td>Anteroposterior frequency spectrum/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mediolateral frequency spectrum/None</td>
</tr>
<tr>
<td>Sprigings et al&lt;sup&gt;49&lt;/sup&gt;</td>
<td>U</td>
<td>Adhesive tape</td>
<td>Peroneus longus reflex spectrum/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropp et al&lt;sup&gt;60&lt;/sup&gt;</td>
<td>B</td>
<td>Adhesive tape</td>
<td>Anteroposterior postural control/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mediolateral postural control/None</td>
</tr>
</tbody>
</table>

* I indicates subjects with injured ankles; U, subjects with uninjured ankles; B, subjects with both injured and uninjured ankles.
† McDavid Sports Medical Products, Woodridge, IL.

on a few sensorimotor variables have been studied. Various sensorimotor values have been measured under the influence of external ankle support (Table 3). Such measures include peroneus longus (PL) muscle reaction time or latency, PL reflex amplitude, PL Hoffmann reflex, joint position sense or joint replication, and various measures of postural control. The sensorimotor variables in question have been measured during static and dynamic conditions.

**Ankle Support and Peroneus Longus Muscle Response**

Peroneus longus neuromuscular function is critical in dynamically supporting the ankle-foot complex against an inversion mechanism of injury. As a result, PL reaction time, or latency, during a simulated ankle sprain has been predominantly studied in normal and chronically unstable ankles, while the effect of ankle support on PL function has not been studied as extensively. The duration of the PL latency quantified in these studies involves activation of the group Ia afferent fibers of the muscle spindle located in the muscle belly, which results in an efferent motor response and contraction of the same muscle. Although a large amount of research has been done examining peroneal muscle-reflex temporal characteristics during sudden inversion, this work has used a quasistatic model for assessment. The time and amplitude in which the peroneal muscles fire under this condition may not reflect what occurs during an injury. Ideally, peroneal muscle function would be assessed during a true dynamic state; however, due to the difficulty in controlling many extraneous variables under a true dynamic model, the use of inversion trapdoors and platforms to simulate an ankle injury has been widely accepted.

In an earlier study of external ankle support and leg muscle function, Glick et al proposed that another benefit of taping the ankle, beyond its apparent mechanical restriction, is the
stimulating effect on the peroneus brevis muscle. Individuals who suffered from excessive inversion talar tilt and whose ankles were taped initiated peroneus brevis contraction before heel strike during running gait. This theory suggests a potential proprioceptive benefit of applying adhesive tape or an ankle brace and that the prophylactic benefits of applying such devices may be more than just mechanical. When considering the effects of external ankle support on PL reflex latency, evidence exists regarding adhesive tape’s efficacy. Peroneus longus reaction time was measured during sudden inversion in subjects with CAI whose ankles were taped. Chronically unstable ankles supported with tape demonstrated faster reaction times of the PL and peroneus brevis during rapid inversion compared with the unsupported condition.

Some researchers have shown no alteration in PL latency after the application of either adhesive tape or a ready-made ankle brace. In subjects with healthy ankles, no change in PL reflex latency with ankle taping was found before or after exercise. Their results were also supported by similar work in which the PL response in healthy, uninjured ankles supported by athletic tape was not altered after sudden inversion. Admittedly, Cordova et al reported that PL reaction time remained unaffected by a sudden inversion perturbation immediately after the application of a lace-up or semirigid ankle brace. Although none of these investigators found a significant reduction in PL latency, their findings can be viewed as a positive result regarding the application of external ankle support. The application of external ankle support (tape, lace-up brace, or semirigid brace) does not affect the latency of the reflex circuitry of the muscle spindles within the PL during sudden inversion.

Specifically, clinicians have surmised anecdotally that long-term application of an ankle brace weakens the ankle’s supporting structures and causes remodeling that induces these structures to become dependent on this support. With the extended use of an ankle brace, the leg musculature’s ability to respond to an external stimulus or perturbation may be delayed, thereby diminishing neuromuscular function and potentially placing the ankle-foot complex at risk for injury. Researchers have investigated the potential long-term effects of external ankle support on PL muscle function. Peroneus longus muscle latency during sudden inversion was assessed in subjects before and after having a lace-up and semirigid style brace applied 8 h-d-1 for 5 d-wk-1 over an 8-week period. No changes were observed in latency across subjects who were assigned to the lace-up or semirigid brace conditions compared with the control condition; thus, athletes with healthy ankles who wish to wear external ankle support for prophylactic considerations throughout the course of a season do not appear at risk for compromising the PL response to sudden inversion.

Understanding the time delay of the PL in the supported ankle as it responds to a sudden perturbation is certainly important; however, others have begun to evaluate neuromuscular characteristics such as electromyographic reflex amplitude. Although not much research has been done in this specific area, the data that do exist are promising in demonstrating the proprioceptive value of external ankle support. Lohrer et al explored the effects of adhesive tape on the proprioceptive amplification ratio (PAR) in healthy subjects. This variable is the ratio of integrated electromyographic activity of the peroneal muscles over the maximum inversion angle produced during sudden inversion. This value is then normalized to the ratio obtained during the control condition. After the application of tape, the PAR increased significantly. Increases in the PAR were found to occur as a result of increases in integrated electromyographic activity along with decreases in the maximum inversion angle. The immediate and chronic effects of ankle bracing on PL reflex amplitude during sudden inversion have been studied. Normalized PL amplitude was significantly enhanced after a lace-up style brace was applied. Additionally, after 8 weeks of chronic brace use, normalized PL amplitude also increased. The results of this work are in agreement with a group that considered the effects of a semirigid brace on the PL Hoffmann reflex in a non-weight-bearing, recumbent seated position. Peroneus longus motoneuron pool excitability increased 10% after the application of a semirigid brace. They electrically stimulated the PL muscle group and afferent nerve fibers percutaneously and not through deformation of the muscle spindles using a trapdoor testing apparatus (simulated ankle sprain). This result may be viewed positively, as it suggests that these types of braces have an excitatory effect on the PL muscle. These data may support the hypothesis that ankle bracing positively enhances PL function through heightened afferent input from cutaneous mechanoreceptors.

Others have found decreases or no change in PL muscle amplitude after the application of external ankle support. In an attempt to evaluate joint stabilization provided by adhesive taping during a simulated inversion trauma, Alt et al found that PL-integrated electromyographic activity reduced significantly by 18% after adhesive tape was applied. They attributed this decrease in PL muscle activity to the decrease in inversion velocity found with the application of adhesive tape. Brooks et al assessed the PL Hoffmann reflex once a week over a 5-week period during semirigid ankle brace and control conditions in uninjured subjects. Use of an ankle brace over a 5-week period did not facilitate or inhibit PL muscle function. The proprioceptive effect of tape and ankle bracing on the underlying muscle groups may be an additional factor in preventing injury in individuals who suffer from CAI. This is critical, as the control and reflexive response of the peroneal muscles appears to have a substantial effect in preventing injury to the ankle-foot complex.

Ankle Support and Joint Proprioception

The importance of coordination and proprioceptive training in reducing the frequency of recurrent ankle sprains has been documented. Evidence indicating that mechanical stability is the main function of external ankle support is substantial. Others contend that not only does external ankle support provide mechanical stability, but it may also facilitate proprioceptive input of the ankle musculature. Although the role of external ankle support in providing mechanical joint stability is known, its effect on joint kinesthesia is less well understood. The ability to improve proprioception occurs not only through the use of exercise and rehabilitation but also through stimulation of cutaneous mechanoreceptors near and around the ankle by the application of various types of ankle support.
talofibular and calcaneofibular ligaments. No significant differences were noted in the constant, variable, or absolute errors between the anesthetized and nonanesthetized conditions; however, both the constant and variable errors in matching reference points were significantly less with the brace than without the brace. Thus, mechanoreceptors within the ligaments tested contributed very little to ankle-joint proprioception as measured by joint replication. Affereut feedback from the cutaneous receptors in the foot and shank appears to be enhanced after application of an ankle brace. More recently, the cutaneous receptors in the foot and shank appears to be between the anesthetized and nonanesthetized conditions; each ankle-support condition also demonstrated less angle-reproduction error than the semirigid brace or tape condition. Each ankle-support condition also demonstrated less angle error than the control condition. In a similar investigation, the effects of a lace-up style brace and adhesive tape on the ability to replicate inversion and plantar-flexion joint position in normal subjects were studied. The authors investigated the effects of adhesive tape, a lace-up brace, and a semirigid brace on replicating ankle-joint position. The lace-up brace was associated with less angle-reproduction error than the semirigid brace or tape condition. Each ankle-support condition also demonstrated less angle error than the control condition. In a similar investigation, the effects of a lace-up style brace and adhesive tape on the ability to replicate inversion and plantar-flexion joint position in normal subjects were studied. Plantar-flexion and inversion joint replication was enhanced in the brace and tape conditions, but the 2 conditions did not differ from each other. Although the scientific evidence in this area is somewhat promising, more research is needed to clearly substantiate the positive effects of external ankle support on joint proprioception.

Ankle Support and Postural Control

Individuals with decreased postural control are believed to be more susceptible to ankle injury than those with better postural control. Rehabilitation programs employing coordination and balance training are effective in reducing recurrent ankle sprains. Ankle-joint function directly correlates with an individual's ability to maintain an upright stance. The potential effects of ankle bracing on postural control have been evaluated using stabilometry, in which many indices of postural control were assessed. Some of the more common postural-control dependent variables measured include center-of-pressure (COP) displacement in the AP and ML directions, total COP excursion, and frequency analysis of COP data. These measures are more sensitive than traditional evaluation of COP displacement and are more revealing with regard to our understanding of how the somatosensory system may be affected by the application of external ankle support.

ANKLE PROPHYLAXES AND FUNCTIONAL PERFORMANCE

Of all the empirical data surrounding the use of external ankle support, the impact of these devices on functional performance is probably most important. Although these devices are beneficial in preventing ankle injury, athletes will avoid wearing ankle supports if they perceive that athletic performance will be hindered. The main purpose of ankle prophylactic devices is to restrict frontal-plane motion occurring at the subtalar joint; however, movement in the sagittal plane is constrained as well, which may interfere with the execution of functional tasks. Prophylactic ankle taping and bracing are not likely to gain wide acceptance in the athletic population if they impede performance. Therefore, it is essential to recognize whether external ankle support hinders an individual's ability to carry out sport-specific tasks. The impact of various ankle prophylaxes on different facets of functional performance will be discussed.
Ankle Support and Running Speed

A dominant movement included in most aspects of physical activity is running. Running speed is an important component for successful performance in many competitive athletic events. The design of an external ankle support may restrict foot and ankle motions that are necessary to propel the body at adequate speeds; thus, the beneficial effects of ankle support in preventing injury may come at the cost of hindering performance. Several investigators have examined the effects of ankle taping and bracing on speed. The type of ankle stabilizer, distance of the sprint test, and how the external support potentially affected this performance varied for each of the studies reported (Table 4). Most subjects were competitive athletes, but several investigators observed ankle-support effects in recreational athletes.

Overwhelmingly, sprint time was not affected by the application of an external ankle device; however, others found a decrease in sprint performance. The description of the testing procedures used in this latter study is vague, which complicates the comparison of these results with those of similar studies. The authors failed to report subject-exclusion criteria, the testing instruments used, and how each test was performed. Therefore, the results presented may be flawed and should be applied cautiously. Due to the convincing evidence indicating that applying external ankle support does not hinder sprint performance, clinicians should not be concerned about healthy subjects using ankle stabilizers for prophylactic reasons.

Ankle Support and Agility

To determine if external ankle stabilizers affect agility, many testing protocols were created to challenge the coordination and speed of subjects (Table 5). The agility drills required quick changes in direction, moments of accelerations and deceleration, and sprinting. The prophylactic ankle devices generally did not alter agility; however, a few studies revealed variations from this majority upon application of an external ankle stabilizer.

Performance restrictions were evaluated in subjects tested while wearing an external ankle device. Subjects wearing the Aircast Training brace performed faster (22.3 seconds) on the agility course when compared with subjects wearing the DonJoy Ankle Ligament Protector (22.7 seconds). Although this time difference was statistically significant, the observed increase would be irrelevant when applied to an actual agility-type event. No detrimental effects were noted for any of the ankle stabilizers when compared with the control condition. This suggests that the agility drills used in the study were unaffected by the use of ankle bracing. Greene and Wight found that the Aircast Training brace resulted in significantly slower base-running times (13.79 seconds versus 12.84 seconds without support), while the other external ankle-support devices (Swede-O Universal and DonJoy Ankle Ligament Protector) did not impede base-running performance. The decreased running speed was attributed to the design of the Aircast training brace. The Aircast contains an air cylinder and a rigid material useful in restricting frontal-plane motion. The excess material in this ankle stabilizer may have hindered the subjects’ ability to make the sharp directional changes required to run the bases; however, numerous other researchers examining the effect of the Aircast Sport Stirrup on agility found no differences from the control condition. After examining the collective research, it becomes apparent that external ankle support has virtually no effect on agility.

Ankle Support and Vertical Jump

Lace-up style ankle support and traditional adhesive-tape application incorporate material anterior and posterior to the talocrural joint axis, which may restrict the extremes of sagittal-plane motion. Restriction of plantar-flexion and dorsiflexion movement is likely to impede vertical-jump performance. Therefore, if ankle taping and bracing prevent optimal perfor-
Table 5. Examinations of External Ankle Support on Agility Performance

<table>
<thead>
<tr>
<th>Study</th>
<th>Agility Test</th>
<th>Ankle Support/Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beriau et al⁴³</td>
<td>Course consisting of sprinting, backward running, and shuffling</td>
<td>Aircast Air Stirrup/Faster time than DonJoy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircast Training Brace/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swede-O Universal/Slower time than Aircast</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DonJoy Ankle Ligament Protector</td>
</tr>
<tr>
<td>Bocchinuso et al⁸⁹</td>
<td>Shuttle run and agility run</td>
<td>Active Ankle/None</td>
</tr>
<tr>
<td>Burks et al⁸⁸</td>
<td>Shuttle run</td>
<td>Aircast Air Stirrup/None</td>
</tr>
<tr>
<td>Greene and Wight²⁴</td>
<td>Softball base running</td>
<td>Swede-O Universal/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kallassy brace/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adhesive tape/Slowed shuttle run</td>
</tr>
<tr>
<td>Gross et al³⁰</td>
<td>5 × 10-m figure-of-8 task (3 laps)</td>
<td>Aircast Training Brace/Resulted in slower times</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swede-O Universal/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DonJoy Ankle Ligament Protector/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircast Air Stirrup/None</td>
</tr>
<tr>
<td>Jerosch et al⁹²</td>
<td>Japan agility test</td>
<td>Aircast Air Stirrup/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ligafix Air Brace (Orthosport, Hessen, Germany)/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mailteolec brace (Bauerfeind Inc, Kennesaw, GA)/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>MacPherson et al⁴⁴</td>
<td>Shuttle run</td>
<td>Aircast Air Stirrup/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DonJoy RocketSoc/None</td>
</tr>
<tr>
<td>Mayhew⁸⁷</td>
<td>Illinois agility run</td>
<td>Adhesive tape/None</td>
</tr>
<tr>
<td>Paris⁴⁵</td>
<td>SEMO (Southeast Missouri State University) agility test</td>
<td>McDavid A101/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New Cross #120/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swede-O Universal/None</td>
</tr>
<tr>
<td>Pienkowski et al⁴⁶</td>
<td>Cone and shuttle run</td>
<td>Swede-O Universal/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircast Air Stirrup/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kallassy brace/None</td>
</tr>
<tr>
<td>Verbrugge⁹¹</td>
<td>Figure-of-8 course</td>
<td>Adhesive Tape/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircast Air Stirrup/None</td>
</tr>
</tbody>
</table>

The mechanism for diminished vertical-jump performance in the presence of lace-up style bracing and adhesive taping can be best explained by the inherent design of these devices. The lace-up stabilizers and ankle taping may have produced plantar-flexion ROM restrictions that contributed to a diminished jump height. Vertical-jump height can certainly become impaired if the external ankle support decreases this functional ROM. Talocrural motion and torque production in the sagittal plane are critical components of any jumping task, as they assist in propulsion from the ground. Restricted plantar flexion from an external ankle stabilizer would likely impair jump height. Although restricting plantar flexion may contribute to the ability of external ankle support to help prevent injury, it may also hinder vertical-jump performance.

The effect of ankle prophylaxes on functional performance has been examined with speed, agility, and vertical jump as the primary dependent measures. The functional ROM allowed at the ankle-foot complex upon application of external ankle stabilizers is determined by the structure and design of the stabilizers.
the brace. Plantar flexion is restricted by ankle taping and lace-up style bracing, which may contribute to impeding functional performance. Although the results of the studies presently reviewed are not 100% conclusive, most of the information currently available suggests that external ankle support produces minimal to small decrements on lower extremity functional-performance tests evaluating speed, agility, and vertical-jump ability.

**CONCLUSIONS**

The use of external ankle supports in sports medicine will continue due to the high incidence of ankle injuries that occur in sport and recreational activity each year. Prophylactic ankle support is primarily advocated for the mechanical stability these devices provide. An abundant amount of research exists to document the effectiveness of external ankle support in restricting ankle and foot range of motion during static positions. Unfortunately, few data exist to help us understand how external ankle supports may act to control joint motion and attenuate joint forces during dynamic activities such as running and lateral-cutting maneuvers. More scientific inquiry is necessary to define the potential role of ankle support in reducing forces and loads placed on the ankle-foot complex. Evidence is emerging that external-ankle support use may also be beneficial by enhancing proprioceptive function of the ankle-foot complex. The implications surrounding this area of study are large, and other factors may be further delineated as we understand the mechanisms by which external ankle supports help prevent injury. It is our contention that this area should be the primary focus of future study involving the use of external ankle support. The potential influence of external ankle supports on lower extremity functional performance has been the subject of many research investigations. The literature shows quite clearly that external ankle support does not impair an individual’s sprint time and agility. Although some work has shown vertical-jump performance to be negatively affected with the use of external ankle support, most of the literature in this area has demonstrated no deleterious effects of such appliances.

**REFERENCES**


**Table 6. Examinations of External Ankle Support on Vertical Jump Performance**

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of Vertical Jump</th>
<th>Ankle Support/Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bocchinfuso et al89</td>
<td>Standing</td>
<td>Active Ankle/None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircast Air Stirrup/None</td>
</tr>
<tr>
<td>Burks et al88</td>
<td>Procedure not described</td>
<td>Swede-O Universal/Negative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kallassy brace/Negative</td>
</tr>
<tr>
<td>Juvenal93</td>
<td>Running</td>
<td>Adhesive tape/Negative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elastic ankle tape/Negative</td>
</tr>
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<td>Gross et al30</td>
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Surgical Considerations in the Treatment of Ankle Instability

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Objective: To review the surgical indications, techniques, biomechanical testing, and clinical results reported for the most common surgical techniques used to treat ankle instability.

Data Sources: We searched MEDLINE from 1960–2001 using the terms ankle instability, functional ankle instability, mechanical ankle instability, ankle ligament surgery, Brostrom, Chrisman-Snook, and Evans.

Data Synthesis: Although 80% to 85% of acute ankle sprains are successfully treated with a functional ankle-rehabilitation program, the remaining 15% to 20% have recurrent ankle instability and re-injury, necessitating surgical intervention. The fundamentals of the surgical approach to lateral ankle instability are based on the anatomy of the lateral ankle ligaments, the anterior talofibular ligament, and the calcaneofibular ligament. Ankle instability surgery has been broadly divided into an anatomic repair consisting of an imbrication of the lateral ligamentous complex and an ankle-ligament reconstruction. An ankle-ligament reconstruction weaves a harvested tendon graft, most commonly the peroneus brevis, to augment the lateral ligaments of the ankle. Goals of surgery are to reestablish ankle stability and function without compromising motion and without complications. Anatomic repair and imbrication of the lateral ligament complex with the Gould modification has an 85% to 95% success rate, and the risk of associated nerve injuries is low. This approach provides increased stability by reinforcing local host tissue, preserving subtalar and talocalcaneal motion, eliminating the comorbidity associated with tendon-graft harvest, and offering a quicker functional recovery. One concern in using the anatomic approach is the resultant strength of the repair, although the literature does not support this concern. Ankle-reconstruction procedures that sacrifice tendons are thought to provide a stronger construct, and hence, more stability. This increased stability results in loss of talocalcaneal and subtalar range of motion, prolonging recovery and decreasing sport performance. Adjacent nerve injury is more common with ankle-ligament reconstruction.

Conclusions/Recommendations: Based on the literature, we believe that a modified Brostrom lateral-ligament repair should be considered the first choice for persistent ankle instability refractory to a functional ankle-rehabilitation protocol. Ankle reconstruction with tendon augmentation should be reserved for patients with generalized ligamentous laxity or long-standing ligamentous insufficiency or as a salvage procedure in a patient with a failed modified Brostrom lateral-ligament repair.

Key Words: Brostrom procedure, Chrisman-Snook procedure, Evans procedure

The primary static restraints to an inversion injury mechanism are the anterior talofibular ligament (ATFL) and the calcaneofibular ligament (CFL). These ligaments make up a portion of the lateral ligamentous complex and help to prevent inversion of the talus during plantar flexion and dorsiflexion of the ankle.1

Burks and Morgan2 have described the anatomy of the ATFL and CFL, which demonstrate considerable anatomic variation. This anatomic variation in ligament position has been hypothesized as one factor predisposing individuals to chronic ankle instability.2,3 Burks and Morgan2 found that the ATFL originates 1 cm proximal to the tip of the lateral malleolus. The ligament averages 7.2 mm in width and inserts into the talus just distal to the articular surface, 18 mm proximal to the subtalar joint. The ATFL is contiguous with the joint capsule and not easily defined in patients who have sustained repetitive inversion sprains. The CFL originates adjacent to the ATFL, approximately 8 mm proximal to the tip of the fibula, and courses posterior and distal to the calcaneus. The angle at which the ligament lies in relation to the fibula is somewhat variable, averaging 133° (range, 113° to 150°) in a neutral ankle position. The CFL inserts onto the calcaneus 13 mm distal to the subtalar joint. The CFL ligament is an extracapsular ligament and makes up the floor of the peroneal sheath (Figure 1).

The ATFL is the primary restraint to inversion of the ankle throughout its arc of motion. Strain of the ATFL increases progressively as the ankle moves into plantar flexion and inversion. As a result, the ATFL is usually torn in inversion, plantar flexion, and internal rotation. The CFL stabilizes both the ankle joint and the subtalar joint. Strain in the CFL is greatest when the ankle is inverted and dorsiflexed. The CFL tears primarily in inversion and ankle dorsiflexion.1 Surgical repairs to correct lateral ankle instability should include repair and augmentation of the CFL if subtalar instability is suspected.4

The posterior talofibular ligament (PTFL) and the lateral talocalcaneal ligament (LTCL) are of less clinical significance in lateral ankle instability. The PTFL originates on the posteromedial aspect of the distal fibula and is directed postero-
medially to the posterior process of the talus. The PTFL is rarely injured as the result of inversion and does not require reconstruction. The LTCL may or may not be present; when present, it limits subtalar motion.

The pattern of ligamentous injury with an inversion mechanism has been well described. The most common mechanism of ankle sprains involves inversion and stress to the anterolateral capsule. The ATFL and CFL are then consecutively injured, depending on the energy and severity of the injury. Rasmussen, in a cadaveric study, noted that the ATFL was always torn when the CFL was torn. Similarly, Brostrom found no isolated tears of the CFL in 60 patients examined surgically.

The task of repairing or reconstructing unstable lateral ankle ligaments is challenging. The surgical approach requires restoration of the anatomic alignment and static functions of the ATFL and CFL. The repair should be durable and stable and allow for functional range of motion of the ankle and hindfoot. The repair should also avoid nerve injury and minimize damage to adjacent host tissue.

INDICATIONS

The initial management of patients with an acute inversion ankle sprain is nonoperative. After the early injury phase, functional rehabilitation begins and includes range of motion for the ankle and hindfoot, concentric and eccentric muscle strengthening, endurance training with particular attention to the peroneal musculature, and proprioceptive training. Proprioceptive exercises improve dynamic stability and are an essential part of the rehabilitation program. Functional bracing or taping may be useful to help prevent recurrent injury during "at-risk" activities. Most athletes can be treated successfully with rehabilitation and protective bracing.

Surgical repair should be considered only if symptoms persist after a functional rehabilitation program for the ankle. These symptoms may include a feeling of "giving way," defined as functional instability, or true mechanical instability demonstrated by provocative tests such as the anterior drawer or talar tilt, either clinically or with stress radiography. Similar surgical procedures have been described for both. Particular attention is needed to diagnose and correct subtle subtalar instability in individuals with functional instability.

SURGICAL CONSIDERATIONS

Various surgical approaches have been taken to lateral ankle instability. Understanding the differences in techniques is important to individualizing each patient’s treatment and rehabilitation. Preoperative assessment of ankle instability includes an evaluation of extremity alignment. Secondary anatomic findings, such as hindfoot varus or generalized ligamentous laxity, are associated with a higher prevalence of chronic ankle sprains. Manual muscle-strength testing of the peroneal and anterior tibial muscles is performed and compared with the contralateral limb (if uninjured). No isolated ligament-stabilizing procedure will be successful in the presence of hindfoot varus malalignment or a primary motor weakness, such as occurs with common peroneal nerve injury. The modified criteria of Bighton et al allow for generalized ligamentous laxity testing. With generalized ligamentous laxity, tenodesis procedures are favored. A thorough history reviewing any previous surgery of the ankle and the duration of the instability problem should be obtained.

In ankle instability surgeries fall into 2 broad categories: anatomic repair of the lateral-ligament complex and nonanatomic repair consisting of an ankle reconstruction using tendon-weave procedures.

SURGICAL TECHNIQUES

Anatomic Repair

Anatomic repairs attempt to reconstruct the normal anatomy by imbricating the existing joint capsule and lateral ligaments. In 1966, Brostrom reported on direct late repair of the lateral ankle ligaments in 60 patients with chronic ankle instability. The torn ends of the ATFL were shortened and repaired directly by midsubstance suturing; in 30% of patients, the CFL was also repaired. He reported a success rate of 80% with this technique. This technique is the foundation of the anatomic repair (Figure 2). Variations of this procedure include imbrication of the midsubstance of the lateral ligaments and modifications in the suturing of the ligaments through drill holes in the fibula, with or without reinforcement with fibular periosteum. The functional outcomes have been excellent, reported as high as 87% to 95% success rates. Outcome variables have included range of motion, strength, return to preinjury activity level, need for reoperation, and complications.

Gould et al reported on a subsequent modification to the Brostrom procedure (Figure 2D) involving the mobilization and reattachment of the lateral portion of the extensor retinaculum to the fibula after imbrication of the ATFL and CFL ligaments. This provided additional talocurcal and, secondarily, subtalar joint stability and was to be performed in any patient requiring a Brostrom ligament repair. Hamilton et al noted excellent results in professional ballet dancers and recreational athletes with the Gould modification of the Brostrom procedure. This finding extended the indications for this procedure into a high-level athletic patient population.

Karlsson et al reported on a modified Brostrom repair in which some patients received isolated ATFL imbrication and some received CFL and ATFL combined repairs. Excellent or good results were obtained in 80% of the patients, with improved mechanical stability as evidenced on stress radio-
Intermediate Dorsal Cutaneous Nerve

Lateral Dorsal Cutaneous Nerve

Figure 2. (A) Anatomy of the superficial peroneal nerve branches (intermediate and lateral dorsal cutaneous nerves) in relationship to the Broström anatomic repair incision (dotted lines). (B) Mid-substance tear of the anterior talofibular and calcaneofibular ligaments. (C) The Broström ligament repair of the anterior talofibular and calcaneofibular ligaments. (D) The Gould modification of the Broström ligament repair, mobilizing the proximal aspect of the inferior extensor retinaculum.

graphs. Most of the unsatisfactory results were in patients with generalized ligamentous laxity, long-standing ligamentous insufficiency, or a previous operation. Better functional results were obtained with repair of both ligaments than with an isolated repair of the ATFL. Karlsson et al.11 recommended routine combined repair of both ligaments.

The benefits of an anatomic repair include the simple surgical approach, the utilization of local host anatomy while preserving talocrural and subtalar motion, and fewer complications. The most severe complication, although quite rare, is injury to the superficial peroneal or sural nerve.

Reconstructive Tenodesis

Nonanatomic reconstructions use tendon or other types of grafts to tighten the lateral ankle. Despite attempts by the surgeon, these grafts have not been found to follow the orientation of the normal ligaments. The most common graft procedures involve a weave of the peroneus brevis tendon. The Chrisman-Snook procedure most closely approximates the ATFL and CFL anatomic. The Evans procedure has been used to augment the modified Broström in special cases. The greatest limitation of these procedures is the decrease in subtalar and, to a lesser extent, talocrural motion and the increased risk of adjacent cutaneous nerve injury. These procedures sacrifice all or a portion of the peroneus brevis, which is important in dynamic stability of the ankle.

The Evans procedure involves harvesting either half or the entire peroneus brevis tendon proximally and leaving it attached to the fifth metatarsal base distally. The free arm is then passed anterior to posterior through a drill hole in the distal fibula or placed over the anterior fibula and sutured to the periotomeum, as originally described by Evans, then anchored to itself (Figure 3). The position of the foot and the amount of tension applied during the suturing influence the degree of stability and the degree of restriction of subtalar motion. Anatomically, the position of this tendon weave does not recreate the ATFL or CFL but lies somewhere in between. While ankle dorsiflexion and plantar flexion are minimally altered with this procedure, anterior translation of the talus is not well controlled and subtalar motion is decreased.3

The procedure described by Chrisman and Snook uses a split peroneus brevis tendon detached proximally, thus preserving dynamic function of the muscle. The graft is brought through the fibula anterior to posterior, then placed through a drill hole in the calcaneus and sutured to itself (Figure 4). If performed as originally described, the procedure limits subtalar motion.

In 1985, Snook et al.15 reported a modification of their procedure in which extensive tightening of the graft is avoided to allow more subtalar motion. In addition, they recommended that the graft insertion into the calcaneus be moved posteriorly to more closely approximate the course of the CFL and avoid overconstraint of talocrural and subtalar motion. They presented a 10-year follow-up with excellent results in 38 of 48 ankles. All patients with fair or poor results had a severe re-injury. Leach et al.16 described a further modification of this reconstruction incorporating the anterior limb of the graft into the ATFL to more nearly replicate the orientation of the ligament. Colville and Grondel17 performed the Chrisman-Snook procedure on cadaveric ankles, which were then dissected to see how closely the reconstruction paralleled the normal courses of the ATFL and CFL. Due to the broad variation in the positioning of these ligaments, the reconstructions deviated significantly from anatomic alignment in a large number of limbs.

The benefits of an extra-anatomic reconstruction include increased strength of the reconstruction in patients in whom the ligaments are attenuated. In most cases, reconstruction tenodesis is reserved for patients with ligamentous laxity in whom the host tissues are severely attenuated. Another relative in-
Figure 3. An Evans reconstructive lateral ankle tenodesis. One half of the proximal peroneus brevis tendon is harvested, leaving it attached distally to the fifth metatarsal base. The proximal end is weaved anterior to posterior through a drill hole in the fibula and sutured to itself.

Figure 4. The Chrisman-Snook reconstructive lateral ankle tenodesis. One half of the proximal aspect of the peroneus brevis tendon is harvested, leaving it attached distally to the fifth metatarsal base. The proximal tendon is weaved anterior to posterior through a drill hole in the fibula and posterior to anterior in a calcaneal bone tunnel and sutured to itself in the region of the anterior talo-fibular ligament.

CLINICAL OUTCOME STUDIES

Karlsson et al\textsuperscript{18} presented long-term follow-up of patients with lateral ankle instability treated by the Evans procedure. Fifty percent of patients had satisfactory long-term results. Twelve patients with early satisfactory results had deteriorated at 3 to 6 years. Kaikkonen et al\textsuperscript{19} similarly found poor results with the Evans procedure. Surgical treatment of chronic ankle instability with the Evans procedure restored the mechanical stability of the joint, but too frequently, the function of the ankle did not return to the preinjury level, with only 35% of their patients achieving an excellent or good result in performance testing. This finding was primarily due to decreased range of motion, swelling of the ankle, and atrophy of the calf.\textsuperscript{19} Both the Evans and Chrisman-Snook procedures result in weakness in the surgical limb compared with the contralateral control limb.\textsuperscript{20}

Colville et al\textsuperscript{21} reported on reconstruction of the lateral ligaments in 15 cadaver ankles. The Evans and Chrisman-Snook procedures were tested for stability, motion, and isometry of graft placement. The Evans procedure allowed for increased anterior displacement, internal rotation, and tilt of the talus compared with the control ankles. Subtalar motion was restricted in all reconstructions. The Chrisman-Snook reconstructive procedure allowed increased internal rotation and anterior displacement. This procedure was effective in limiting talar tilt but restricted subtalar joint motion.

Many clinical comparisons have been performed between anatomic repairs and reconstructive tenodeses. Karlsson et al\textsuperscript{18} found that the tenodeses did not restore normal anatomy of the lateral ankle ligaments, unlike the anatomic repairs in their 2- to 10-year follow-up in a multicenter trial. The absence of normal anatomy resulted in restricted range of motion, reduced long-term stability, and an increased risk of medial degenerative joint disease of the ankle. They found a larger number of reoperations and less satisfactory overall results. Hennrikus et al\textsuperscript{22} demonstrated that both the Chrisman-Snook and modified Broström procedures provided good or excellent stability in more than 80% of patients; however, the modified Broström procedure resulted in higher patient satisfaction. In addition, a greater proportion of complications occurred with the Chrisman-Snook procedure.

Biomechanically, the modified Broström procedure was associated with less anterior talar displacement and a decreased talar-tilt angle compared with the Chrisman-Snook procedure.\textsuperscript{23} The modified Broström procedure produced a greater mechanical restraint than either the Evans or Chrisman-Snook procedures.\textsuperscript{23}

SPECIAL CONSIDERATIONS

Limitations of the modified Broström anatomic repair are rare and appear to be confined to specific patient populations, such as the overweight, the hypermobile, and high-demand, strenuous workers or athletes. Girard et al\textsuperscript{24} reported on a modified Broström lateral-ligament repair augmented with an Evans procedure in 21 patients who were considered higher-demand athletes. These patients showed a statistically significant loss of inversion and eversion motion in addition to loss...
of peroneal strength; however, they were able to return to sporting activities.

In patients with a fixed varus hindfoot, a calcaneal osteotomy should be considered to reestablish a plantigrade foot position. A calcaneal osteotomy can be performed concurrently with an ankle-repair or tendon-weave procedure.

Thermal shrinkage is now commonly performed adjunctively in the shoulder and knee to provide additional ligamentous support. Whether it offers any benefit as an adjunct to anatomic or tenodesis reconstruction of the ankle is unknown. One study showed that thermal shrinkage of the anterolateral capsule reduced angular displacement to varus stress and reduced anterior-talar excursion with an anterior drawer test. The appropriateness of this technique awaits further study.

CONCLUSIONS

The fundamentals of the surgical approach to lateral ankle instability are based on the anatomy of the lateral ankle ligaments, the anterior talofibular ligament, and the calcaneofibular ligament. Anatomic repair of the lateral-ligament complex supplemented with the Gould modification has become the preferred method of surgical treatment, with an 85% to 95% success rate. This approach provides increased stability through the reinforcement of local host tissue; preserves subtalar and talocural motion; has fewer associated nerve injuries and less morbidity associated with the harvest of tendon grafts; and provides a quicker functional recovery. Ankle-reconstruction procedures that sacrifice tendons to be used as donor tissues are thought to provide a theoretically stronger construct and, hence, more stability. This increased stability can result in loss of talocural and subtalar range of motion and lead to prolonged recovery and decreased sports performance. Adjacent nerve injury is more common with reconstructive ankle-ligament surgery. An ankle-reconstruction procedure using tendon augmentation should be reserved for patients with generalized ligamentous laxity or long-standing ligamentous insufficiency or as a salvage procedure in an individual with a failed modified Broström lateral-ligament repair.

ACKNOWLEDGMENTS

We thank Benedict DiGiovanni, MD, for his assistance in the preparation of this manuscript. The copyright for Figures 1–4 is maintained by the Hughston Sports Medicine Foundation, Inc, Columbus, GA.

REFERENCES

Longitudinal Split of the Peroneus Brevis Tendon and Lateral Ankle Instability: Treatment of Concomitant Lesions

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Objective: To describe the clinical picture, pathophysiology, and treatment of concomitant lesions of the peroneus brevis tendon and lateral ligament injuries to the ankle.

Background: In some cases, chronic lateral ankle instability is associated with a longitudinal partial tear in the peroneus brevis tendon. Patients who suffer from this lesion usually have atypical posterolateral ankle pain combined with signs of recurrent ligament instability (“giving way”). The tendon injury is often overlooked because it is combined with the ligament injury, and the injury mechanisms are similar.

Description: Tears or laxity in the superior peroneal retinaculum allow the anterior part of the injured peroneus brevis tendon to ride over the sharp posterior edge of the fibula, leading to a longitudinal tear in the tendon. This combined injury should be suspected in patients with recurrent giving way of the ankle joint and retromalleolar pain. The diagnosis can be established using either ultrasonography or magnetic resonance imaging.

Differential Diagnosis: Ligament injury, tenosynovitis, peroneus longus tendon lesion, os peroneum fracture, distal peroneus brevis tendon tear, or anomalous peroneus tertius tendon.

Treatment: The tendon injury and the ligament insufficiency should be repaired at the same time.

Conclusions: We recommend reconstruction of the superior peroneal retinaculum, combined with repair of the tendon, using side-to-side sutures and anatomical reconstruction of the lateral ankle ligaments.

Key Words: ankle ligament instability, ankle reconstruction

Longitudinal tear or attrition of the peroneus brevis tendon (PBT; the peroneus longus tendon is very seldom involved) has recently been mentioned as a cause of lateral ankle pain.1-9 The combination of PBT and chronic ankle instability has also received attention.1,2,9-12

The PBT is located in the retrofibular groove, behind the lateral malleolus. Longitudinal tear of the tendon was first mentioned by Meyers in 1924.13 More recently, both clinical and cadaveric studies have shown that the lesion is probably more common than previously believed.3,5,10 Some researchers2,3 have reported that this lesion is found in as many as 37% of cadaveric specimens. The clinical relevance of the autopsy lesion is, however, not entirely known. The pathophysiologic changes are repeated overload of the tendon in the retrofibular groove, compromising the vascularity of the tendon. The superior peroneal retinaculum (SPR) is partially torn from the posterior aspect of the fibula, making the PBT somewhat unstable.8,9 This may result in inhibition of the tissue-repair response, leading to subsequent tendon degeneration and tear.2,5

PERONEUS BREVIS TENDON TEAR AND LIGAMENT INJURY

Several researchers4-6,9 have proposed a correlation between a longitudinal tear in the PBT and chronic lateral ankle-ligament instability. An inversion injury to the ankle may thus not only produce ligament damage to the anterior talofibular and calcaneofibular ligaments but also injury to the SPR and the peroneal tendons (Figure 1). Almost always, the central portion of the tendon is damaged.7 The peroneus longus pulls on the PBT in the retrofibular groove, over the sharp posterior edge of the fibula, during eversion of the foot in the swing phase.2,8,14 This leads to the dislocation of the most anterior part of the damaged tendon6,14,15 and almost invariably to pain at the posterior aspect of the fibula.5,9

Typically, the patient gives a history of lateral ankle-inversion injury. In most cases, the tendon damage is overlooked, and the diagnosis may be delayed or even missed. Because of the damage to the SPR, the instability of the PBT, and the tendon tissue degeneration, these cases are often refractory to nonsurgical treatment, and the tendon tear progresses.1,5,6,9,16,17

During the last decade, several investigations of the microvascular anatomy and descriptions of the pathophysiology and the biomechanics of the PBT8,11,14,15,18,19 and several investigations of the treatment of concomitant ankle instability and partial longitudinal tears in the PBT1,5,6,8,9,12,14 have been published. The cause of the tendon injury is inversion ankle injury, with secondary insufficiency of the lateral ligaments and rupture (or possibly elongation) of the SPR. The damaged retinaculum cannot restrain the PBT behind the sharp posterior edge of the fibula, an injury mechanism well described by
Figure 1. Relationship among the longitudinal tear in the peroneus brevis tendon, the sharp posterior edge of the fibula, and the superior peroneal retinaculum. 1, Torn peroneus brevis tendon. 2, The sharp posterior edge of the fibula. 3, Superior peroneal retinaculum. 4, Normal peroneus longus tendon (retracted).

Figure 2. Sagittal oblique spin-echo proton density-weighted magnetic resonance image showing high signal intensity within the peroneus brevis tendon at the lateral malleolar level (black arrow). The peroneus longus tendon (white arrow) is normal.

Sobel et al\textsuperscript{4,6} and subsequently verified by other researchers.\textsuperscript{5,9,17} Some other possible mechanisms have been mentioned; they include the distally located muscle belly of the peroneus brevis or the presence of an anomalous peroneus tertius tendon.\textsuperscript{16,20} However, the importance of these structures in the degenerative process of the PBT has been questioned.

The most likely cause of a combined lesion is recurrent ankle instability, followed by SPR insufficiency, leading to a secondary PBT subluxation and attrition of the tendon. This evolves to become a degenerative longitudinal tear in the PBT. The main predisposing factor is probably the tear in the SPR, but the exact pathophysiologic mechanism is not known.\textsuperscript{4,5,10} Intraoperative findings in several studies have been consistent with this hypothesis.\textsuperscript{5,6,9,17} A longitudinal tear in the PBT has also been described more distally, along the lateral wall of the calcaneus or in the cuboid tunnel.\textsuperscript{21} However, another somewhat uncommon injury is chronic lateral ankle pain associated with a fracture of the os peroneum, which, in some cases, should be considered in the differential diagnosis.\textsuperscript{22,23}

**CLINICAL PRESENTATION**

The typical patient describes recurrent lateral instability of the ankle joint as the primary problem. In addition, retromalleolar pain combined with recurrent giving way is typical. The pain is almost always localized posterior to the lateral malleolus. This is in contrast to patients with chronic lateral ankle instability alone, who usually mention giving way as the main complaint and anterior ankle pain as a secondary problem, most frequently caused by anterior tibial or talar osteophytes or loose intra-articular bodies (bone or cartilage). A thorough physical examination includes an assessment of ligament integrity (ie, positive anterior drawer test or increased supination of the foot suggests injury). An assessment of range of motion is mandatory. Palpable swelling around and behind the lateral malleolus can raise the suspicion of a tendon tear.

**RADIOGRAPHIC EVALUATION**

There is a substantial risk of delayed or missed diagnosis with PBT tear. Either magnetic resonance imaging (Figure 2) or ultrasound imaging is recommended to increase the diagnostic accuracy in these patients.

**TREATMENT**

One constant finding at surgery is the subluxation of the anterior half of the PBT over the sharp posterior edge of the fibula. Moreover, the SPR is partially torn away from the posterior ridge of the fibula. Some authors\textsuperscript{5} have mentioned that this lesion resembles a Bankart lesion in recurrent anterior dislocation of the shoulder. Recurrent dislocation of the peroneal tendons is, however, not a primary problem.\textsuperscript{24} If concomitant lateral ankle instability is present, the consensus in the literature is that the tendon injury should be repaired at the same time as the ligament stabilization. Only a few reports on surgical treatment have been published, and we found no large series. Sobel and Geppert\textsuperscript{14} recommended a modification of the Broström-Gould procedure\textsuperscript{25} for the treatment of concomitant lateral ankle instability and PBT tear using a posterolateral approach.

A modified Chrisman-Snook procedure has been suggested by some researchers.\textsuperscript{8,24} The largest series is described by
Figure 3. Lateral view of the left ankle. A longitudinal tear is present in the peroneus brevis tendon. The peroneus longus tendon is normal.

Bonnin et al., who operated on 18 patients with split lesions of the PBT associated with chronic ankle instability. During a 3-year period, 18 of 77 patients (23%) with chronic ankle-ligament laxity who underwent surgical repair had a concomitant PBT tear. The modified Chrisman-Snook procedure was used in 13 of 18 patients studied. Regrettably, the clinical results were not described in detail in this report, making it impossible to draw any conclusions in terms of the choice of treatment. One potential problem when using this procedure is fraying of the tendon, making repair technically impossible.

In several reports, the anatomical reconstruction of the lateral ankle ligaments has been described as simple and safe, producing stable ankles with a low risk of complications in most patients. This procedure can be combined with the reconstruction of the SPR (Figures 3 through 5). The operation begins with a curvilinear 7- to 8-cm long incision along the posterior ridge of the fibula, exposing the peroneal tendons and the anterior talofibular and calcaneofibular ligaments. The ligaments are tested for laxity, and the SPR is exposed. The peroneal tendon sheath is incised approximately 5 mm posterior to the attachment to the fibula. Then the PBT is carefully examined. The degenerative tissue is carefully excised, and the tendon is repaired with side-to-side sutures. In some cases, the ruptured anterior part of the tendon may have to be excised; however, this is infrequent, and complete rupture of the PBT is extremely uncommon. A reconstruction of the SPR is performed, using three 2.0-mm drill holes in the posterior aspect of the fibular edge. Because insufficiency of the lateral ligaments is usually present, anatomical reconstruction of both the anterior talofibular and calcaneofibular ligaments is performed.

Postoperatively, a plaster cast is applied for 2 to 6 weeks, or, instead of prolonged postoperative immobilization, an Aircast brace (Aircast, Inc, Summit, NJ) can be used to facilitate range-of-motion training after the second postoperative week. Full weight bearing is allowed. After the sixth week, coordination training using tilt boards is initiated. Strength training with weight boots is initiated 6 to 8 weeks after the operation and increased until full functional strength has been regained. After approximately 12 weeks, the athlete is allowed to return to full sport activity provided that functional stability is normal and the ankle is not swollen. An external ankle support (ankle tape or Aircast brace) can thereafter be used as preferred by the athlete.

The results after anatomical reconstruction have been reported as satisfactory in most patients. Ligament stabilization should always be combined with repair of the tendon tear and reconstruction of the SPR.
CONCLUSIONS

Patients with a partial longitudinal tear in the peroneus brevis tendon most often present with atypical posterolateral (retromalleolar) pain. The tendon injury may be combined with injury to the lateral ankle ligaments. In order to produce the best clinical results, both the tendon injury and the ligament insufficiency should be repaired at the same time.

REFERENCES

Assessment of Ankle-Subtalar-Joint-Complex Laxity Using an Instrumented Ankle Arthrometer: An Experimental Cadaveric Investigation

John E. Kovaleski; J. Marcus Hollis; Robert J. Heitman; Larry R. Gurchiek; Albert W. Pearsall, IV

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Objective: To show the relationship between direct measurements of tibial-calcaneal bone motion and instrumented measurements of ankle-subtalar-joint–complex laxity using a portable ankle arthrometer; to assess within and between-tester measurement reliability; and to determine if the ankle arthrometer can detect increased mechanical laxity of the ankle-subtalar-joint–complex after simulated injury of the lateral ankle ligaments.

Design and Setting: We used linear regression analysis to examine the relationship between direct measurements of tibial-calcaneal bone motion and instrumented measurements of ankle-subtalar-joint–complex laxity. An intraclass correlation coefficient (2,1) was calculated to determine intratester and intertester reliability for instrumented measurements of ankle-subtalar-joint–complex laxity. In addition, 2 separate, one-way, repeated-measures analyses of variance were used to compare instrumented measures of anteroposterior displacement and inversion-eversion rotation among the intact ankles after sectioning the anterior talofibular ligament and both the anterior talofibular and calcaneofibular ligaments. Data were collected in a biomechanics laboratory setting.

Subjects: Six fresh-frozen human-cadaver ankle specimens were studied.

Measurements: Testing involved the concurrent measurement of tibial-calcaneal bone motion and ankle-subtalar-joint–complex motion during the application of external loads. An instrumented ankle arthrometer was used to load the ankle in a controlled manner. Two spatial kinematic linkages measured the 3-dimensional motion of the calcaneus relative to the tibia and the motion of the arthrometer's footplate relative to the tibia.

Results: The correlation between tibial-calcaneal bone motion and instrumented measurement for anterior-posterior displacement was .878 (P = .0001). Its linear relationship with bone motion accounted for approximately 77% of the variance of the instrumented measurement. The correlation between tibial-calcaneal bone motion and instrumented measurement for inversion-eversion rotation was .858 (P = .0001), with approximately 74% of the variance of the instrumented measurement accounted for by its linear relationship with bone motion. High intratester and intertester reliability coefficients (ICC [2,1] = .80 to .97) were observed for instrumented measurements of ankle-subtalar-joint–complex laxity. In addition, ligamentous sectioning resulted in significantly increased ankle-subtalar-joint–complex laxity. When compared with the intact condition, sectioning both the anterior talofibular and calcaneofibular ligaments produced significant increases in anterior-posterior displacement (P = .0001) and inversion-eversion rotation (P = .002).

Conclusions: We found a strong relationship between tibial-calcaneal bone motion and arthrometric measurements of ankle-subtalar-joint–complex laxity. The instrumented ankle arthrometer may be suitable as a diagnostic tool for the evaluation of lateral ankle-ligament laxity.

Key Words: mechanical laxity measurement, ankle instability, ankle sprain, ankle displacement

Lateral ankle-ligament sprains frequently involve an inversion mechanism or ankle hypersupination as the ankle undergoes abnormal plantar flexion, inversion, and internal rotation in the weight-bearing position.1,2 Although we treat most lateral ankle sprains effectively with physical rehabilitation and nonoperative treatment, more severe sprains involving complete tears of the anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL) may lead to chronic instability and subsequent disability.3–5 These injuries can often be treated satisfactorily with late repair or reconstruction.6–9 However, despite surgical intervention, some patients continue to experience chronic disability, including mechanical and functional instability, pain, motion loss, or weakness.9,10–14
Incompetence of the lateral talocrural ligaments has been shown to affect normal talocrural (ankle) joint motion. Lateral ankle instability can disrupt the normal gliding motion during the swing phase of walking and produce anterolateral rotational instability that permits the talus to rotate internally and subluxate anteriorly on the tibia. Associated injuries found in chronic lateral ankle instability include anterolateral impingement lesion, attenuated peroneal retinaculum, and ankle synovitis. Furthermore, the lateral ligaments of the talocalcaneal (subtalar) joint may also be injured during lateral ankle sprain, leading to subtalar-joint instability.

In detecting lateral-ligament abnormalities in patients with suspected acute and chronic ankle-subtalar instability, several diagnostic methods are helpful for making treatment and surgical decisions. Magnetic resonance imaging provides significant anatomic detail to evaluate disorders of the soft tissues and osseous structures of the ankle, and magnetic resonance imaging arthrography is a sensitive technique for detecting tears of the lateral collateral ligaments. Although these diagnostic tools are recognized as the modalities of choice for assessing pathologic conditions of the ankle, treatment is often based on the amount of ankle instability observed during the clinical examination.

Clinical assessment of ankle-joint and subtalar-joint laxity typically involves manual examination techniques such as the anterior drawer, talar tilt, and inversion-eversion stress tests. The inherent subjectivity of manual examination along with limitations in differentiating the degree of lateral ankle-ligament stability make manual stress tests inaccurate for diagnosing specific ligament involvement. In addition, stress radiography for assessing ankle mechanical laxity has been shown to be unreliable despite its use in numerous ankle-ligament injury studies. Stress radiography using a calibrated loading device allows for reproducible force application and patient positioning but does not provide direct linear and angular measurements. Subjective evaluation can lead to inadequate treatment after lateral ankle injury, which can result in chronic instability. Therefore, accurate clinical diagnosis is imperative in differentiating mechanical laxity among grades of lateral ankle sprain. Further investigation using other reliable and quantifiable techniques for measuring lateral ankle laxity is needed.

Ankle-subtalar-joint–complex laxity has been studied using 3-dimensional kinematics, pneumatic loading, and spatial kinematic methods by applying forces and moments across the joint and measuring the resulting displacements. Recently, a 6-degrees-of-freedom, spatial kinematic instrumented linkage has been described as a suitable evaluation tool for ankle-ligament laxity. We reported on an instrumented ankle arthrometer for clinical use that quantifies the anteroposterior load-displacement and inversion-eversion rotational laxity characteristics of the ankle-subtalar-joint complex. The arthrometer measures all components of ankle-subtalar-joint complex motion: 3 rotations and 3 translations. A foot-clamp frame is secured to the patient’s foot, and a point of reference is established on the tibia with a shin pad secured to the calf by restraining straps. During measurement, the force and torque loads produced via the arthrometer’s loading handle are transferred to the skeletal and soft tissues of the ankle-subtalar-joint complex. The spatial kinematic linkage attached to the overlying skin via the ankle arthrometer measures the relative motion between the arthrometer footplate and the reference pad placed on the tibia.

We have reported ankle-subtalar-joint–complex laxity in uninjured subjects using a portable ankle arthrometer. High intratester reliability coefficients for anteroposterior (AP) displacement (range, .82 to .89) and inversion-eversion (I-E) rotation (range, .86 to .97) were found. However, measurement validity and intertester reliability have not been examined. In this paper, we report the relationship between tibial-calcaneal bone motion (skeletal motion) and instrumented measurement of ankle-subtalar-joint–complex laxity. To measure skeletal motion, the spatial kinematic linkage must be attached directly to bone to follow and monitor the relative positions between the 2 bone segments to which it is attached. We theorized that the arthrometric measures of displacement and rotation would be greater but associated with skeletal motion because of the ankle arthrometer attached to the overlying skin of the foot and the soft tissues located between the arthrometric device and the skeleton.

The load-displacement and mobility characteristics of the ligamentous structures of the ankle complex and their individual contributions to the mechanical stability of the joint have traditionally been studied by sequential sectioning of the lateral ligamentous structures. In cadaveric studies, researchers have documented the motion patterns of the ankle joint, subtalar joint, and ankle-subtalar-joint complex, first with intact ligaments and then after sectioning the ATFL and CFL. It is possible to distinguish among grades of lateral ligamentous damage by examining bone-to-bone motion along with ankle-subtalar-joint–complex laxity. The load-displacement and laxity characteristics of the ankle-subtalar-joint complex before and after sectioning of the ATFL and CFL have not been shown using the ankle arthrometer.

Objective and reliable measurements of mechanical laxity could provide a greater understanding of ankle-subtalar-joint–complex laxity after injury. Our major goal was to assess a portable instrumented ankle arthrometer as a tool in the evaluation of lateral ankle ligamentous laxity. The primary objective was to show the relationship between direct measurements of tibial-calcaneal bone motion and instrumented measurements of ankle-subtalar-joint–complex laxity. The second objective was to assess intratester and intertester measurement reliability to determine the applicability of the ankle arthrometer for clinical use. The third objective was to determine if the ankle arthrometer can detect increased ankle-subtalar-joint–complex laxity after simulated injury of the lateral ankle ligaments.

**METHODS**

Our experimental protocol involved the concurrent measurement of tibial-calcaneal bone (skeletal) motion and instrumented ankle-subtalar-joint–complex laxity during the application of external loads to human-cadaveric ankle specimens. An instrumented ankle arthrometer was used to load the ankle in a controlled manner (Figure 1). Each session consisted of testing the intact ankle first, followed by 2 simulated injury conditions that involved sectioning the ATFL and then the CFL.

**Specimens**

Six fresh-frozen human-cadaveric ankles (mean donor age, 67 years) without clinical evidence of ligamentous injury were harvested for study. The lower leg was separated from the rest...
of the limb approximately 25 cm above the ankle joint and frozen at −20°C.

Instrumentation

In order to measure tibial-calcaneal bone motion and ankle-subtalar-joint–complex laxity, 2 separate spatial kinematic linkages were used. A spatial kinematic linkage is a 6-degrees-of-freedom electrogoniometer that measures 3-dimensional motion. A bone linkage was attached directly to the tibia and the calcaneus, and a second linkage was incorporated into the instrumented ankle arthrometer. The bone spatial linkage measured motion of the 2 ends of the linkage, thus measuring calcaneal motion relative to the tibia (ie, ankle and subtalar bone motion) (Figure 2). The arthrometer spatial linkage connected the tibial pad to the footplate and measured the motion of the footplate relative to the tibial pad. The arthrometric measurements reflect relative motion of the bones and underlying soft tissues of the ankle-subtalar-joint complex.

The ankle arthrometer consisted of an adjustable plate fixed to the foot, a load-measuring handle attached to the footplate through which the load was applied, and a tibial pad attached to the tibia. A computer with an analog-to-digital converter was used to simultaneously calculate and record the data. The resulting AP displacement (millimeters) and I-E rotation (degrees of range of motion) from the tibial-calcaneal bone linkage and instrumented arthrometer linkage, along with the corresponding AP load and I-E torque, were recorded. We used a custom software program written in LabVIEW (National Instruments Corp, Austin, TX) for data collection.

Experimental Setup

The specimen was thawed to room temperature before testing and a tibial rod screwed into the medullary cavity of the tibia down to 3 to 5 cm above the ankle joint. The rod was further fixed into the bone with screws inserted perpendicular through the tibia and the rod. Before mounting, the muscles and the soft tissues of the posterior calf were dissected to expose the posterior tibia and calcaneus. This allowed for the attachment of the bone spatial kinematic linkage via bone plates that were screwed into the calcaneus and the tibia (see Figure 2). Each specimen was secured in a vice so that the lower leg was positioned parallel to the floor and the foot was positioned vertically (0° flexion angle) to the floor so that it extended over the edge of the table. A restraining strap attached to the support bar beneath the ankle was secured around the distal lower leg 1 cm above the malleoli and tightened to prevent lower leg movement during testing (see Figure 1). The specimens were mounted at the proximal end of the tibial rod to a table clamp that allowed full freedom of motion of the ankle and subtalar joints.

Test Protocol

One examiner (J.E.K.) tested all ankles following a testing protocol previously described. The examiner placed the bottom of the foot onto the footplate and adjusted a dorsal foot clamp on the forefoot until it compressed the heel against a posterior heel pad. Medial and lateral heel clamps were then adjusted to grip the sides of the calcaneus. The dorsal foot clamp rested over the area of the talonavicular joint and secured the foot posteriorly and distally. The dorsal foot clamp, in combination with the plate under the plantar surface of the
foot and the medial, lateral, and posterior heel pads, held the hindfoot and midfoot securely. The tibial pad was then positioned 5 cm above the ankle malleoli and secured to the lower leg using restraining straps. In order to minimize the variation among the forces applied to the ankles, the arthrometer was oriented in a similar manner on each foot for all tests.

The ankles were positioned at zero AP load and zero I-E moment at a neutral (0°) flexion angle, which was defined as the measurement reference position. The other degrees of freedom (internal-external, medial-lateral, and proximal-distal) were also maintained at their zero-load neutral position during testing. Thus, the measurement reference position represented zero moment and force loads. Foot motion anterior to the measurement reference position was defined as anterior displacement and motion posterior to that position as posterior displacement. Total AP displacement was the sum of the anterior and posterior translation at a given force load. Total I-E rotation was the sum of the inversion and eversion rotation for a given torque load. High reliability of measurement has been shown for total laxity versus one-way laxity around the neutral, unloaded ankle-joint complex. Thus, total AP displacement and total I-E rotation are reported as ankle-subtalar-joint-complex laxity.

The ankles were loaded first in AP drawer and then in heel I-E at neutral (0°) flexion angle. This angle was measured from the plantar surface of the foot relative to the anterior tibia and determined by the 6-degrees-of-freedom electrogoniometer within the instrumented linkage. Anteroposterior loading, I-E torque, and the flexion angle were applied through the load handle in line with the footplate by the examiner. For AP displacement, the ankles were loaded to 125 N with both anterior and posterior forces. Starting at the neutral position, anterior loading was applied first, followed by posterior loading. Displacement of the calcaneus (mm) in AP motion, as applied by the load handle, was recorded along with the load. Total AP displacement at the 125-N force load was recorded and defined as AP laxity. For I-E rotation, the ankles were loaded to 4000 N-mm with inversion and eversion torque. Starting at the neutral position, inversion loading was applied first, followed by eversion loading. Rotation (degrees of range of motion) of the calcaneus, as applied by the load handle, was recorded along with the torque. Total I-E rotation at 4000 N-mm was recorded and defined as I-E laxity. By watching the computer monitor, the examiner could visualize the applied load to obtain a maximum of 125 N for AP displacement and 4000 N-mm for I-E rotation (Figure 3).

Procedure for Intratester and Intertester Measurements

To determine intratester and intertester reliability of the ankle ligament arthrometer, 2 examiners (J.E.K. and J.M.H.) tested the intact ankles, with the order of testing randomly assigned between the examiners. Anteroposterior loading was performed first, followed by I-E loading. The ankle arthrometer was removed after both AP and I-E loading sequences were completed and was reapplied by the examiner before the measurement was repeated.

Procedure for Simulated Lateral-Ankle Injury

After testing the intact ankle-subtalar-joint complex, the ATFL was sectioned, simulating injury, and the testing was repeated. The ATFL was visualized along its length from the anterior edge of the lateral malleolus to the lateral aspect of the talar neck. Calcaneofibular-ligament sectioning followed, and the testing was repeated. The CFL was visualized along its length from the anterior edge of the fibular malleolus obliquely distal, posterior, and medial to the midlateral surface of the calcaneus. Minimal soft tissue dissection was performed to expose the ligaments, with each ligament sectioned between midsubstance and its proximal attachment.

Figure 3. Screen image of ankle arthrometer program.

### RESULTS

#### Bone Motion and Arthrometric Correlations

Total AP displacement and I-E rotation between tibial-calcaneal bone motion and instrumented measurements of AP displacement and I-E rotation. An intraclass correlation coefficient (ICC 2,1) was used to determine intratester and intertester reliability for instrumented measurement of AP displacement and I-E rotation. An intraclass correlation coefficient of .75 or greater was considered high reliability. The standard error of measurement was also calculated to provide an estimate of measurement precision.

Two separate, one-way, repeated-measures analyses of variance were calculated to determine the effects of ligamentous injury on instrumented measures of AP displacement and I-E rotation. The independent variable, ankle-subtalar-joint integrity, had 3 levels: intact ankle, ATFL sectioned, and ATFL and CFL sectioned. The dependent variables were total AP displacement (mm) and I-E rotation (degrees of range of motion). The Bonferroni post hoc procedure was used to identify differences between injury conditions. An α level of $P < .05$ was set for all analyses.
Table 1. Total Anteroposterior Displacement (mm) and Inversion-Eversion Rotation (Degrees) for Skeletal Motion (Tibial-Calcaneal Bone Motion) and Instrumented Measurements of Ankle-Subtalar-Joint-Complex Laxity

<table>
<thead>
<tr>
<th></th>
<th>Anteroposterior Displacement</th>
<th>Inversion-Eversion Rotation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Skeletal Motion</td>
<td>Arthrometer</td>
</tr>
<tr>
<td>Intact Ankle</td>
<td>7.43</td>
<td>13.77</td>
</tr>
<tr>
<td>ATFL Cut</td>
<td>11.38</td>
<td>16.28</td>
</tr>
<tr>
<td>ATFL + CFL Cut</td>
<td>12.77</td>
<td>18.89</td>
</tr>
</tbody>
</table>

*SD indicates standard deviation; ATFL, anterior talofibular ligament; and CFL, calcaneofibular ligament.

Table 2. Intratester and Intertester Measurements for Anteroposterior Displacement and Inversion-Eversion Rotation

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
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<tbody>
<tr>
<td></td>
<td>Intratester Reliability</td>
<td></td>
<td>Intertester Reliability</td>
<td></td>
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<tr>
<td></td>
<td>Mean SD</td>
<td>Mean SD</td>
<td>ICC SEM</td>
<td></td>
</tr>
<tr>
<td>Anteroposterior displacement (mm)</td>
<td>13.77 3.6</td>
<td>14.10 3.1</td>
<td>.97 0.58</td>
<td></td>
</tr>
<tr>
<td>Inversion-eversion rotation (range of motion in degrees)</td>
<td>30.13 4.3</td>
<td>33.59 6.5</td>
<td>.82 2.40</td>
<td></td>
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<tr>
<td>Tester 1</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Anteroposterior displacement (mm)</td>
<td>13.77 3.6</td>
<td>14.08 3.1</td>
<td>.91 1.02</td>
<td></td>
</tr>
<tr>
<td>Inversion-eversion rotation (range of motion in degrees)</td>
<td>30.13 4.3</td>
<td>34.08 5.8</td>
<td>.80 2.37</td>
<td></td>
</tr>
</tbody>
</table>

*SD indicates standard deviation; ICC, intraclass correlation coefficient (2,1); and SEM, standard error of measurement.

Arthrometric Measurements After Simulated Injury

The AP laxity analysis of variance revealed a significant main effect for ankle-subtalar-joint–complex integrity ($F_{2,10} = 18.81, P = .001, \eta^2 = .79$). Compared with the intact condition, sequentially cutting the ATFL and the ATFL + CFL produced significant increases in total AP laxity. Ankle-subtalar-joint–complex laxity increased 2.51 mm (Bonferroni $P = .046$) in AP displacement after the ATFL was sectioned and 5.12 mm (Bonferroni $P = .003$) after the CFL was sectioned. An example of AP-displacement differences between the intact ankle and after sectioning the ATFL for 1 specimen is shown in Figure 4.

For I-E loading, the injury effect was significant ($F_{2,10} = 12.64, P = .012, \eta^2 = .716$). In total I-E rotation, range of motion increased significantly by 4.5° (Bonferroni $P = .013$) after ATFL sectioning compared with the intact ankle. With sectioning of the CFL in addition to the ATFL, range of motion increased significantly by 13.97° (Bonferroni $P = .026$) compared with the intact ankle. Figure 5 shows I-E rotation differences between the intact ankle and after sectioning the ATFL and CFL for 1 specimen.

DISCUSSION

The ATFL and CFL primarily maintain lateral joint stability in the normal ankle. Important changes occur in ankle stability with tearing of one or both of these ligaments. The relative magnitudes of the changes induced by these disruptions are often difficult to quantify and evaluate. Manual techniques for assessing ankle-subtalar-joint–complex laxity involve applying unknown forces and moments to the ankle and observing the resulting displacements and rotations. Although many clinicians become skilled in evaluating ligamentous injuries...
and develop a qualitative “feel” for laxity, the examination procedure is largely subjective, and its reliability depends on the skill and experience of the examiner. Our findings support the use of the ankle arthrometer to quantifiably measure ankle-subtalar-joint-complex laxity.

The use of the portable ankle arthrometer to quantify ankle-subtalar-joint-complex laxity is possible due to the development of an instrumented spatial linkage that measures 3-dimensional ankle motion. Because all joints of the human body permit 6 degrees of freedom to varying extents, all 6 must be taken into account to accurately measure motion at the joint. The spatial linkage connected to the ankle arthrometer measured the 6-degrees-of-freedom motion of the footplate relative to the tibial pad. Skeletal motion was also of interest, and the bone spatial linkage was attached directly to the bone, thereby measuring tibial-calcaneal bone motion. The 2 linkage systems followed and monitored the relative positions between the 2 body segments to which each was attatched. The motion measurements obtained from the ankle-arthrometer linkage system were higher than the skeletal motions due to motion within the soft tissue, between the arthrometer pads, and of the bones. Between 74% and 77% of the variance of the arthrometric measurement about the mean resulted from joint motion, as measured by the bone-to-bone linkage. Therefore, the variation in arthrometer measurement was due primarily to variations in bone-to-bone motion. Because the ankle arthrometer was attached to the overlying skin, the linkage measured relative motions between the tibial pad and the footplate. Thus, the compliance characteristics of the overlying soft tissues were measured along with joint motion. Ankle-subtalar-joint-complex laxity, as measured by the ankle arthrometer, included both bone-to-bone motion and soft tissue motion. This accounts for the systematic differences observed between the tibial-calcaneal bone motion and arthrometric measurements of ankle-subtalar-joint-complex laxity.

The clinical use of instrumented arthrometry for detecting and differentiating lateral ligamentous laxity of the ankle-subtalar-joint-complex requires the establishment of reliable measurements. Theoretically, instrumented measurement of ankle-complex laxity might be used to determine the appropriate direction of treatment for the patient, whether it be operative or nonoperative. Also, objective measurement may be used to quantitatively assess outcome in terms of joint stability after treatment of the ankle injury. If used as a tool to determine treatment and outcome for the individual patient, the ankle arthrometer must be found to be reliable before clinical use can be justified. Two reports have examined in vivo test-retest reliability of the portable ankle arthrometer for measuring ankle-subtalar-joint-complex laxity. Kovaleski et al. reported reliability coefficients and joint-laxity characteristics of 82 ankles with no previous history of ankle injury. High reliability coefficients were found across different force loads for total AP displacement (range, .82 to .89) and I-E rotation (range, .86 to .97). DiSanto et al. examined measurement reliability using the instrumented ankle arthrometer in 44 subjects with either stable or unstable ankles. Correlation coefficients for AP displacement (r = .44 to .87) and inversion-eversion rotation (r = .82 to .95) were generally high. In comparison with these 2 earlier studies, the intratester and intertester measurements of reliability in the current study are comparable with the within-tester measurements we previously reported and somewhat higher than those reported by DiSanto et al.

We also determined standard errors of measurement for AP displacement (intratester = 0.58 mm, intertester = 1.02 mm) and I-E rotation (intratester = 2.4°, intertester = 2.37°). The low standard error scores (AP displacement = 1.94 mm, I-E rotation = 2.84 degrees) reported from our earlier study in vivo along with the small standard error scores obtained in the present study, lend support to the precision of instrumented measurement of ankle-subtalar-joint-complex laxity. This suggests that any inconsistency of measurement (intratester or intertester) occurs in an acceptably small range of laxity values. However, our reliability findings are limited to the 6 cadaveric samples studied.

We identified several factors that could affect reliability measurement of ankle-subtalar-joint-complex laxity and might explain clinical-measurement differences. These factors include ankle-flexion angle, magnitude of loading, direction of the displacement or rotation force, and limb muscle tone (relaxation). Examiner experience with instrumented measurement of joint laxity can also result in measurement differences. Two testers experienced in using the ankle arthrometer for assessing ankle-subtalar-joint-complex laxity examined all specimens in the current study. Together, the high reliability coefficients and low standard errors of measurement demonstrated small measurement differences between testers.

Simulated Injury

In several in vitro biomechanical studies, researchers have examined the effects of ligament sectioning on laxity of the ankle and subtalar joints. Less research is reported on the effects of ligament sectioning on ankle-subtalar-joint-complex laxity. Measuring the relationship between ligament damage and mechanical laxity by simulating ligamentous injury could improve our understanding of ankle motion and the effect ligament damage has in producing ankle-subtalar-joint instability. Therefore, we believed it clinically important to

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*References 24, 25, 36, 41, 48, 49, 51, 52, 58, 59.
examine this device using cadaver specimens in which we could study different imposed laxity conditions.

Ankle lateral-ligament injury produced statistically significant changes in ankle-subtalar-joint–complex laxity. The ankle arthrometer can detect changes in mechanical laxity produced by damage to the ATFL and CFL. Sectioning the ATFL significantly increased mean AP displacement by 15.4% and sequentially sectioning the CFL increased mean AP displacement by 27.1% compared with the intact ankle. Inversion-eversion rotation significantly increased 13.0% after sectioning the ATFL and 31.7% after sectioning the ATFL and CFL when compared with the intact ankle. After the CFL was sectioned, AP displacement increased 13.8% and I-E rotation increased 21.5% compared with the ATFL-sectioned condition. These findings agree with other experimental studies that showed increased ankle-subtalar-joint–complex laxity after sectioning the lateral ankle ligaments.6,41,50

Holliis et al36 found significant increases in mechanical laxity after sectioning of the ATFL with both AP and I-E loading. In addition, they reported that sectioning of the CFL and the ATFL produced a large increase in I-E rotation but little change in AP displacement. Kaersgaard-Anderson et al35 found that sectioning of the ATFL increased AP laxity and sectioning of the CFL increased inversion laxity. In addition, Lapointe et al41 reported that isolated sectioning of the ATFL increased anterior flexibility by 60% and combined damage to the ATFL and CFL increased flexibility by 57% in total inversion and eversion of the ankle-subtalar-joint complex. Direct comparisons of our data using comparable force or moment loading with those in the literature are difficult because the other in vitro investigations that examined ankle-subtalar-joint–complex laxity did not use the same loads. Loading the ankle-subtalar-joint complex with 50 N of AP force and 1000 N-mm of I-E force resulted in bone-laxity values 3 to 4 times greater than those we observed.36 Despite the lower magnitude of loading used, differences in dissection of the soft tissues from the ankle down to the level of the joint capsule and ligaments likely accounted for the larger laxity values reported.

Ankle-laxity values produced with the same force and moment loads we used have been reported with the portable ankle arthrometer.35,40 In a recent study,61 mean AP displacement was 18.29 mm (±4.39 mm) for uninjured ankles. In our earlier study of uninjured ankles, mean AP displacement was 17.51 mm (±5.4 mm), compared with 13.77 mm (±3.6 mm) for the intact ankles in the present study.35 In contrast, DiSanto et al40 reported a mean AP displacement of 10.62 mm (±2.6 mm) in uninjured ankles. The relatively large standard deviations indicate sizeable variations in AP laxity among normal ankles. For I-E loading, range of motion was very similar among the studies. In the current study, we found a mean range of motion of 44.10° (±12.2°), which was only slightly less than the 46.19° (±12.2°) and 48.20° (±9.0°) range of motion reported by Kovaleski et al35 and DiSanto et al, respectively. Our current results are based on cadaveric ankles in which muscle action did not contribute to stability. In clinical practice, when partial tears or ruptures of the lateral ligaments are encountered, the muscular component of stability will also be present, at least to some extent. The in vivo laxity values, therefore, should be expected to be similar to or lower than those reported for the current study.

CONCLUSIONS

The development of a 6-degrees-of-freedom instrumented spatial kinematic linkage allows for measurement of the mechanical-laxity characteristics of the ankle-subtalar-joint complex. We used a portable ankle arthrometer to load and measure ankle-subtalar-joint laxity. Strong relationships between tibial-calcanear bone motion and arthrometric measurements of ankle-subtalar-joint–complex laxity were shown. Sectioning the anterior talofibular ligament significantly increased anteroposterior displacement, and the sequential sectioning of the calcaneofibular ligament significantly increased inversion-eversion rotation. The observed increases in mechanical laxity show that the ankle arthrometer is capable of detecting ligamentous injury. Future investigations are warranted to establish the diagnostic merit of the ankle arthrometer through testing of uninjured and ligamentously injured ankles to evaluate the sensitivity and specificity of this device to accurately predict ankle-integrity status.

REFERENCES


Peroneal Reaction Times and Eversion Motor Response in Healthy and Unstable Ankles

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Objective: To measure and compare latency, electromechanical delay, and speed of motor response of the peroneus longus muscle in a large sample of subjects with healthy or unstable ankles.

Design and Setting: Subjects with healthy or unstable ankles underwent identical test procedures consisting of 6 consecutive, sudden 50° ankle-inversion movements in the standing position with full weight on the tested leg. Latency, first and second decelerations, and total inversion time were monitored. In a separate setting, electromechanical delay was measured during a voluntary ankle eversion.

Subjects: We tested 81 subjects (27 males, 54 females) with healthy ankles or unilateral or bilateral ankle instability: 40 in ankles after inversion-sprain trauma when compared with healthy ankles. Our study does not confirm the results of the systematic literature search showing a longer latency in subjects with unstable ankles. Key Words: standing ankle inversion, electromyography, latency, accelerometry, peroneal muscles, proprioception

Evidenced-based reasoning in designing rehabilitation programs for patients with complaints of ankle instability can be documented if researchers can identify objective causes of the health problem. One plausible explanation of ankle instability is based on a low level of effective control during sudden ankle inversion. Control during sudden inversion can have active and passive components, active being the control through muscle intervention and passive being the control through resistance of soft tissue tension.

Active control can be evaluated through measurement of muscle strength or reflex speed of the muscles decelerating a possibly harmful ankle inversion. Using latency of the peroneal muscles as a measure of insufficient control can help us to recognize causes of instability. Two studies confirmed the reliability of the peroneal latency measurement during standing inversion. Latency of the peroneal muscles has been measured by a number of research teams in comparable experimental setups using sudden inversion in the standing position to document differences among subjects with healthy, sprained, and unstable ankles. A common characteristic for these studies is the invoked inversion angle of about 30°.

The published results are controversial. A number of investigators have shown significantly lower peroneal latency in ankles after inversion-sprain trauma when compared with healthy ankles, whereas other investigations did not confirm those results.

Understanding the normal control mechanisms of a sudden joint-inversion movement, based on measuring and analyzing alterations of these mechanisms in affected ankles, is a prerequisite to evaluating treatment outcome. The aims of our study were to add original data for latency measured in a 50° sudden-inversion setting and to introduce other dependent variables, such as total inversion time, first and second deceleration times, and electromechanical delay.

METHODS

Experimental Design and Subjects

The experimental part of this study was a so-called ex-post facto design in which the behavior of subjects with unstable
ankles was compared with that of subjects with healthy ankles during sudden inversion. The subjects’ age range was 15 to 29 years. Inclusion criteria for the experimental group were a history of a traumatic lateral ankle sprain followed by pain, swelling, and inability to participate in recreational or other activities for at least 3 weeks; complaints of repetitive lateral ankle sprains causing pain and swelling for at least 48 hours; and having an insecure feeling of the ankle “giving way.” The exclusion criteria for the experimental group were having had a traumatic lateral ankle sprain or surgery to the ankle in the last 3 months; a lower extremity injury preventing the subject from putting full body weight on the tested ankle; and ankle inflammation at the time of testing.

All the criteria except the last one were verified by means of a questionnaire. The last criterion was assessed by clinical examination at the time of testing.

The inclusion criterion for the control group was having no history of an ankle injury or complaints in the foot and ankle. Subjects with a lower extremity injury were excluded.

The experimental group consisted of 40 individuals (18 males, 22 females; age range, 18 to 23 years) with ankle instability based on complaints of repetitive sprains after an inversion ankle trauma. The control group consisted of 41 individuals (9 males, 32 females; age range, 15 to 29 years) with healthy ankles. In the experimental group, 48 unstable ankles were tested, while in the control group, 46 healthy ankles were tested. All the subjects signed a written informed consent approved by Vrije Universiteit, Brussels, Belgium, which also approved the study.

Testing Procedure

The subjects stood on a custom-designed inversion platform, with both feet tightly fixed on independently movable trapdoors. Each foot was strapped with hook-and-loop tape strips in a sport shoe, which was fixed to the footplate of the platform in 40° of plantar flexion and 15° of abduction (Figure 1). The subject was asked to put full body weight on the unstable ankle.

The operator, who was situated behind the subject, visually controlled if the knee of the tested leg was in extension and if the opposite knee was unloaded. That is, after the subject was instructed to put full weight on the tested leg and unload the opposite leg, the operator verified that these actions had occurred. The operator then launched a sudden inversion of 50°. The tilting of the platform occurred without warning, while the subject wore earphones and listened to music. Subjects were not allowed any external support before or during the perturbation. During the inversion, the acceleration and deceleration of the tilting trapdoor were measured with an accelerometer (model 4393, Bruel and Kjör, Naerum, Denmark) mounted on the platform. The accelerometer signal was amplified and subsequently integrated to a velocity signal using a charge amplifier (model 2635, Bruel and Kjör). The combined accelerometer and conditioning amplifier produced error values of ±3%. The change in velocity and the position in time of the falling platform are presented in 2 graphs on the computer screen (Figure 2).

During the sudden inversion, electromyographic (EMG) activity of the peroneus longus muscle was recorded using an electromyograph (model 34, Siemens-Elema-Schonander, Erlangen, Germany) and silver surface electrodes (13 mm in diameter, 1-cm center-to-center distance). The electrodes were fixed at the level of the motor point of the peroneus longus. Upper and lower cut-off frequencies were 700 Hz and 25 Hz, respectively. In order to enhance electric conductance, the skin was shaved and rubbed with alcohol before electrode fixation, and an electrolyte paste was used between the skin and electrodes. The criterion for the onset of recording of the peroneus longus muscle EMG activity during the sudden inversion was an increase in the signal more than twice the noise level (see Figure 2).

The electromechanical delay (EMD) was measured in an additional experimental set-up. This EMD can be defined as the time lapse between the onset of EMG from the peroneus longus muscle and the start of the eversion movement recorded by the accelerometer. The instant of appearance of this movement (motor response), decelerating inversion during the sudden balance disturbance, was calculated by adding the EMD (measured during voluntary contraction) to the latency of the peroneus longus muscle (measured during standing inversion). At present, the EMD can only be measured during a concentric voluntary contraction. To measure the EMD of the peroneus longus muscle, subjects were seated with the lower leg supported by a chair and the foot in a relaxed position, not touching the chair. After an auditory signal, subjects were asked to move the foot as quickly as possible from a resting position into an everted position. We recorded the voluntary peroneal
An electromechanical delay of the peroneus longus muscle during a sudden inversion was significantly different between healthy and unstable ankles. This first deceleration time was responsible for protecting the ankle very quickly after the onset of inversion. Unstable ankles showed no significant differences for the time of the second deflection point or for latency when compared with healthy ankles. Electromechanical delay during voluntary eversion was not significantly different when comparing healthy (n = 46) with unstable ankles (Table 2; only 30 of the 48 were measured). The calculated motor response (latency + EMD) between the 2 groups was not significantly different (Table 3).

**DISCUSSION**

**Systematic Literature Search**

We searched MEDLINE and Web of Science for 1980–2001 using the key words human, latency, ankle instability, peroneal muscle, and electromyography. The retrieved studies were subsequently screened based on the following inclusion criteria: standing inversion, comparison of healthy and affected ankles, and posttraumatic or unstable ankles. Studies concerning the effectiveness of therapy, reliability of EMG, external ankle support, tape, and brace were excluded. Using this procedure, we included 11 studies. In 5 of 11 comparable studies, latency of the peroneus longus muscle during a sudden inversion was significantly different.
different between healthy ankles and affected ankles, while in 6 studies, it was not\(^9\)–13 (Table 4). Latencies were significantly longer in affected ankles.

In 5 studies (marked \(\dagger\) in Table 4), posttraumatic ankles were included without specifications concerning complaints of chronic instability. No significant difference was found between healthy and posttraumatic ankles in any of these studies. After eliminating these studies and considering only those specifying “functionally unstable ankles” as the affected ankles, only one nonsignificant result remains.\(^5\) Thus, a significantly longer latency in functionally unstable ankles compared with healthy was noted in 5 of 6 studies.

### Peroneal Latency

According to Karlsson et al.,\(^15\) 10% to 20% of grade III sprained ankles develop instability. In 5 studies of normal subjects and those with posttraumatic ankles and complaints of instability, latency was not different between the groups during standing inversions of 18 to 35° (see Table 4). This could mean that muscle response, if it is affected at all, is not permanently delayed by the traumatic inversion.

Functional instability was described by Karlsson et al.\(^9\) as “the subjective complaint of a patient; this is recurrent giving way of the ankle joint, apprehension or recurrent ligament sprain.” Of the 7 sets of authors studying sudden standing inversion in subjects with functionally unstable ankles (including our study), 5 showed significant longer peroneus longus muscle latency in unstable ankles. (see Table 4.)

When investigating the possible cause of the lack of consensus among the 7 studies, differences in defining the clinical characteristics are apparent. The criteria for selection of subjects reveal differences in methods. Although not the focus of this study, the criteria used to clinically define ankle instability should be understood. The following citations from 6 studies and the study presented here involving chronically unstable ankles illustrate how the selection of unstable and control ankles differed.

- “Functional instability was considered to be present in subjects who complained of frequent sprains and or sensations of the ankle giving way. [Fifteen] had complaints of severe instability and used tape or ankle orthoses whenever participating in sports.” Controls were healthy subjects with functionally stable ankles.\(^10\)
- “Twenty individuals with unilateral ankle joint instability were tested. All these patients had a reduced activity level due to functional instability. All the patients had mechanical instability of the functionally unstable ankle, verified by standardized radiographic measurements. . . .” Controls were contralateral unaffected ankles of the subjects presenting unilateral instability.\(^9\)
- “Thirteen patients with chronic lateral instability of the ankle for at least 12 months were included.” Matched control group had no history of ankle instability.\(^11\)
- “Active individuals with a history of unilateral inversion type ankle sprain were selected (questionnaire). Each subject’s self-perception of a chronic, functionally unstable ankle, in addition to the history, was used as a means to identify suitability for inclusion into the study.” Controls were contralateral uninjured ankles of the subjects presenting unilateral instability.\(^5\)
- “Sixty-five patients with self reported ankle instability. . . detailed questionnaire was used to evaluate the patients history of instability and the frequency of inversion trauma.” Controls were contralateral stable legs of the subjects presenting unilateral ankle instability.\(^13\)
- “Subjects were categorized as having unstable ankles if they suffered from at least 1 traumatic ankle sprain that needed immobilization, with complaints of pain, swelling or stiffness lasting at least 3 weeks. The first trauma had to be followed by at least 2 ankle sprains, with complaints of pain and swelling lasting at least 2 days; or by a feeling of instability or complaints of repetitive sprains. A questionnaire (5

### Table 3. Responses in Healthy (Control) and Unstable Ankles*  

<table>
<thead>
<tr>
<th>Sample</th>
<th>n</th>
<th>Latency Mean</th>
<th>Delay Mean</th>
<th>Motor Response Mean</th>
<th>SD</th>
<th>(P(t))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>46</td>
<td>57.29</td>
<td>23.18</td>
<td>80.47</td>
<td>11.65</td>
<td>0.72</td>
</tr>
<tr>
<td>Unstable</td>
<td>30</td>
<td>57.30</td>
<td>24.20</td>
<td>81.50</td>
<td>12.70</td>
<td></td>
</tr>
</tbody>
</table>

* indicates number of subjects; motor response equals the sum of latency and electromechanical delay values (ms); SD, standard deviation; and \(P(t)\) probability of \(t\) for independent groups.

### Table 4. Latencies of the Peroneus Longus Muscle as Reported in Studies Comparing Healthy and Unstable Ankles*  

<table>
<thead>
<tr>
<th>Study</th>
<th>Inversion</th>
<th>Latency (ms) in healthy ankles</th>
<th>n</th>
<th>Latency (ms) in affected ankles</th>
<th>n</th>
<th>Difference ((P))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nawoczenski et al, 1985</td>
<td>35°</td>
<td>Left-right difference = 9.4</td>
<td>15</td>
<td>Left-right difference = 13.6(\dagger)</td>
<td>15</td>
<td>ns</td>
</tr>
<tr>
<td>Isakov et al, 1986(^c)</td>
<td>20°</td>
<td>59.4–78.8</td>
<td>11</td>
<td>58.2–81.8(\dagger)</td>
<td>11</td>
<td>ns</td>
</tr>
<tr>
<td>Konradsen and Ravn, 1990</td>
<td>30°</td>
<td>65</td>
<td>15</td>
<td>82(\ddagger)</td>
<td>15</td>
<td>.01§</td>
</tr>
<tr>
<td>Karlsson and Andréasson, 1992</td>
<td>30°</td>
<td>68.8</td>
<td>20</td>
<td>84.5(\ddagger)</td>
<td>20</td>
<td>.001§</td>
</tr>
<tr>
<td>Johnson and Johnson, 1993</td>
<td>35°</td>
<td>68.2</td>
<td>11</td>
<td>65.1(\dagger)</td>
<td>7</td>
<td>ns</td>
</tr>
<tr>
<td>Beckman and Buchanan, 1995</td>
<td>30°</td>
<td>57</td>
<td>10</td>
<td>57(\dagger)</td>
<td>10</td>
<td>ns</td>
</tr>
<tr>
<td>Löfvenberg et al, 1995(^\ddagger)</td>
<td>30°</td>
<td>49</td>
<td>15</td>
<td>65(\dagger)</td>
<td>15</td>
<td>.001§</td>
</tr>
<tr>
<td>Ebig et al, 1997(^a)</td>
<td>20°</td>
<td>65.3</td>
<td>13</td>
<td>58.6(\dagger)</td>
<td>13</td>
<td>ns</td>
</tr>
<tr>
<td>Rosenbaum et al, 2000(^\ddagger)</td>
<td>30°</td>
<td>54.4</td>
<td>35</td>
<td>60.2(\ddagger)</td>
<td>35</td>
<td>.0001§</td>
</tr>
<tr>
<td>Fernandes et al, 2000(^c)</td>
<td>15°</td>
<td>96.5</td>
<td>25</td>
<td>96.9(\dagger)</td>
<td>16</td>
<td>ns</td>
</tr>
<tr>
<td>Vaes et al, 2001(^c)</td>
<td>50°</td>
<td>47.7</td>
<td>16</td>
<td>58.9(\ddagger)</td>
<td>18</td>
<td>.017§</td>
</tr>
<tr>
<td>Vaes et al, 2002</td>
<td>50°</td>
<td>57.3</td>
<td>46</td>
<td>58.7(\dagger)</td>
<td>48</td>
<td>ns</td>
</tr>
</tbody>
</table>

\(n\) indicates number of subjects; \(P\), \(P\) value; and ns, not significant.

\(\dagger\) Unstable ankles in subjects with a history of traumatic ankle sprain.

\(\ddagger\) Unstable ankles in subjects with a history of traumatic ankle sprain and complaints of instability.

\(\ddagger\) Indicates a significant \(P\) value.
questions) was used to identify individuals with functionally unstable ankles." Controls were subjects with bilateral stable ankles and unaffected contralateral ankles of subjects presenting unilateral instability.14

Another source of the observed bias may be the fact that controls can either be individuals with healthy ankles or the unaffected, contralateral ankles of subjects with unilateral unstable ankles. Evidence is growing for a difference in proprioception—as measured through kinesthesia or joint position sense—between bilaterally stable ankles and a unilateral stable ankle.16 This leads us to the following suggestions for further research:

- Gravity of traumatic inversion sprain(s) in the history of included individuals should be stated;
- A standard questionnaire should be used to recognize reliable criteria for chronic ankle instability (ie, how many sprains must a patient experience to be recognized as having an unstable ankle?);
- Control subjects should preferably have bilateral healthy ankles;
- Standing inversion tests should be standardized: maximal inversion angle, speed of inversion, construction of platform, distance between feet, weight on the tested ankle or on both feet, unexpected launching (headphones);
- Comparability with "true sprain" remains to be questioned; when an individual sprains an ankle, the weight is not on both legs, and the individual is not standing but walking, running, or landing after a jump.

Total Inversion Time, First and Second Deceleration Times, and Electromechanical Delay

Standing with full body weight on 1 ankle and then suddenly having the support removed, provoking ankle inversion, initiates a fall that one could expect to be accelerating all the way down. The accelerometric screening of this movement, however, shows that this is not the case (see Figure 2). In all ankles, one can observe a systematic pattern of acceleration-deceleration-acceleration and deceleration before landing (ie, 2 deceleration points influencing total inversion time).

The total time between the start and the end of the trapdoor movement, or the total inversion time, informs us about the average speed of the inversion movement. Longer or shorter total inversion time indicates better or worse control of the inversion, respectively. A shorter total inversion time shows worse control of inversion because of higher inversion speed. This slower or faster inversion can be further analyzed using first and second deceleration times, based on the accelerometric graph.

Measuring first deceleration time can offer information about the strategy used by body motor control to avoid tissue damage during the first phase of the standing inversion. At this moment, inversion speed reduces. The time between the start of the inversion movement and the occurrence of the first upward deflection of the velocity curve is measured. Comparing the time of the first deceleration with the latency clarifies that this first deceleration cannot be caused by active muscle intervention.

Nevertheless, if the sum of the latency plus the EMD is shorter than the total inversion time (see Table 3), the muscles have time to contract and help protect ankle cartilage, joint capsule, and ligaments before the inversion causes tissue dam-


Kinesthesia Is Not Affected by Functional Ankle Instability Status

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Tricia J. Hubbard, MS, ATC, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Thomas W. Kaminski, PhD, ATC/R, contributed to conception and design; analysis and interpretation of the data; and drafting, critical revision, and final approval of the article.

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Objective: To determine whether subjects with functional ankle instability suffered kinesthetic deficits in the injured ankle compared with the healthy ankle and to examine the effect of prophylactic ankle bracing on kinesthesia in uninjured and functionally unstable ankles.

Design and Setting: We tested subjects over 4 consecutive days in a climate-controlled athletic training/sports medicine laboratory setting. A single-group time-series design enabled all subjects to serve as their own controls. A different braking condition was tested on each of those occasions.

Subjects: Sixteen subjects (8 men, 8 women; age = 21.6 ± 1.7 years; mass = 73.5 ± 15.0 kg; height = 172.9 ± 8.8 cm) with unilateral functional ankle instability participated in this study.

Measurements: Kinesthetic threshold-to-detection of passive motion (TTDPM) measurements were obtained during passive inversion and eversion movements (0.5°·s⁻¹) under 4 different braking or taping conditions (unbraced, Swede-O Ankle Lok, Aircast Air-Stirrup, and tape).

Results: We analyzed the data using a 3-factor analysis of variance with repeated measures on the ankle and motion factors. Threshold-to-detection of passive motion scores in the unbraced condition were significantly better than the TTDPM scores in any of the other 3 test conditions. No significant differences were seen in TTDPM scores between the 2 ankles under any of the 4 conditions.

Conclusions: Threshold-to-detection of passive motion scores did not differ in uninjured ankles and those with functional instability; however, bracing with either the Ankle Lok or Air-Stirrup decreased the ability to detect passive motion when compared with the no-tape (unbraced) condition. Further research is needed to determine the exact contributions of taping and bracing on ankle joint kinesthesia.

Key Words: proprioception, threshold to detection of passive motion, lateral ankle sprain, functional ankle dysfunction

A cute injury to the ankle-foot complex is of primary concern to the rehabilitation professional. Ankle sprains are among the most common injuries incurred by participants in running and jumping activities. Approximately 85% of these ankle sprains are due to an inversion injury involving lateral ligament damage. To help prevent possible recurrence, rehabilitation programs are designed to increase muscle strength (primarily peroneal muscle strength) and improve ankle joint proprioception. Despite meticulous rehabilitation programs and diligence on the parts of the patient and athletic trainer, functional ankle instability may persist.

The term functionally unstable ankle was first introduced by Freeman et al⁴ and has been refined to mean joint motion, lateral ankle sprain, functional ankle dysfunction, or ankle sprain, functional ankle dysfunction. Kaminski et al¹³ reported that evertor muscle weakness was not present in subjects with unilateral FAI when compared with a control group with uninjured ankles. Other researchers have also reported no deficits in eversion strength in subjects with FAI. Perhaps the role of proprioception as a cause of FAI has been scrutinized the most in the literature.³,⁴,¹² Proprioception has been defined as the ability to detect sensory stimuli such as touch, pain, pressure, and movements.¹⁴ Assessment of joint proprioception is divided into 2 components: kinesthesia and joint position sense (JPS). Kinesthesia is assessed by measuring the threshold-to-detection of passive motion (TTDPM), while JPS is assessed by measuring the reproduction of both passive and active positioning.¹⁴,¹⁵

Some authors¹⁶,¹⁷ have examined proprioception via JPS, but only a few¹²,¹⁸ have examined TTDPM. Glencross and Thornton¹⁶ studied JPS and reported significantly greater errors in the functionally unstable ankle compared with the uninjured ankle. Detection of passive movement was also stated to be significantly impaired in the functionally unstable ankle. However, Gross¹⁷ reported no differences in JPS in sub-
jects suffering from recurrent ankle sprains. More recently, Refshauge et al.\textsuperscript{18} examined TTDPM in a group of subjects with recurrent ankle sprains and reported no differences between the injured and uninjured limbs. With such disparity in results, further research is needed to assess ankle joint proprioception via kinesthesia.\textsuperscript{18}

When assessing kinesthesia in those with FAI, it would seem plausible to explore the effects of ankle bracing, given the fact that bracing is often used when athletes with FAI are returned to activity. Numerous researchers\textsuperscript{19–21} have examined ankle bracing's effect on range of motion and proprioception in healthy ankles, but a void exists in contemporary research on the potential effects of bracing on FAI. For example, JPS has been reported to be improved significantly in both taped and braced uninjured ankles.\textsuperscript{22} The question remains whether the kinesthetic component of proprioception is affected by the use of prophylactic ankle bracing and taping. If wearing prophylactic ankle braces improves kinesthesia in subjects with FAI, lateral ankle sprains could be reduced.

Our purpose was twofold: to determine whether subjects with unilateral FAI had kinesthetic deficits compared with the healthy ankle and to examine the effect of prophylactic ankle bracing on proprioception in uninjured and functionally unstable ankles. We hypothesized that a kinesthetic deficit would exist between the functionally unstable ankle and the uninjured ankle. Additionally, we also believed that prophylactic ankle bracing and taping would significantly improve kinesthesia in both ankles.

METHODS

A 2 × 2 × 4 factorial with repeated measures on 2 factors (ankle and motion) guided the study. The independent variables were condition (unbraced, prophylactic ankle tape, Swede-O Ankle Lok [Swede-O Inc, North Branch, MN], and Aircast Air-Stirrup [Aircast Inc, Summit, NJ]), ankle (FAI and uninjured), and motion (inversion and eversion). The dependent variable was TTDPM score measured in degrees.

Subjects

Sixteen subjects (8 men, 8 women; age = 21.6 ± 1.7 years; mass = 73.5 ± 15.0 kg; height = 172.9 ± 8.8 cm) with unilateral FAI from the College of Human Medicine at the University of Florida were recruited to participate. Any positive findings on an anterior drawer or talar tilt test were grounds for exclusion. A positive finding was laxity on either test when compared with the uninjured ankle. The University of Florida Institutional Review Board approved the study, and informed consent was obtained from each subject.

Instrumentation

Threshold-to-detection of passive motion was achieved using a specially built device (Figure 1) that measured passive inversion and eversion ankle movements in degrees while maintaining a constant speed of 0.5° s\textsuperscript{-1}. It was imperative that the TTDPM device move at this slow angular velocity to minimize the contribution of the musculotendinous mechanoreceptors (muscle spindles and Golgi tendon organs) in providing feedback to the central nervous system regarding limb position.\textsuperscript{14,15} The design of this instrument was closely related to the instrument previously described and validated by Lentell et al.\textsuperscript{12} The device is equipped with a reversible motor that allowed the researchers to start and then return the footplate to the original starting position (zero degrees of talocrural joint flexion). The movable footplate rotates on a single axis. With the foot resting on the footplate, movement into ankle inversion and eversion from a starting position of zero degrees can occur.

Test Procedures

Subjects who self-reported functional ankle disability were convened at a general informational meeting before the study began. The potential subjects filled out the Functional Ankle Instability Questionnaire (Table 1), which contained the criteria for FAI. Subjects had no prior knowledge of these criteria. We then carefully scrutinized the completed questionnaires. Each qualified subject was then examined by an orthopaedic surgeon to rule out mechanical instability via an anterior drawer and talar tilt test. Of the 50 subjects who satisfied the criteria, only 16 were mechanically stable and invited to participate in the study. The subject's opposite, uninjured ankle served as the control. A third party collected all information so that the tester (T.J.H.) was blinded to which ankle was impaired.

A pilot study was conducted in order for the tester to become familiar with the use of the device. Testing was conducted over 4 consecutive days. A different bracing condition was tested on each day. Subjects were instructed not to reveal which ankle was affected, so the tester remained blinded throughout data collection. We used a Latin square to determine the bracing order for each subject. The 4 bracing conditions were unbraced, prophylactic ankle tape, Swede-O Ankle Lok, and Aircast Air-Stirrup. In all conditions, the subject was barefoot. For the taped condition, we used a closed basketweave ankle-taping technique\textsuperscript{23} with 3.81-cm (1.5-in) adhesive tape. The tester collected data and performed all taping procedures, in addition to fitting and securing all ankle braces. All braces were fitted according to the manufacturer's specifications. We flipped a coin to randomize the order of testing for ankle (FAI versus uninjured) and motion (inversion versus eversion). In 7 subjects, the injured ankle was tested first.
Table 1. Criteria for Functional Ankle Instability*

Part I: Functional Ankle Instability Questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
</table>
| 1. Concerning your purported ankle instability, does this injury involve only one ankle?  
If yes, did the initial episode involve your ankle "rolling inward"?  
If no, do not continue to fill out this questionnaire. | Y | N |
| 2. Which ankle suffers the instability?                                  | R | L |
| 3. Did the initial injury to your ankle require crutches, immobilization, or both, of any form (cast, braces, etc)? | Y | N |
| 4. Have you had any fractures (breaks) in either of your ankles?          | Y | N |
| 5. Is the injured/unstable ankle functionally weaker, more painful, "looser," and less functional than your uninvolved ankle? | Y | N |
| 6. Do you ever have episodes of your ankle "giving way" or "rolling over" during daily activity (athletic or otherwise)? | Y | N |
| 7. Do you attribute your current instability to past injuries to the affected ankle? | Y | N |
| 8. Have you had an episode of injury ("your ankle was hurt," "you were in great pain") to the affected ankle within the last 3 months? | Y | N |
| 9. Have you been walking around unassisted without a "limp," for at least the past 3 months? | Y | N |
| 10. Are you currently involved in a "formal" rehabilitation program for the affected ankle?  
If you answered yes, please describe here. | Y | N |
| 11. Can you describe a symptom(s) of your ankle "giving way"?             |   |   |

Part II: Clinical Examination of Ankle Stability

<table>
<thead>
<tr>
<th>Test</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Drawer Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ankle</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Left ankle</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Talar Tilt Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ankle</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Left ankle</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Cleared for participation in the study?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Signature</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*To qualify as functional ankle instability, questions 3, 5, 6, 7, and 9 should be answered "yes." Questions 4, 8, and 10 should be answered "no," and no clinical signs of mechanical instability can be present.

while in the remaining 9 subjects, the uninjured ankle was tested first.

Each subject was instructed in the operation of the TTDPM measuring device and positioned on the device as previously described. The on-off switch was given to the subject, and he or she was instructed to turn it to the off position when any movement was first felt. To prevent the subject from trying to learn the time before the motor was started, the examiner instituted a delay from 0 to 10 seconds before turning on the device. The tester randomly selected a card that designated the delay (0 to 10 seconds) before each trial.

To eliminate auditory feedback, the subjects were blindfolded and listening to classical music through headphones while TTDPM measurements were taken (Figure 2). The subjects sat on a table with the knee and hip flexed to 90°. The foot to be tested rested on the footplate to promote a subtalar joint axis of rotation by aligning the midpoint of the heel with the interval between the first and second toe.12,24 As the device moved the tested ankle into either inversion or eversion, the subject stopped the device when movement was first felt by using the handheld on-off switch. The degrees of motion were determined based on the distance the footplate moved from the start position, using the law of sines.25 The law of sines states that the ratio between the length of any side of a triangle and the angle opposite that side is equal to the ratio between the length of any other side of the triangle and the angle opposite that side.25 We performed 3 trials on each ankle and motion, with the average TTDPM score from the 3 trials used for later analysis.

Statistical Analysis

Data were analyzed using a 2 × 2 × 4 analysis of variance with repeated measures on the ankle and motion. Statistical Package for the Social Sciences (SPSS) for Macintosh (version 6.1.1, SPSS Inc, Chicago, IL) assisted in the statistical analysis. The within-subject factors included condition (unbraced, Swede-O Ankle Lok, Aircast Air-Stirrup, and tape), ankle (FAI, uninjured), and motion (inversion, eversion). Threshold-to-detection of passive motion scores (degrees) served as the dependent measure. The Tukey Honestly Significant Difference (HSD) post hoc test was used to further examine significant differences of interest either as interactions or main effects. Level of significance was set a priori at \( P < .05 \) for all comparisons. An a priori power analysis was conducted to determine the power of the statistical design to detect significant differences of >1° error. Using our proposed sample size of 16 and an effect size of 1, the analysis resulted in a power of 0.87.

RESULTS

No significant interactions were noted among any of the variables (Table 2). This is best illustrated when the effect sizes for the differences between the functionally unstable ankle and the uninjured ankle are compared across both condition and motion. These values ranged from .01 to .43, with
Table 2. Eversion and Inversion Threshold-to-Detection of Passive Motion Scores for the Functionally Unstable and Uninjured Ankles Under Each of the Test Conditions*  

<table>
<thead>
<tr>
<th>Condition</th>
<th>Functionally Unstable Ankles</th>
<th>Uninjured Ankles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbraced Eversion</td>
<td>2.89 ± 2.56</td>
<td>2.63 ± 2.23</td>
</tr>
<tr>
<td>Inversion</td>
<td>3.39 ± 2.99</td>
<td>3.05 ± 2.66</td>
</tr>
<tr>
<td>Tape Eversion</td>
<td>3.78 ± 2.81</td>
<td>3.22 ± 2.77</td>
</tr>
<tr>
<td>Inversion</td>
<td>3.34 ± 2.79</td>
<td>3.84 ± 3.37</td>
</tr>
<tr>
<td>Swede-O Ankle Lok</td>
<td>Eversion</td>
<td>4.24 ± 4.22</td>
</tr>
<tr>
<td>Inversion</td>
<td>4.03 ± 3.72</td>
<td>3.04 ± 2.32</td>
</tr>
<tr>
<td>Aircast Air-Stirrup</td>
<td>Eversion</td>
<td>4.10 ± 3.26</td>
</tr>
<tr>
<td>Inversion</td>
<td>3.77 ± 3.69</td>
<td>3.80 ± 3.74</td>
</tr>
</tbody>
</table>

*Mean ± SD, N = 16.

DISCUSSION

Proprioceptive deficits have been suggested as a cause of functional ankle dysfunction.\(^8,10,13,18,26,27\) As a result, restoring proprioception has become an important rehabilitative consideration to the clinician. Our results suggest that kinesthesia as measured by TTDPM did not differ significantly in subjects with unilateral FAI when compared with the opposite, unaffected ankle. Several studies\(^17,18\) support our results, whereas other authors\(^12,16\) have reported different results. Refshauge et al\(^18\) noted similar findings in a study using TTDPM scores for passive plantar-flexion and dorsiflexion motions in both functionally unstable and uninjured ankles.\(^18\) Refshauge et al\(^18,28\) and Hall and McCloskey\(^29\) contended that muscle afferents surrounding the major joints in the body provide the most important proprioceptive information to the central nervous system. Therefore, joint mechanoreceptors may duplicate information provided by these other sources (muscle afferents), so a decrease in the joint mechanoreceptor discharge would not result in a noticeable proprioceptive deficit.\(^18,28,29\) Gross\(^17\) reported that JPS scores in subjects with unilateral FAI and a control group with uninjured ankles were no different. He also tested both inversion and eversion motions. However, Lentell et al\(^12\) reported that TTDPM scores were significantly different between the ankles of 39 subjects suffering from unilateral FAI and the nonimpaired ankles were able to detect the passive movement sooner than the opposite, affected ankles.

When the means for the untaped condition in our study are compared with the untaped condition in the Lentell et al\(^12\) study, they are quite similar. In addition, Lentell et al\(^12\) had high TTDPM averages (4.3° ± 3.1°) for the FAI side, similar to our reported data. Interestingly, we used a similar set of criteria for determining FAI, along with a comparable TTDPM measuring device, yet we report different results. We are also quick to note that we had far fewer subjects (16) than Lentell et al\(^12\) (39). In contrast to our study, they only tested TTDPM into inversion and did not rule out mechanical instability.\(^12\) In fact, the additional eversion TTDPM scores may have confounded our results and contributed to the lack of significant findings between conditions in the FAI and uninjured groups.

To what extent, if any, learning influenced our results is unknown. We randomly tested both inversion and eversion motions, whereas some authors have examined just one motion (ie, inversion or plantar flexion)\(^12,16,30\) and reported differences between the FAI and uninjured groups. In contrast, Gross\(^17\) and Refshauge et al\(^18\) conducted studies similar to ours and failed to find differences between the groups. It is yet to be determined whether these differences can be attributed to the
learning curve. The threat of this effect (learning curve) on the study outcomes must be addressed in future studies that involve the testing of more than 1 motion over several different conditions. We would suggest a 1- to 2-week familiarization period in which subjects have an opportunity to be tested repeatedly on the TTDPM device to alleviate the initial learning curve.

We were surprised that ankle bracing (Swede-O Ankle Lok or Aircast Air-Stirrup) decreased the subject’s ability to detect passive motion. The taped condition was not significantly different from the unbraced condition when TTDPM scores were compared. This suggests that ankle taping did not significantly influence one’s ability to detect the passive movement and had the same effect on TTDPM scores as the unbraced or untaped condition. Several sets of researchers have indicated that proprioception can be enhanced or improved by ankle taping or bracing. These studies used JPS as the measure of proprioception and several involved healthy, uninjured subjects. In a study similar to ours, Refshauge et al reported no change in proprioception from bracing with athletic tape applied to the ankle. It may be that the enhanced proprioceptive benefits of ankle taping or bracing are evident only when JPS is tested.

One of the potential limitations of our study is that we cannot be sure if our TTDPM device measured platform motion more than ankle motion. This discrepancy may explain the results of bracing decreasing kinesthesia. If the brace restricts motion at the foot, then the platform may have to move further before actual foot movement is detected. Thus, the finding may be better explained by mechanics than by sensory changes. It may have been appropriate to use a goniometer in addition to the law of sines to determine the amount of movement at the ankle. Future researchers should emphasize different measurement techniques so there is no discrepancy between the platform and ankle motion.

The unbraced ankle detected motion less than 1° before the braced ankle. This difference is statistically significant, but it may not be clinically significant. Konradsen et al discussed the significance of detecting 1° of motion. During the late swing phase of gait, the lateral edge of the foot passes close to the ground with a clearance of only 5 mm. Impact between the lateral edge of the foot and the supporting surface causes the ankle to invert, plantar flex, and internally rotate, potentially resulting in a stumble. The degree of inversion error necessary to cause an impact is approximately 8°. Further study is needed to examine exactly which TTDPM score differences are considered clinically significant and which are not.

The criteria used to define FAI vary greatly in the literature, which makes it difficult to compare studies. A consistent set of criteria for describing FAI is needed. The criteria used in the study by Lentell et al offer an excellent starting point. We built upon those criteria set forth by Lentell et al by incorporating additional responses. Furthermore, we solicited the expertise of an orthopaedic surgeon to rule out the possibility of mechanical instability. One of the potential flaws of the criteria is that they rely heavily on subjective responses. The subjective method by which FAI has been determined is questioned in reports because of the possibility of the subjects providing inaccurate information. We feel that clarification is needed as to whether recurrent ankle sprains or instances of the ankle giving way should be used as part of the criteria. The ambiguity between these criteria can potentially confound the dependent measure, because there are no data proving which of these factors contribute to FAI. We also suggest that mechanical instability be ruled out before subjects are classified as having FAI. This is important to ensure that subjects who have mechanical deficits, which may confound the functional instability, do not contaminate the subject pool. We recommend that a standard set of criteria be used in the determination of FAI status and made available for future research. This precaution should enable a more accurate assessment of FAI, more consistency across studies, and easier comparison of data pools, while lessening the variability in study designs.

CONCLUSIONS

The contribution of kinesthetic deficits to FAI remains unknown. A number of causes have been suggested, but the precise cause of FAI remains elusive. The use of prophylactic ankle bracing and taping in those with FAI may not enhance kinesthesia, as measured in this study. While other measures of ankle-joint proprioception may be improved with prophylactic ankle bracing and taping, the measures of TTDPM appear to be decreased when compared with the unbraced or untaped condition. Clinicians who have previously used ankle bracing and taping to enhance ankle-joint kinesthesia may want to reexamine whether the kinesthetic benefits are worthwhile.

REFERENCES

Proprioception and Muscle Strength in Subjects With a History of Ankle Sprains and Chronic Instability

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*Ghent University, Ghent, Belgium; †University Hospital Ghent, Ghent, Belgium; ‡Brussels University, Brussels, Belgium

Tine Willems, PT, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Erik Witvrouw, PT, PhD, contributed to conception and design; acquisition of the data; and drafting, critical revision, and final approval of the article. Jan Verstuyft, MD, contributed to acquisition of the data and critical revision and final approval of the article. Peter Vaes, PhD, PT, MT, contributed to conception and design and critical revision and final approval of the article. Dirk De Clercq, PE, PhD, contributed to conception and design; analysis and interpretation of the data; and critical revision and final approval of the article.

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Objective: To examine if patients with chronic ankle instability or a history of ankle sprains without chronic instability have worse proprioception or less inverter and evertor muscle strength.

Design and Setting: We assessed proprioception and muscle strength on the Biodex isokinetic dynamometer in the laboratory of the Department of Sports Medicine, University Hospital Ghent.

Subjects: Subjects included 87 physical education students (44 men, 43 women, age = 18.33 ± 1.25 years, mass = 66.09 ± 8.11 kg, height = 174.11 ± 8.57 cm) at the University of Ghent in Belgium. Their ankles were divided into 4 groups: a symptom-free control group, subjects with chronic ankle instability, subjects who had sustained an ankle sprain in the last 2 years without instability, and subjects who sustained an ankle sprain 3 to 5 years earlier without instability.

Measurements: Active and passive joint-position sense was assessed at the ankle, and isokinetic peak torque was determined for concentric and eccentric eversion and inversion movements at the ankle.

Results: Statistical analysis indicated significantly less accurate active position sense for the instability group compared with the control group at a position close to maximal inversion. The instability group also showed a significantly lower relative eversion muscle strength (% body weight). No significant differences were observed between the control group and the groups with past sprains without instability.

Conclusions: We suggest that the possible cause of chronic ankle instability is a combination of diminished proprioception and evertor muscle weakness. Therefore, we emphasize proprioception and strength training in the rehabilitation program for ankle instability.

Key Words: joint position sense, isokinetic strength, ankle injury, rehabilitation

Lateral ankle sprain is an extremely common athletic injury. Despite extensive clinical and basic science research, the recurrence rate remains high and the reasons why sprains tend to recur are unclear; thus, successful rehabilitation is difficult.¹ In a review of the potential causes of functional ankle instability, Hertel² cited joint position-sense deficits, muscle-strength deficits, delayed peroneal muscle-reaction time, balance deficits, altered common peroneal nerve function, and decreased dorsiflexion range of motion. However, it remains important to search for the contributory factors of chronic ankle instability (CAI), which is hypothesized to predispose individuals to reinjury after lateral ankle sprains.

Freeman et al³ proposed that ankle injury may disrupt joint afferents located in the supporting ligaments. After injury to the nervous and musculotendinous tissue, proprioceptive deficits are likely to occur and may manifest as reduced joint position sense. The ability to detect motion in the foot and to make postural adjustments in response to these detected motions is thought to be crucial in the prevention of ankle injury. Similarly, the ability of an individual to detect the position of the foot before foot contact is important. Several authors⁴⁻⁸ have suggested that inversion ankle sprains may occur due to improper positioning of the foot just before and at foot contact. Improper positioning may be due to the loss of proprioceptive input from mechanoreceptors.

Joint position sense is a component of proprioception and is often measured to assess proprioception. Studies of joint position sense in the chronically unstable ankle have demonstrated varying results.⁹⁻¹¹ Glencross and Thornton⁹ reported a decrease in active joint-position sense of the chronically unstable ankle over that of the uninjured ankle. Gross¹⁰ and Holmes et al.¹¹ however, failed to reveal any significant differences between injured and uninjured ankles in either active or passive joint-position sense.

The evertor muscles are often suggested to play an important role in preventing ligamentous injuries. The strength of the peroneus longus and brevis muscles is supposed to provide support to the lateral ligaments.⁴ Bosien et al.¹² and Staples¹³...
were the first to measure peroneal muscle strength, but they used manual methods to detect peroneal muscle weakness and found long-term evector muscle weakness after inversion sprains. Tropp14 was the first to measure muscle torque at the ankle with an isokinetic dynamometer. His results confirmed an earlier theory that peroneal muscle weakness is a component of CAI. He suggested that the muscular impairment is due to inadequate rehabilitation and secondary muscle atrophy. Baumhauer et al15 even found in a prospective study that individuals with muscle-strength imbalance exhibited a higher incidence of inversion ankle sprains. Conversely, Lentell et al16 found no significant differences in muscle strength, either isometrically or isokinetically, between the chronically unstable ankles and the uninvolved ankles, suggesting that muscular weakness is not a major contributing factor to the chronically unstable ankle.

We are not aware of any previous investigators who have examined muscle strength and joint position sense in subjects who sustained a sprain in which instability was not a factor. The most common risk factor for ankle sprains in sports is a history of a previous sprain17; therefore, we think it is important to search for proprioception or muscle-strength deficits in subjects with a history of previous sprains who do not report CAI to learn if these subjects are still at risk for sustaining sprains. Also, we would like to know if the risk for sustaining a sprain is higher for subjects who suffered sprains 1 or 2 years ago compared with subjects who had a sprain more than 2 years ago.

In addition, few researchers have examined eccentric muscle strength. Most researchers have measured isometric or concentric muscle strength in subjects with CAI, although the evector muscle must contract eccentrically to resist an ankle inversion sprain. Therefore, our purpose was to search for deficits in ankle proprioception and invertor and evector concentric and eccentric muscle strength in subjects with CAI and a history of ankle sprains.

METHODS

Subjects

Subjects included 87 physical education students (44 men, 43 women; age range, 17–26 years; mean age, 18.33 ± 1.25 years) who were freshmen in 2000–2001 at the University of Ghent, Belgium (Table 1). Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Based on these histories, we divided the ankles into 4 groups. Of the 174 ankles (both ankles of 87 subjects), 106 served as a control group (group 1). The 53 subjects (29 men, 24 women) in this control group had no prior history of injury to either ankle. The instability group (group 2) consisted of 14 chronically unstable ankles of 10 subjects (4 men, 6 women) who had a history of more than 3 inversion sprains of the same ankle, frequent giving-way episodes, and some complaints of pain during heavy and intense loading. Four subjects in this instability group complained of bilateral CAI. No subjects in the instability group had suffered severe injury to the unstable ankle for at least 3 months before testing. Group 3 consisted of 20 ankles of 16 subjects (8 men, 8 women) who had sustained 1 to 3 inversion sprains in the previous 2 years but did not complain of instability or other symptoms. Four persons in this group had inversion sprains of both ankles in the same period. Group 4 consisted of 8 ankles in 8 subjects (3 men, 5 women) who had sustained 1 to 3 inversion sprains 3 to 5 years before testing and did not complain of instability or other symptoms. Mechanical instability of the subjects’ ankles was not measured. Each volunteer signed an informal consent. The study was approved by the Ethical Committee of Ghent University Hospital.

Table 1. Subject Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control Group</th>
<th>Instability Group</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 53)</td>
<td>(n = 10)</td>
<td>(n = 16)</td>
<td>(n = 8)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>18.3 ± 1.2</td>
<td>18.3 ± 1.1</td>
<td>18.1 ± 0.2</td>
<td>19.4 ± 2.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.9 ± 9.0</td>
<td>173.5 ± 8.4</td>
<td>173.9 ± 7.5</td>
<td>170.2 ± 8.3</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>66.1 ± 7.7</td>
<td>65.7 ± 11.2</td>
<td>67.0 ± 6.6</td>
<td>64.9 ± 10.1</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Mean ± SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.

Figure 1. Positioning of the subject for testing active and passive joint-position sense on the Biodex 2 isokinetic dynamometer.

Figure 1. Positioning of the subject for testing active and passive joint-position sense on the Biodex 2 isokinetic dynamometer.

INSTRUMENTATION AND PROTOCOL

Proprioception

Active and passive joint position sense was assessed using the Biodex 2 isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY) (Figure 1). Each subject was positioned supine on the associated chair, with the calf of the tested leg resting on a 40-cm-high platform. The bare foot of the subject was aligned with the axis of the dynamometer and attached to the footplate by a very small wrap to reduce cutaneous receptor input. The talocrural joint was in 15° of plantar flexion. The lower leg was secured to the platform by hook-and-loop systems Inc, Shirley, NY) (Figure 1). Each subject was positioned supine on the associated chair, with the calf of the tested leg resting on a 40-cm-high platform. The bare foot of the subject was aligned with the axis of the dynamometer and attached to the footplate by a very small wrap to reduce cutaneous receptor input. The talocrural joint was in 15° of plantar flexion. The lower leg was secured to the platform by hook-and-loop
throughout the examination.

For passive testing, the subject’s foot was first passively moved by the investigator to maximal eversion. The investigator then moved the foot to 1 of the 2 test positions, randomly determined. The test position was maintained for 10 seconds, with each subject instructed to concentrate on the position of the foot. The foot was then passively brought to maximal eversion and moved passively back toward inversion with a speed of 5° s⁻¹. The subject was instructed to push on a stop button when he or she thought the test position had been reached. The subject was tested twice at each of the 2 test positions. The active test was performed in the same manner, except after having the foot passively placed in the test position and moved to maximal eversion, the subject was asked to move the foot actively back to the test position. The subject was again asked to push on the stop button when he or she thought the test position was reached. The testing order, test positions, and side of body tested were randomly chosen. The amount of error in degrees was noted for further analysis.

We examined 3 types of errors in the subjects’ ability to match the reference angles: the absolute, exact, and variable error. Average scores of the 2 trials were used for analysis. The absolute error is the difference in absolute value in degrees between the position chosen by the subject and the test-position angle. The exact error, calculated as the difference between the chosen position and the test-position angle, provides an indication of whether the subjects tended to, on average, systematically overshoot (positive exact error) or undershoot (negative exact error) the test-position angle. The variable error, which was calculated as the standard deviation of the exact error, provides an indication of the random error in matching the test-position angle.

**Muscle Strength**

We used a Biodex System 3 Dynamometer and Biodex Advantage Software Package (Biodex Medical Systems Inc, Shirley, NY) to determine isokinetic peak torque and peak torque/body-weight values for reciprocal concentric and eccentric inversion/eversion movements of the ankle (Figure 2). Subjects were tested in a semirecumbent position with 30° of seat-back tilt. The ankle was in 10° of plantar flexion. The knee of the tested ankle was in extension to minimize substitution from the hamstrings and other tibial rotators. Dynamometer and chair adjustments were made to align the midline of the foot with the midline of the patella. Two straps were wrapped around the extremity proximal to the patella and the pelvis to minimize movements of the hip and knee during testing. Subjects wore their own athletic shoes during testing; each shoe was tightly secured with 2 straps to the dynamometer footplate to minimize movement between the shoe sole and the footplate surface. The tested range of motion was maximal active inversion and eversion minus 5° for both directions. The first test consisted of 3 maximal repetitions of concentric-eccentric inversion at 30° s⁻¹ to assess the strength of the invertor muscles. The second test for the same ankle consisted of 5 repetitions of concentric-eccentric eversion at 120° s⁻¹. The same 2 tests (concentric-eccentric at 30° s⁻¹ and 120° s⁻¹) were performed for inversion to assess the strength of the inversion muscles. The same 4 tests were then performed with the contralateral limb. The first tested ankle was randomly chosen.

**Figure 2.** Positioning of the subject for testing isokinetic ankle inversion/eversion on the Biodex 3 isokinetic dynamometer.

Before data collection, each subject was given an opportunity to become familiar with the testing procedure and to perform 3 warm-up repetitions. Consistent verbal encouragement for maximal effort was given to each subject throughout the testing procedure. None of the subjects felt any discomfort while testing.

Peak torque and peak torque/body-weight values were obtained for each ankle motion (concentric and eccentric) of each limb at the 2 speeds. Eversion-to-inversion strength ratios and eccentric-to-concentric strength ratios were calculated.

**Statistical Analysis**

Statistical Package for the Social Sciences (SPSS) for Windows (version 10.0, SPSS Inc, Chicago, IL) was used for statistical analysis. The exact, absolute, and variable data from the proprioception test were examined with a nonparametric Kruskal-Wallis test to determine significant differences among the 4 groups. Peak torque, peak torque/body-weight values, and eversion-to-inversion and eccentric-to-concentric strength ratios were also analyzed for between-group differences. Post hoc comparisons of means were accomplished with Mann-Whitney U tests and corrected with the Bonferroni correction. Additionally, a Pearson correlation analysis was performed between peak torque and body weight. A significance level of $P < .05$ was used throughout the data analysis.

**RESULTS**

**Proprioception**

For the absolute error, we found no significant differences among the 4 groups for either active or passive joint-position sense (Table 2). For the exact error, a significant difference was noted for the active joint-position sense in the test position of maximal inversion minus 5° ($P = .012$) (Table 3). The instability group showed a significantly lower value for active joint-position sense at maximal inversion minus 5° compared with the control group ($P = .042$), group 3 ($P = .012$), and group 4 ($P = .036$). No significant differences were observed for the variable error among the 4 groups.
20 These techniques do not isolate variations in perfor­
tation during the original trauma. 1 Many methods have been
recur is due to a proprioceptive deficit caused by deafferen-
stance on a wobble board, 19 and standing with eyes open or
between inversion and eversion peak torque and body weight

**Table 2. Absolute Error on the Proprioception Test***

<table>
<thead>
<tr>
<th>Variables</th>
<th>Control Group</th>
<th>Instability Group</th>
<th>Group 3</th>
<th>Group 4</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active joint-position sense</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal active inversion minus 5°</td>
<td>3.06 ± 2.05</td>
<td>3.89 ± 2.07</td>
<td>2.40 ± 1.61</td>
<td>2.50 ± 1.95</td>
<td>161</td>
</tr>
<tr>
<td>15° of Inversion</td>
<td>3.86 ± 3.06</td>
<td>4.25 ± 2.96</td>
<td>3.90 ± 2.59</td>
<td>4.50 ± 3.34</td>
<td>826</td>
</tr>
<tr>
<td>Passive joint-position sense</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal active inversion minus 5°</td>
<td>6.49 ± 5.52</td>
<td>6.64 ± 5.97</td>
<td>7.05 ± 4.31</td>
<td>5.19 ± 3.20</td>
<td>784</td>
</tr>
<tr>
<td>15° of Inversion</td>
<td>7.90 ± 4.88</td>
<td>7.68 ± 3.95</td>
<td>9.02 ± 3.73</td>
<td>8.50 ± 4.80</td>
<td>572</td>
</tr>
</tbody>
</table>

*Values are mean degrees ± SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.

**Table 3. Exact Error on the Proprioception Test***

<table>
<thead>
<tr>
<th>Variables</th>
<th>Control Group</th>
<th>Instability Group</th>
<th>Group 3</th>
<th>Group 4</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active joint-position sense</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal active inversion minus 5°</td>
<td>-0.68 ± 3.21</td>
<td>-2.96 ± 2.96</td>
<td>0.10 ± 2.47</td>
<td>0.62 ± 2.79</td>
<td>12</td>
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<tr>
<td>15° of Inversion</td>
<td>-1.58 ± 3.64</td>
<td>-3.25 ± 3.18</td>
<td>-1.65 ± 4.21</td>
<td>-2.37 ± 4.90</td>
<td>18</td>
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<tr>
<td>Passive joint-position sense</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal active inversion minus 5°</td>
<td>-5.83 ± 5.93</td>
<td>-5.93 ± 6.68</td>
<td>-6.50 ± 4.67</td>
<td>-4.56 ± 3.63</td>
<td>889</td>
</tr>
<tr>
<td>15° of Inversion</td>
<td>-7.27 ± 5.58</td>
<td>-7.18 ± 4.64</td>
<td>-7.97 ± 5.18</td>
<td>-7.87 ± 5.39</td>
<td>857</td>
</tr>
</tbody>
</table>

*Values are mean degrees ± SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.

**Muscle Strength**

We found significant differences in the strength of the eversion muscles compared with body weight at both speeds (30°·s⁻¹ and 120°·s⁻¹) for concentric and eccentric test conditions (Table 4). The instability group had a significantly lower value compared with the control group for eversion strength/body weight at 30°·s⁻¹ for both concentric (P = .048) and eccentric (P = .024) test conditions and at 120°·s⁻¹ for the eccentric condition (P = .024). The instability group also had a significantly lower value compared with group 3 for eversion strength/body weight at 120°·s⁻¹ (P = .024) and with group 4 for eversion strength/body weight at 30°·s⁻¹ (P = .018), both for the eccentric condition. There were no significant differences for strength/body weight between the control group and the other 2 groups that sustained ankle sprains in the past without instability as complaint. No significant differences were observed among the 4 groups for eccentric and concentric strength ratio (P > .05). We noted a significant association between inversion and eversion peak torque and body weight (P < .001, -.47 < r > -.60) for the concentric and eccentric conditions and for both speeds.

**DISCUSSION**

**Proprioception**

It is widely believed that the tendency for ankle sprains to recur is due to a proprioceptive deficit caused by deafferentation during the original trauma. 1 Many methods have been devised to assess ankle proprioception, such as quantification of postural sway in standing using instant single-leg stance, 18 stance on a wobble board, 19 and standing with eyes open or closed. 20 These techniques do not isolate variations in performance to the ankle region and may involve other factors such as visual and vestibular cues, neuromuscular control, and the influence of other joints 21; however, these techniques have the advantage of testing in the weight-bearing position. 21 Although visual and vestibular inputs contribute to proprioception, the peripheral mechanoreceptors are most important from a clinical orthopaedic perspective. These peripheral mechanoreceptors include cutaneous, muscle, and joint types. The neural input provided by these mechanoreceptors and the visual and vestibular receptors are all integrated by the central nervous system to generate a motor response. These motor responses generally may be categorized within 3 levels of motor control: spinal reflexes, brain stem activity, and cognitive programming. Quantifying the reproduction of joint position (either active or passive) and the detection of changes in joint position is processed at the highest level of organization: the somatosensory cortex. These methods can objectively isolate the measurement of joint position at the ankle, although in a non-weight-bearing position. Our study involved a protocol simulating positions associated with the most common mechanism of injury for the ankle joint: inversion and plantar flexion.

Our results show 2 ways to interpret proprioceptive data: the absolute and exact error. Most previous investigators of joint position sense have examined only absolute errors. 9-11,21 These studies lack a distinct measure of whether subjects were systematically biased to overestimate or underestimate the reference angle. In our study, the exact error was usually negative; thus, our subjects were mostly biased to undershoot the test-position angle. These data do not support the findings of Feuerbach et al, 22 who found that exact error was not significantly different from zero for subjects without injuries. Measuring proprioception in different planes could cause these conflicting results. In this study, proprioception was measured in 1 plane (inversion-eversion). Subjects studied by Feuerbach et al 22 were required to match test positions in 3 planes.

We demonstrated significant differences among the 4 groups for the absolute error; however, we found a difference between
Glencross and Thornton reported postinjury deficits in judgment of active joint-position sense in the planar flexion-dorsiflexion plane. Boyle and Negus found significantly less accurate judgment of active and passive joint-position sense in subjects with recurrent ankle sprains compared with uninjured subjects. Hartsell also showed those with chronically unstable ankles to have poorer active joint-position sense awareness than did those with healthy ankles at a test position of 15° inversion.

Our results for the exact error indicated that subjects with instability had a significantly less accurate active joint-position sense awareness than did those with healthy ankles at a test position of 15° inversion.

Interestingly, we found no significant differences between the control group and the 2 groups of subjects who had sus-

Table 4. Muscle Strength

<table>
<thead>
<tr>
<th>Variables</th>
<th>Control Group</th>
<th>Instability Group</th>
<th>Group 3</th>
<th>Group 4</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eversion (Nm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30°·s⁻¹ Concentric</td>
<td>27.09 ± .99</td>
<td>21.44 ± 2.13</td>
<td>26.48 ± 2.12</td>
<td>30.80 ± 4.97</td>
<td>.207</td>
</tr>
<tr>
<td>30°·s⁻¹ Eccentric</td>
<td>29.02 ± .86</td>
<td>25.23 ± 2.09</td>
<td>28.09 ± 1.83</td>
<td>31.07 ± 3.82</td>
<td>.475</td>
</tr>
<tr>
<td>120°·s⁻¹ Concentric</td>
<td>24.86 ± .78</td>
<td>21.87 ± 1.93</td>
<td>25.53 ± 1.40</td>
<td>27.70 ± 3.63</td>
<td>.405</td>
</tr>
<tr>
<td>120°·s⁻¹ Eccentric</td>
<td>30.60 ± .87</td>
<td>26.57 ± 2.30</td>
<td>31.48 ± 1.39</td>
<td>30.27 ± 3.65</td>
<td>.445</td>
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<tr>
<td>Inversion (Nm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30°·s⁻¹ Concentric</td>
<td>28.49 ± .92</td>
<td>29.80 ± 2.89</td>
<td>29.46 ± 2.16</td>
<td>29.16 ± 3.24</td>
<td>.916</td>
</tr>
<tr>
<td>30°·s⁻¹ Eccentric</td>
<td>28.97 ± .75</td>
<td>29.66 ± 1.87</td>
<td>29.79 ± 1.48</td>
<td>29.81 ± 2.84</td>
<td>.939</td>
</tr>
<tr>
<td>120°·s⁻¹ Concentric</td>
<td>25.30 ± .66</td>
<td>24.57 ± 1.69</td>
<td>27.21 ± 1.63</td>
<td>25.54 ± 3.22</td>
<td>.709</td>
</tr>
<tr>
<td>120°·s⁻¹ Eccentric</td>
<td>30.43 ± .73</td>
<td>30.22 ± 1.96</td>
<td>30.93 ± 1.51</td>
<td>29.54 ± 2.36</td>
<td>.964</td>
</tr>
<tr>
<td>Eversion (Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>30°·s⁻¹ Concentric/body weight</td>
<td>0.41 ± .01</td>
<td>0.31 ± .02</td>
<td>0.38 ± .02</td>
<td>0.48 ± .05</td>
<td>.015††</td>
</tr>
<tr>
<td>30°·s⁻¹ Eccentric/body weight</td>
<td>0.44 ± .01</td>
<td>0.35 ± .02</td>
<td>0.40 ± .02</td>
<td>0.50 ± .04</td>
<td>.006††</td>
</tr>
<tr>
<td>120°·s⁻¹ Concentric/body weight</td>
<td>0.38 ± .01</td>
<td>0.30 ± .02</td>
<td>0.36 ± .01</td>
<td>0.45 ± .05</td>
<td>.040††</td>
</tr>
<tr>
<td>120°·s⁻¹ Eccentric/body weight</td>
<td>0.46 ± .01</td>
<td>0.36 ± .02</td>
<td>0.44 ± .01</td>
<td>0.47 ± .04</td>
<td>.021††</td>
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<tr>
<td>Inversion (Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30°·s⁻¹ Concentric/body weight</td>
<td>0.43 ± .01</td>
<td>0.42 ± .31</td>
<td>0.43 ± .30</td>
<td>0.46 ± .03</td>
<td>.880</td>
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<tr>
<td>30°·s⁻¹ Eccentric/body weight</td>
<td>0.44 ± .01</td>
<td>0.42 ± .02</td>
<td>0.43 ± .02</td>
<td>0.46 ± .04</td>
<td>.728</td>
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<tr>
<td>120°·s⁻¹ Concentric/body weight</td>
<td>0.38 ± .01</td>
<td>0.35 ± .02</td>
<td>0.39 ± .02</td>
<td>0.40 ± .03</td>
<td>.433</td>
</tr>
<tr>
<td>120°·s⁻¹ Eccentric/body weight</td>
<td>0.46 ± .01</td>
<td>0.40 ± .04</td>
<td>0.45 ± .02</td>
<td>0.46 ± .03</td>
<td>.368</td>
</tr>
</tbody>
</table>

*Mean ± SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.
†Significant difference among the 4 groups (P < .05).
‡Significant difference between the instability group and the control group (P = .048).
§Significant difference between the instability group and the control group (P = .024) and between the instability group and the group with sprains 3-5 years earlier (P = .019).
¶No significant differences among the groups after the Bonferroni correction was applied.
\[Significant difference between the instability group and the control group (P = .024) and between the instability group and the group with sprains 1–2 years earlier (P = .024).
tained ankle sprains in the past. We demonstrated significant differences between the ankles that had previously sustained an inversion sprain not associated with instability and the chronically unstable ankles. Therefore, past ankle sprains without resultant instability did not affect an individual’s ability to judge ankle position.

Because subjects with past sprains without instability had normal proprioception, the proprioceptive deficit may be the reason ankle sprains recur in patients with CAI. One of the main goals in the treatment of lateral ankle injuries should be the prevention of CAI.

Joint position sense is affected in subjects with CAI, and taping or bracing may counterbalance this deficit. Previous studies have already shown that taping and bracing reduce the error in joint position sense.22,24 Feuerbach et al22 suggested that application of an orthosis may increase the afferent feedback from cutaneous receptors, which may lead to improved ankle joint-position sense. This increased stimulation could result in a more appropriate positioning of the unstable ankle and may protect it from reinjury.

**Muscle Strength**

Many investigators have found a relationship between peroneal muscle weakness and chronically unstable ankles.12,14,23 Others have found significant invertor weakness in the chronically unstable ankles.19,23 Ryan19 suggested that the invertor weakness could be the result of interruption of the muscles’ nerve supply or the result of selective inhibition of the invertors’ ability to start moving in the direction of initial injury. However, we found no relationship between invertor muscle strength and ankle sprains, although we did find a significant difference for evertor muscle strength (peak torque/body weight) between subjects with CAI and the control group. Subjects with CAI seemed to have less concentric and eccentric evertor muscle strength than normal subjects.

Previous investigators have tested evertor and invertor muscle strength at different speeds. We chose to use 30°·s⁻¹ and 120°·s⁻¹ to measure muscle peak torque because slower speeds, identified in the literature as those between 30°·s⁻¹ and 120°·s⁻¹, define strength, while the faster speeds, identified in the literature as those between 120°·s⁻¹ and 300°·s⁻¹, define muscle power.25 Otherwise, high-velocity eccentric contractions are not without risk and are very hard to perform.

Most researchers report only mean peak-torque values rather than values normalized by body weight. We find the peak torque for both muscle groups at both speeds to be significantly related to body weight. Normalizing by body weight is, thus, an important consideration for better comparison among subjects of varied body types. Additionally, as inversion sprains most often occur in the closed kinetic chain, body weight also has an influence on the inversion moment generated at the ankle. Therefore, we consider peak torque/body weight a more relevant value compared with peak torque. In addition, the functional assessment of muscular stabilization must consider the fact that the evertor muscles contract eccentrically to resist an inversion trust.16 Nevertheless, isokinetic assessment of ankle muscles has traditionally been tested by concentric contractions only. Hartsell and Spaulding23 were the first to retrospectively test the strength of the invertor and evertor muscles eccentrically in subjects with healthy and chronically unstable ankles. Chronically unstable ankles were significantly weaker concentrically and eccentrically for both inversion and eversion. Although we did not find significant differences among the groups for inversion muscle strength, we did find the unstable ankles weaker concentrically and eccentrically for eversion strength/body weight at both speeds.

Hartsell and Spaulding23 calculated eccentric/concentric ratios at several velocities (60, 120, 180, and 240°·s⁻¹). Their hypothesis was that the eccentric/concentric ratios would be significantly different for subjects with CAI because abnormalities in the ratio may imply abnormality or predispose to injury.26–28 Bennett and Stauber28 tested patients with knee problems who showed a deficiency in eccentric activity. They found a particularly low eccentric/concentric ratio and proposed that this was a potential cause of patellofemoral problems. The problem was proposed to be related to an error in the neuromotor control of the quadriceps muscle, although another feasible explanation may be selective inhibition of eccentric performance of the quadriceps as the result of pain. Although Hartsell and Spaulding23 tested subjects with healthy and chronically unstable ankles over a velocity continuum, they were not able to identify an eccentric/concentric ratio pattern suggestive of instability. Our results affirm these findings of no significant differences for the eccentric/concentric ratio between subjects with healthy ankles and those with unstable ankles or ankles with past inversion sprains. Perhaps the invertor and evertor muscles produce too little torque in relation to the quadriceps muscles to display differences in the eccentric/concentric ratios.

In a prospective study of ankle-injury risk factors, Baumbauer et al15 found that individuals with muscle-strength imbalance, as measured by an elevated inversion-to-inversion ratio, exhibited a higher incidence of inversion ankle sprains. We examined this factor retrospectively in uninjured subjects and subjects with instability or past sprains and noted no significant differences among the groups.

As in the proprioception test, none of the variables tested showed significant differences between the control group and the 2 groups of subjects who had previously sustained ankle sprains without instability. Interestingly, some eversion-strength factors showed significantly higher values for the groups with past sprains compared with the instability group. This could mean that a deficit in muscle strength is one cause of instability; however, it is difficult to say whether these findings are the cause or the effect of the instability. Probably the 2 tested components, proprioception and muscle strength, both play a role in ankle instability. We suggest that neuromuscular disorders such as proprioceptive deficits and muscle weakness may cause persistent instability of the ankle. We also think that subjects who sustain an inversion sprain without associated CAI are at less risk to reinjure their ankles than subjects with CAI because they have greater muscle strength and more accurate joint position sense.

**CONCLUSIONS**

Chronic instability was significantly related to active joint-position sense in the ankle at angles near maximal inversion. Ankle instability and evertor muscle weakness coexist; however, we found no evidence for a lack of muscle strength or proprioceptive deficit in subjects who had sustained sprains in the past without instability as a complaint.

We suggest that a possible cause of recurrent sprains in the instability group is the combined action of diminished proprioception and evertor muscle weakness. If the ankle is inverted...
at the moment the foot touches the ground, due to the diminished proprioception, the result could be a varus thrust from an inversion lever through the subtalar axis. If the evertor muscles are not strong enough to counteract this motion, the tensile strength of the lateral ligaments may be exceeded, resulting in injury.

Our results affirm the importance of proprioception training and strength training of the peroneal muscles in the rehabilitation of ankle injuries. These exercises may effectively stabilize an unstable ankle and break the vicious cycle of recurrent sprains and subsequent loss of proprioception and muscle atrophy.

ACKNOWLEDGMENTS

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REFERENCES

An Examination of the Stretch-Shortening Cycle of the Dorsiflexors and Evertors in Uninjured and Functionally Unstable Ankles

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Objective: To determine if there were differences in concentric peak torque/body-weight (PT/BW) ratios and concentric time to peak torque (TPT) of the dorsiflexors and evertors in uninjured and functionally unstable ankles using a stretch-shortening cycle (SSC) protocol on an isokinetic dynamometer.

Design and Setting: We employed a case-control study design to examine the test subjects in a climate-controlled athletic training/sports medicine research laboratory.

Subjects: Thirty subjects volunteered to participate in this study, 15 with unilateral functional ankle instability and 15 matched controls.

Measurements: Participants were assessed isokinetically using an SSC protocol for the dorsiflexors and evertors at 120 and 240°·s⁻¹, bilaterally. Strength was assessed using PT values normalized for body mass. Concentric TPT measurements were also compared between the groups.

Results: No differences in concentric PT/BW ratios or concentric TPT were evident between the groups (P > .05). Additionally, there were no differences in these measurements between the ankles for the same motion and speed between the ankles in the subjects with functional instability.

Conclusions: Using the SSC protocol as a measure of ankle function and the stretch-reflex phenomenon, we found no evidence to support the notion that differences in strength and TPT in the active, conscious state exist between those with functional ankle instability and a group of healthy control subjects.

Key Words: stretch reflex, peak torque, time to peak torque, isokinetics, plyometrics, chronic ankle dysfunction

Interest in ankle instability research has grown in the past few years. Previous researchers have examined several factors purported to be involved in this entity.¹⁻⁵ Most recently, neuromuscular factors related to ankle instability have been evaluated.⁶⁻¹⁰ The biomechanics of the ankle function to transfer forces accepted during locomotion and produce a propulsive impetus to maintain movement. In response to these continual demands placed on the ankle during activity, ankle overload may occur, causing injury. Once an athlete experiences an initial traumatic event, he or she may continue to describe feelings of “giving way” or instability long after pain and inflammation have disappeared. This syndrome of continued dysfunction is termed functional ankle instability (FAI).¹¹⁻¹⁴ Ankle joint stability is provided by both static and dynamic mechanisms. Dynamic joint stability relies heavily on a properly functioning neuromuscular communication network. Disruption in the pathway may predispose the ankle to further injury and future instability.

Freeman et al¹¹ suggested that a loss of neuromuscular control was responsible for the giving way associated with FAI. Kaikkonen et al¹³ indicated that ankle proprioception is often disrupted after an ankle-ligament injury, resulting in impaired peripheral sensation. Having adequate peripheral feedback is important for the maintenance of static and dynamic postural stability of the body. Meanwhile, partial deafferentation of joint afferent receptors is believed to alter the muscles' ability to provide joint stability via antagonist cocontraction and synergistic muscle activation.¹⁵ Baumhauer et al⁴ prospectively investigated risk factors associated with susceptibility to lateral ankle sprain. Generalized joint laxity, anatomical measurements of the foot and ankle, anatomical alignment, and ankle-ligament stability were not found to be significant risk factors leading to ankle injury. However, evertor-to-invertor and plantar flexor-to-dorsiflexor strength ratios were elevated in the experimental group, indicating that altered antagonist strength relationships may be responsible for the long-term disability. Thus, neuromuscular control and force production are important to maintaining adequate joint stabilization. A number of studies have been conducted to examine strength and its re-
relationship to FAI. No significant differences were noted in concentric, eccentric, or isometric ankle strength between subjects with FAI and those with healthy ankles. Bernier et al. found no differences in eversion or inversion eccentric strength between participants with FAI and the uninjured group. However, they did show a strong inverse relationship between the degree of mechanical instability and invertor eccentric peak torque \( r = -0.71 \). There is a belief that disrupted muscle-reaction time and amplitude to high-speed inversion may be more closely related to factors other than strength.

With growing evidence that differences in concentric, eccentric, and isometric strength, measured independently, may not be predisposing risk factors for those with unstable ankles, the problem may lie in a delayed reaction of the peroneal muscles to imposed stretch forces. Several groups have demonstrated the detrimental effect of either acute or chronic joint injury on reflex joint stabilization. These studies re-created the mechanism of the inversion ankle sprain using a trap-door stimulus. Latencies to ankle muscle response were measured via electromyographic analysis. The researchers concluded that stretch reflexes were slower to respond during sudden, unexpected passive inversion in subjects with FAI as compared with their uninjured counterparts.

The stretch-shortening cycle (SSC) has been studied extensively using muscles of the calf and thigh regions. Helgeson and Cadjosik suggested that measuring the SSC with an isokinetic dynamometer in isolated muscle groups could provide a better indication of how each muscle group performs during functional activities. Functional activities such as walking, running, and jumping are examples of the SSC, in which a continuous series of eccentric and concentric muscle actions occur.

The phases of the SSC include eccentric, amortization, and concentric intervals. The amortization phase is the transition between eccentric and concentric actions, during which time the muscle must switch from overcoming work to acceleration in the opposite direction. The amortization phase may be affected by the electromechanical delay, which is defined as the interval between initiation of sudden joint displacement and the generation of sufficient muscle tension to effectively resist the displacement moment. In individuals prone to ankle sprain, the SSC of the ankle dorsiflexors and evertors is of primary importance. The electromechanical delay between mechanoreceptor activation and generation of adequate resistive muscle tension probably plays an important role in susceptibility to lateral ankle sprain. Perhaps the more quickly the individual can switch from yielding eccentric work to overcoming concentric work, the more powerful the response to the inversion and plantar-flexion motions will be. This is especially important given the fact that most lateral ankle sprains occur via this mechanism. It has been previously reported that the concentric contraction within the SSC may be 100% more powerful than an isolated concentric contraction in uninjured individuals when tested isokinetically. The researchers’ reasons for this improvement in power, although there may be additional explanations, are the elastic recoil of the eccentrically stretched muscles and the stretch reflex. However, there is logical and strong debate concerning the significance of the contribution of the elastic recoil in the SSC. The stretch reflex recruits additional motor units, creating a more powerful concentric contraction. When the amortization phase is long, the elastic energy is lost as heat, and the stretch reflex fails to activate. In effect, the concentric contraction is less powerful. Whether or not the same holds true in an injured population, especially those with FAI, remains to be seen.

Therefore, our purpose was to determine if there were differences in dorsiflexor and evertor concentric force in subjects with uninjured and functionally unstable ankles executing an isokinetic SSC protocol. Concentric peak torque/body weight (PT/BW) and concentric time to peak torque (TPT) were employed as indicators of power. We hypothesized that concentric PT/BW would be less and concentric TPT would be slower in those with unilateral FAI compared with uninjured controls. A secondary purpose of this study was to compare those same values in the involved and uninjured ankles in subjects with FAI.

METHODS

Subjects

Fifteen subjects (age = 22.1 ± 3.7 years, height = 170.3 ± 8.5 cm, mass = 73.6 ± 12.0 kg) experienced unilateral FAI with no evidence of mechanical instability. Mechanical instability was assessed via anterior drawer and talar tilt tests performed by a certified athletic trainer. The FAI subjects satisfied the criteria previously established by Hubbard and Kaminski. The control group (CON) subjects (age = 21.7 ± 3.1 years, height = 169.5 ± 7.6 cm, mass = 72.4 ± 11.8 kg) were paired with the FAI subjects. The control group’s ankles had no history of injury, no functional or mechanical instability (as assessed via anterior drawer and talar tilt tests), and no other conditions affecting the ankle. Satisfaction of the inclusionary and exclusionary requirements was determined by questionnaire and initial assessment by the principal investigator (G.K.P.). Subjects were matched by height, weight, sex, activity level, and skill foot. Each group consisted of 6 men and 9 women. The skill foot was determined by asking the subjects which foot they would use to kick a ball. All 30 subjects were found to have a right skill foot. Informed consent was provided by all subjects. The study was approved by the University of Florida Institutional Review Board.

Instrumentation

The Kinetic Communicator (Kin Com) 125 AP (Chattanooga Group, Chattanooga, TN) isokinetic dynamometer, integrated with a computer and appropriate software, was used to assess both TPT and PT. The reliability of this device in the testing of ankle strength has been previously established. An SSC (eccentric action preceding a concentric contraction without delay) protocol was developed for the ankle dorsiflexors and evertors. The Kin Com footplate was programmed to move continuously with medium acceleration and deceleration, and the dynamometer was set to gather data in a continuous mode. We calibrated the dynamometer before each testing session.

PROCEDURES

Familiarization Session

A 5-minute warm-up consisting of moderate-intensity stationary bicycling at 90 revolutions per minute preceded the isokinetic activity. Subjects were also allowed to perform a series of lower extremity flexibility exercises. After warm-up and stretching, the participants were acquainted with the test-
ing protocol. All subjects practiced the movements of the isokinetic test protocol at a submaximal effort at least 5 days before their scheduled test date. Because of the complexity and uniqueness of the testing protocol, subjects were able to practice until they felt comfortable with the SSC movements and the isokinetic dynamometer.

Testing

An experienced researcher (T.W.K.), who was blinded to the ankle status of the test subjects, performed all isokinetic tests. All testing occurred in the quiet, climate-controlled environment of the Athletic Training/Sports Medicine Research Laboratory. A warm-up and stretch identical to that used during the familiarization session was completed before all testing. Ankle eversion and dorsiflexion strength were tested with subjects seated on the chair of the dynamometer. A knee-flexion angle of 45° was maintained during the dorsiflexion testing, while a plantar-flexion angle of 10° was sustained during the eversion tests. Participants were stabilized in the chair according to the manufacturer's guidelines, with straps securing the chest and the waist. The isokinetic dynamometer was moved to the appropriate position for strength testing using the automatic-positioning function. A universal stabilizer was used to position and hold the lower leg to prevent unwanted muscle substitutions. The foot was securely fastened into the footplate attachment using hook-and-loop closures. With the foot securely fastened into the footplate, the subject's available range of motion (ROM) was determined using the built-in electrogoniometer. A position of subtalar joint neutral determined with Donatelli's procedure was the midpoint (zero degrees) of ROM for both ankle movements tested. Eighty percent of the subject's available inversion-eversion and plantar-flexion-dorsiflexion ROM was employed during testing of these muscle groups. For the inversion-eversion motions, we used the 80% midrange of the entire inversion-to-inversion range, while 80% from full plantar flexion was used when setting the ROM stops for the plantar flexion-dorsiflexion motion. The start and stop angles were then set at the ends of this 80% ROM. During pilot testing, we found that a setting of 100% of the subject's available ROM would not allow the smooth eccentric-to-concentric transition that was necessary for this study. In this position at the end of the physiologic range, the muscle is stretched and rendered weak and unable to generate enough force to move the dynamometer arm in the opposite direction. Furthermore, by incorporating this test range, we attempted to mimic a range that the subjects experienced during activities of daily living. Once the subject reached the start and stop angles, the force required to initiate the eccentric and concentric movements was set at 20 Newtons. This adjustment was also necessary to maintain a quick, smooth eccentric-to-concentric transition during the SSC maneuver.

The gravity-correction procedure described in the Kin Com manual was performed for dorsiflexion testing to ensure accurate data collection. The eversion SSC protocol did not require gravity correction. We chose isokinetic velocities of 120°-s⁻¹ and 240°-s⁻¹ for testing both the ankle invertors and dorsiflexors, and we examined both eccentric and concentric muscle actions. Similar SSC testing procedures have revealed increased force or power output in comparison with only concentric contraction protocols.17,19

Each subject performed 3 to 5 submaximal warm-up repetitions before each test condition. A 1-minute rest followed the warm-up period. The order of extremity (right versus left), muscle group (evertors versus dorsiflexors), and velocity (120°-s⁻¹ versus 240°-s⁻¹) was randomized by a coin toss. Each subject in the matched-pair control group performed the test sequence in the same order as his or her FAI counterpart. Five maximal test repetitions were completed without interruption for both muscle groups at each test velocity. In order to accomplish this goal, each subject was allowed to look at the computer screen for visual feedback and received constant verbal encouragement ("pull, pull, pull, etc . . .") to perform better on each test repetition. A 1-minute rest was provided between velocity presentations.

Data-Extraction Procedure

The data were extracted manually from the Kin Com computer by moving the cursor marker along the torque curves. Placing the marker on the last eccentric point along the curve denoted the start of concentric motion for each repetition. The start time of each concentric action was noted, and then the cursor was moved along the curve to the point of concentric PT and the subsequent time recorded. The time of concentric PT was then subtracted from the concentric starting time, producing concentric TPT. The highest concentric PT and associated concentric TPT were extracted from each 5-repetition test. All PT data were normalized for body mass (kg).

Statistical Analysis

In this case-control study, comparisons were made between FAI and matched-pair control subjects. The involved ankle from the FAI group was compared with the same ankle in the control match. For example, if the FAI subject had chronic disability in the left ankle, then it was compared with the left side in the control match. Similarly, the uninvolved ankle was compared with the same ankle in the control. In addition, the FAI group's involved ankle was compared with the opposite uninvolved ankle.

We performed four 2 × 2 × 2, three-way, mixed-model analyses of variance to investigate the group-by-ankle-by-speed interaction. The between-subjects factor was group status (FAI versus CON) with repeated measures on the 2 ankles (involved versus uninvolved) and 2 isokinetic speeds (120°-s⁻¹ versus 240°-s⁻¹). The dependent variables were concentric PT/BW for dorsiflexion, concentric PT/BW for eversion, concentric TPT for dorsiflexion, and concentric TPT for eversion. Significant interactions were examined with a Tukey Honestly Significant Difference post hoc analysis. An a priori alpha level of significance was set at P < .05 for all comparisons. We used the Statistical Package for the Social Sciences for Windows (version 10.0.0, SPSS Inc, Chicago, IL) to assist with the statistical analyses. Post hoc effect sizes were also determined for each of the 4 dependent variables studied using a method described by Cohen.25 Effect sizes for the 4 dependent measures ranged from 1.00 to 1.25 (Table 1).

RESULTS

Concentric Dorsiflexion

The PT/BW ratios for concentric dorsiflexion ranged from 0.68 to 1.30 in the FAI group and from 0.69 to 1.57 in the
CON group. Concentric PT/BW means for each group are found in Table 2. We found no significant differences among any of the factors (ankle, speed, and group) involving the PT/BW ratios ($F_{1,28} = .054$, $P = .817$). Of particular interest, there was no difference in PT/BW ratio measures between the involved and uninvolved ankles in the FAI subjects and no differences between the groups.

The TPT values ranged from 0.00 to 0.05 seconds in both the FAI and CON groups. Concentric TPT means for each group are found in Table 3. We found a significant 3-way (ankle-by-speed-by-group) interaction ($F_{1,28} = 6.131$, $P = .035$) for the concentric TPT variable (Figure). The Tukey post hoc analysis demonstrated that differences of ≥ .010 seconds were needed for significance. The concentric TPT measurements taken at 240°·s$^{-1}$ were significantly higher than the concentric TPT measurements at 120°·s$^{-1}$ for the FAI involved, CON uninvolved, and FAI uninvolved ankles. There was no statistical difference in concentric TPT between these 2 speeds in the FAI involved ankles. Furthermore, no significant differences were noted in concentric TPT between the FAI and CON groups when the involved and uninvolved ankles were compared. As expected, the speed main effect was significant ($F_{1,28} = 47.815$, $P < .001$). The TPT values at 240°·s$^{-1}$ (.032 ± .009 seconds) were significantly greater than the TPT values at 120°·s$^{-1}$ (.020 ± .009 seconds).

**Concentric Eversion**

The PT/BW ratios for concentric eversion ranged from 0.29 to 0.96 in the FAI group and from 0.29 to 1.09 in the CON group. Concentric PT/BW means for each group are found in Table 4. The main effect for ankle was significant ($F_{1,28} = 4.918$, $P = .035$). The ratios in the involved ankles (0.47 ± 0.10) were significantly lower than the ratios in the uninvolved ankles (0.51 ± 0.14). What is important to remember, however, is that the main effect combines the ratios across both speeds and groups. Interestingly, there were no differences in eversion PT/BW ratios between the ankles of the FAI group alone or between the groups.

The TPT values ranged from 0.00 to 0.04 seconds in the FAI group, while the values in the CON group ranged from 0.00 to 0.05 seconds. Concentric TPT means for each group are found in Table 5. As expected, the main effect for speed was significant ($F_{1,28} = 70.313$, $P < .001$). The TPT values at 240°·s$^{-1}$ (.030 ± .007 seconds) were significantly slower than those TPT values at 120°·s$^{-1}$ (.018 ± .009 seconds). No significant interactions or other main effects were demonstrated in this analysis.

---

**Table 1. Effect Sizes of All Dependent Variables**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect Size</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric dorsiflexion peak torque/body-weight ratios</td>
<td>1.00</td>
<td>.85</td>
</tr>
<tr>
<td>Concentric dorsiflexion time to peak torque</td>
<td>1.11</td>
<td>.85</td>
</tr>
<tr>
<td>Concentric eversion peak torque/body-weight ratios</td>
<td>1.00</td>
<td>.85</td>
</tr>
<tr>
<td>Concentric eversion time to peak torque</td>
<td>1.25</td>
<td>.94</td>
</tr>
</tbody>
</table>

*N = 15.

**Table 2. Dorsiflexion Concentric Peak Torque/Body-Weight Ratios**

<table>
<thead>
<tr>
<th>Group</th>
<th>Ankle</th>
<th>120°·s$^{-1}$</th>
<th>240°·s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionally unstable</td>
<td>Involved</td>
<td>.96 ± .19</td>
<td>.95 ± .15</td>
</tr>
<tr>
<td>Functionally unstable</td>
<td>Uninvolved</td>
<td>.95 ± .15</td>
<td>.95 ± .16</td>
</tr>
<tr>
<td>Control</td>
<td>Matched involved</td>
<td>1.06 ± .26</td>
<td>1.04 ± .24</td>
</tr>
<tr>
<td>Control</td>
<td>Matched uninvolved</td>
<td>1.05 ± .26</td>
<td>1.06 ± .23</td>
</tr>
</tbody>
</table>

* Means ± SD.

**Table 3. Dorsiflexion Concentric Time to Peak Torque Values**

<table>
<thead>
<tr>
<th>Group</th>
<th>Ankle</th>
<th>120°·s$^{-1}$</th>
<th>240°·s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionally unstable</td>
<td>Involved</td>
<td>.02 ± .010</td>
<td>.03 ± .006</td>
</tr>
<tr>
<td>Functionally unstable</td>
<td>Uninvolved</td>
<td>.02 ± .007</td>
<td>.03 ± .012</td>
</tr>
<tr>
<td>Control</td>
<td>Matched involved</td>
<td>.02 ± .008</td>
<td>.03 ± .005</td>
</tr>
<tr>
<td>Control</td>
<td>Matched uninvolved</td>
<td>.02 ± .012</td>
<td>.03 ± .011</td>
</tr>
</tbody>
</table>

*Mean ± SD in seconds.

**Table 4. Eversion Concentric Peak Torque/Body-Weight Ratios**

<table>
<thead>
<tr>
<th>Group</th>
<th>Ankle</th>
<th>120°·s$^{-1}$</th>
<th>240°·s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionally unstable</td>
<td>Involved</td>
<td>.45 ± .11</td>
<td>.46 ± .11</td>
</tr>
<tr>
<td>Functionally unstable</td>
<td>Uninvolved</td>
<td>.51 ± .16</td>
<td>.50 ± .12</td>
</tr>
<tr>
<td>Control</td>
<td>Matched involved</td>
<td>.49 ± .09</td>
<td>.50 ± .08</td>
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<tr>
<td>Control</td>
<td>Matched uninvolved</td>
<td>.53 ± .19</td>
<td>.51 ± .11</td>
</tr>
</tbody>
</table>

*Mean ± SD.

**Table 5. Eversion Concentric Time to Peak Torque Values**

<table>
<thead>
<tr>
<th>Group</th>
<th>Ankle</th>
<th>120°·s$^{-1}$</th>
<th>240°·s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionally unstable</td>
<td>Involved</td>
<td>.02 ± .008</td>
<td>.03 ± .006</td>
</tr>
<tr>
<td>Functionally unstable</td>
<td>Uninvolved</td>
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<td>.03 ± .007</td>
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<td>.03 ± .009</td>
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<tr>
<td>Control</td>
<td>Matched uninvolved</td>
<td>.02 ± .007</td>
<td>.03 ± .007</td>
</tr>
</tbody>
</table>

*Mean ± SD in seconds.
DISCUSSION

We hypothesized that the involved and uninvolved ankles from the group experiencing FAI would have significantly smaller concentric PT/BW ratios than those ankles in the CON group for both eversion and dorsiflexion motions. Therefore, we were surprised to find that this was not the case. When comparing the matched ankles of the FAI and CON groups, the PT/BW ratios were not significantly different. Others provide limited support, reporting no differences in strength of the evertors when comparing FAI ankles with controls. The clear distinction between those authors’ findings and ours is that they used isolated concentric, eccentric, and isometric muscle actions to compare strength differences and not an SSC protocol. Perhaps strength is not an issue in the FAI group regardless of the strength-testing protocol administered.

Our study was designed to identify differences in concentric PT/BW ratios and concentric TPT of the dorsiflexors and evertors in uninjured and functionally unstable ankles using an SSC protocol with an isokinetic dynamometer. After an exhaustive literature review, we determined that our study was the only one known to investigate the SSC in individuals with FAI. Other researchers have investigated isolated eccentric, concentric, and isometric muscle actions of the ankle. Although these studies were necessary and historically important in determining raw strength differences in unstable ankles, our study takes a functional perspective on strength testing for those with FAI. Concentric contractions are commonly preceded by eccentric actions in sports and activities of daily living. Isolated muscle actions are unnatural in sports, and it is unusual to begin a movement from a static position; typically, an initial countermovement in the opposite direction is required. For example, when a basketball player attempts to rebound a ball, he or she normally squats immediately before jumping up for the ball. Everyday activities such as walking, running, and jumping meet the SSC criteria, in which an eccentric preload is immediately followed by a concentric contraction. Walking, running, and jumping consist of many SSC sequences in which the eccentric and concentric actions are coupled. This coupling creates a stronger concentric contraction than an isolated concentric contraction. Using a Kin Com dynamometer, Svanesson et al demonstrated that a concentric contraction preceded by an eccentric action (ie, SSC) generated approximate average torque values 100% larger than a concentric contraction alone. They examined the SSC phenomenon in the ankle plantar flexors at both 120°·s⁻¹ and 240°·s⁻¹. Helgeson and Gajdosik reported similar results when testing the SSC with the quadriceps femoris muscle group on a Biodex isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY).

Mechanisms for the increase in the concentric contraction within the SSC have been proposed. One plausible explanation is that the time to develop force is longer when an eccentric action precedes a concentric contraction, allowing the muscle to become fully activated before beginning concentric contraction. Because the positive work is measured as area under the curve, an increase in muscle force due to greater muscle activation at the beginning of a concentric contraction would enhance the amount of work that can be done. An additional explanation is force potentiation, which suggests that muscle-force production is enhanced due to the preceding stretch stimulus. Reasons most often suggested for this stronger concentric contraction include the myotactic stretch re-

flex and the reaction of the muscle’s elastic properties to the eccentric prestretch. Testing isolated actions may not account for these responses. Therefore, an SSC protocol may be more functional than a protocol using isolated eccentric, concentric, and isometric actions. Training with the SSC, the basis of plyometric exercise, is quite functional and would be advocated if our hypotheses were correct. Training using an SSC protocol has been suggested to improve the stretch reflex via an increase in muscle-spindle sensitivity and Golgi tendon organ inhibition, enriching the muscles’ elasticity, decreasing amortization time, and promoting neuromuscular coordination, all of which in concert enhance force output and dynamic stability. Therefore, we felt that an investigation of the SSC in subjects with FAI was warranted.

We further hypothesized that the FAI group’s involved and uninvolved ankles would have significantly slower concentric TPTs than the CON group ankles across both eversion and dorsiflexion movements. The ankle-by-speed-by-group interaction involving the dorsiflexion concentric TPT measures was significant; however, differences were evident only between the 2 isokinetic speeds within the ankles. We found it quite surprising that no difference in TPT existed between the FAI and CON group ankles. Without other studies for comparison, it is difficult for us to offer explanations. Yet it must be noted that TPT measurements taken from the Kin Com dynamometer were measured to 0.01 second. Perhaps if the TPT measurements had been derived using a more precise timing instrument (one that can read in milliseconds), differences in TPT between the groups might have been evident. We believe that this was a limitation of our method for assessing this variable.

No previous studies accounted for TPT in a functionally unstable ankle. Our hypothesis was based on passive ankle-perturbation studies that indicated slower reaction times in subjects with functionally unstable ankles when compared with uninjured subjects. In these passive perturbation studies, subjects stood on a trapdoor that dropped downward in a motion imitating the classic inversion ankle sprain. Motor latencies were measured by electromyography for the lower leg muscle’s reaction to perturbation. These studies demonstrated that the myotactic stretch reflex was slower in people with functional ankle instability during passive perturbations.

In our study, we thought that a slower reactive stretch reflex could influence concentric TPT in the FAI group in an active SSC state; however, this idea was not supported by the evidence. Some possible explanations are the open chain testing method, the relatively small arc of inversion, and the relatively slow velocities permitted by the instrument. Ricard et al reported maximum inversion velocity during closed chain testing at 740°·s⁻¹. Unfortunately, the Kin Com dynamometer we used has a maximum velocity setting of 240°·s⁻¹, making it impossible for us to measure at such high speeds. Another possible reason for not finding differences between groups in our study may be that the testing protocol did not facilitate a stretch response in the subjects. Perhaps the stretch reflex in a conscious, active state does not affect muscle activity in the FAI subjects to the same degree that it does during passive ankle perturbation. Subjects in our study consciously and actively moved the footplate of the isokinetic dynamometer, whereas during an ankle perturbation, a passive strategy is employed. During passive states, the stretch reflex serves as a monosynaptic negative-feedback model devoted to postural controls; however, in the active states, the reflexes may be
modified by polysynaptic central controls. In active states, the muscle-spindle activity may be mentally biased by the alpha motor neuron for optimal extrafusal muscle contraction. Therefore, processing differences exist in the stretch reflex between the active and passive states. By chance, functionally unstable ankles may be more likely to be sprained while the subjects are in an unconscious, passive, perturbed state compared with an active, conscious state.

Lastly, we were interested in determining if differences in concentric TPT and PT/BW ratios existed between the involved and uninvolved ankles in the FAI group. We had anticipated no differences and, indeed, this was the case. Our PT/BW ratio results were supported by Lentell et al., who indicated no concentric strength differences, and by Bernier et al., who noted no eccentric strength differences in the FAI group when bilateral isokinetic comparisons were made. In contrast, our results are inconsistent with those reported by Tropp, who showed evector concentric strength deficits in the involved ankle in the FAI group when isokinetic measurements were compared with the uninjured side. However, none of these studies involved an SSC strength protocol. The lack of differences in concentric TPT between the ankles is supported by 2 studies that showed no differences in reaction time in subjects with functional ankle instability during passive ankle perturbation when compared bilaterally. If there were indications that the myotatic stretch reflex was similar bilaterally in the FAI group, then this could influence concentric TPT in the active SSC condition. However, eliciting the stretch reflex in the active and passive states may be processed differently across individuals. This may explain the differences between our study and those studies previously performed using passive perturbations.

CONCLUSIONS

We chose a stretch-shortening protocol for this study because this method of testing was purported to be a more functional isokinetic test than testing eccentric and concentric actions in isolation. Using this protocol, we were unable to delineate any muscle-performance deficiencies in subjects with chronic ankle instability. No differences were noted in concentric strength or time to peak torque under the conditions of the study. These variables were hypothesized to be deficient in the group with functionally unstable ankles due to indications that the stretch reflex in these subjects may be affected. Typically, the peak torque values of our subjects were within 2° or .05 seconds from the concentric start angle. However, we speculate that group differences might have been evident had a greater ankle range of motion been used during testing. Further research is needed to understand the neuromuscular aspects of the ankle with regard to the stretch reflex and other proprioceptive variables.

REFERENCES


Efficacy of the Star Excursion Balance Tests in Detecting Reach Deficits in Subjects With Chronic Ankle Instability

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*Pennsylvania State University, University Park, PA; †Duquesne University, Pittsburgh, PA; ‡University of North Carolina at Greensboro, Greensboro, NC

Lauren C. Olmsted, MEd, ATC, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final drafting of the article. Christopher R. Carcia, PhD, PT, SCS, Jay Hertel, PhD, ATC, and Sandra J. Shultz, PhD, ATC, CSCS, contributed to conception and design; analysis and interpretation of the data; and drafting, critical revision, and final drafting of the article.

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Objective: Chronic instability after lateral ankle sprain has been shown to cause balance deficits during quiet standing. Although static balance assessment in those with ankle instability has been thoroughly examined in the literature, few researchers have studied performance on more dynamic tasks. Our purpose was to determine if the Star Excursion Balance Tests (SEBTs), lower extremity reach tests, can detect deficits in subjects with chronic ankle instability.

Design and Setting: We performed all testing in a university athletic training facility. We tested lower extremity reach using the SEBTs, which incorporates single-leg stance with maximal reach of the contralateral leg.

Subjects: Twenty subjects with unilateral, chronic ankle instability (age = 19.8 ± 1.4 years, height = 176.8 ± 4.5 cm, mass = 82.9 ± 21.2 kg) and 20 uninjured subjects matched by sex, sport, and position (age = 20.2 ± 1.4 years, height = 178.7 ± 4.1 cm, mass = 82.7 ± 19.9 kg).

Results: The group with chronic ankle instability demonstrated significantly decreased reach while standing on the injured limb compared with the matched limb of the uninjured group (78.6 cm versus 82.8 cm). Additionally, subjects with chronic ankle instability reached significantly less when standing on their injured limbs as compared with their uninjured limbs (78.6 cm versus 81.2 cm).

Conclusions: The SEBTs appear to be an effective means for determining reach deficits both between and within subjects with unilateral chronic ankle instability.

Key Words: functional reach, dynamic balance, postural control, ankle sprain

Lateral ankle sprain (LAS) is among the most common injuries in sport.1-5 The incidence of residual symptoms and development of chronic ankle instability (CAI) after LAS have been reported to be between 31% and 40%.6-9 When LAS occurs, damage not only occurs to the structural integrity of the ligaments but also to various mechanoreceptors in the joint capsules, ligaments, and tendons about the ankle complex.9-12 Collectively, these receptors offer feedback regarding joint pressure and tension, ultimately providing a sense of joint movement and position.9,12 Via afferent nerve fibers, this information is integrated with the visual and vestibular sensory systems into a complex control system that acts to control posture and coordination.13 When afferent input is altered after injury, appropriate corrective muscular contractions may be altered. Thus, damage to the mechanoreceptors surrounding the ankle joint with an LAS may contribute to functional impairments and chronic instability subsequent to initial injury.9,12,14

Postural-control deficits during quiet standing after acute LAS and in those with CAI have been frequently reported9-7,15-20; however, the sensitivity of these measures has been questioned.21 Balance is a motor skill of clinical relevance, as balance deficits may result in multiple episodes of recurrent LAS and diminished lower extremity function.22-24 In order to maintain postural control, the body is in a state of continuous movement, adjusting to keep the center of gravity over the base of support.13 Balance is maintained by strategies at the hip, knee, and ankle and may be disturbed when joint positions cannot be properly sensed or when corrective movements are not executed in a coordinated fashion.25 Sensory information obtained from the somatosensory, visual, and vestibular systems is interpreted in the central nervous system, and appropriate signals are relayed to the muscles of the trunk and extremities in order to maintain postural stability.26,27 Maintenance of postural control also requires factors such as preprogrammed reactions, nerve-conduction velocity, joint range of motion, and muscle strength.28

To evaluate proprioceptive and neuromuscular deficits after lower extremity injury, postural control has typically been assessed with variations of the Romberg test. Instrumented devices such as forceplates have often been used to quantify postural control during variations of quiet standing.25,26 A crit-
Healthy and injured subjects has yet to be determined. Therebility. The reliability of the SEBTs has been investigated in previous studies. While measures from the SEBTs are reliable, the ability of this tool to detect impairments between groups before testing. To perform the SEBTs, the subject maintains a single-leg stance while reaching with the contralateral leg (Figure 1). The stance leg requires ankle-dorsiflexion, knee-flexion, and hip-flexion range of motion and adequate strength, proprioception, and neuromuscular control to perform these reaching tasks. The SEBTs are best described as functional tests that quantify lower extremity balance on the contralateral leg (Figure 1). The stance leg reaches as far as possible with one leg in each of 8 prescribed directions while maintaining balance on the contralateral leg (Figure 1). The stance leg requires ankle-dorsiflexion, knee-flexion, and hip-flexion range of motion and adequate strength, proprioception, and neuromuscular control to perform these reaching tasks. The SEBTs are best described as functional tests that quantify lower extremity reach while challenging an individual’s limits of stability. The reliability of the SEBTs has been investigated in previous studies. While measures from the SEBTs are reliable, the ability of this tool to detect impairments between healthy and injured subjects has yet to be determined. Therefore, our purpose was to determine if the SEBTs could detect reach deficits in subjects with unilateral CAI.

**METHODS**

**Subjects**

Twenty subjects with unilateral CAI (10 men, 10 women; age = 19.8 ± 1.4 years; height = 176.8 ± 4.5 cm; mass = 82.9 ± 21.2 kg; leg length = 93.3 ± 7.1 cm) and 20 uninjured subjects (10 men, 10 women; age = 20.2 ± 1.4 years; height = 178.7 ± 4.1 cm; mass = 82.7 ± 19.9 kg; leg length = 95.5 ± 5.2 cm) were recruited from the general athletic population at an NCAA Division III university. Chronic ankle instability was operationally defined for this study as recurrent episodes of ankle instability (“giving way”), regardless of the existence of neuromuscular deficits or pathologic laxity. Volunteers were selected for the CAI group according to the following criteria: (1) at least one episode of an acute LAS but none within the past 6 weeks, (2) multiple episodes of the ankle giving way within the past 12 months, (3) free of cerebral concussions, vestibular disorders, and lower extremity injuries for 3 months before testing, (4) no ear infection, upper respiratory infection, or head cold at the time of the study, and (5) no prior balance training.

Volunteers were selected for the uninjured group according to the following criteria: (1) no history of injury to either ankle, (2) free of cerebral concussions, vestibular disorders, and lower extremity injuries for 3 months before testing, (3) no ear infection, upper respiratory infection, or head cold at the time of the study, and (4) no prior balance training. Subjects with CAI were matched with controls according to sex, sport, and position.

All subjects read and signed an informed consent form approved by the university’s institutional review board, which also approved the study. All subjects completed a medical history questionnaire concerning previous ankle injuries and the other inclusion and exclusion criteria.

**Procedure**

The SEBTs are functional tests that incorporate a single-leg stance on one leg with maximum reach of the opposite leg. The SEBTs are performed with the subject standing at the center of a grid placed on the floor, with 8 lines extending at 45° increments from the center of the grid. The 8 lines positioned on the grid are labeled according to the direction of excursion relative to the stance leg: anterolateral (AL), anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), and lateral (L) (Figure 2). The grid was constructed in an athletic training facility using a protractor and 3-in (7.62-cm)-wide adhesive tape and was enclosed in a 182.9-cm by 182.9-cm square on the hard tile floor.

A verbal and visual demonstration of the testing procedure was given to each subject by the examiner (L.C.O.). Each subject performed 6 practice trials in each of the 8 directions for each leg to become familiar with the task, as recommended by Hertel et al. After the practice trials, subjects rode a stationary bike for 5 minutes at a self-selected pace and then stretched the quadriceps, hamstrings, and triceps surae muscle groups before testing. To perform the SEBTs, the subject maintained a single-leg stance while reaching with the contralateral leg (reach leg) as far as possible along the appropriate vector. The subject lightly touched the furthest point possible on the line with the most distal part of the reach foot. The
Left Limb Stance

<table>
<thead>
<tr>
<th>Anterolateral</th>
<th>Anterior</th>
<th>Anteromedial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral</td>
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<td></td>
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<tr>
<td>Posterior</td>
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</table>

Right Limb Stance

<table>
<thead>
<tr>
<th>Anteromedial</th>
<th>Anterior</th>
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<td>Medial</td>
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<tr>
<td>Posteromedial</td>
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</tr>
</tbody>
</table>

Figure 2. The 8 directions of the Star Excursion Balance Tests are based on the stance limb.

The subject was instructed to touch the furthest point on the line with the reach foot as lightly as possible in order to ensure that stability was achieved through adequate neuromuscular control of the stance leg. The subject then returned to a bilateral stance while maintaining equilibrium. The examiner manually measured the distance from the center of the grid to the touch point with a tape measure in centimeters. Measurements were taken after each reach by the same examiner.

Three reaches in each direction were recorded. Subjects were given 15 seconds of rest between reaches. The average of the 3 reaches for each leg in each of the 8 directions was calculated. Reach leg (right, left), order of excursions performed (clockwise, counterclockwise), and direction of the first excursion (A, M, L, P) were counterbalanced to control for any learning or order effect. All trials were then performed in sequential order in either the counterclockwise or clockwise directions.

Trials were discarded and repeated if the subject (1) did not touch the line with the reach foot while maintaining weight bearing on the stance leg, (2) lifted the stance foot from the center grid, (3) lost balance at any point in the trial, or (4) did not maintain start and return positions for one full second. If a subject was judged by the examiner to have touched down with the reach foot in a manner that caused the reach leg to considerably support the body, the trial was discarded and repeated. In other words, if the reach foot was used to widen the base of support, the trial was not recorded. The base of support was the stance foot for the entire trial with the fraction of a second in which the reach foot very lightly touched the ground. It was atypical for subjects to have discarded trials, and none reported fatigue during or after the testing session.

Statistical Analysis

We used a $2 \times 2 \times 8$ repeated-measures analysis of variance for analysis. The between-subjects factor was group with 2 levels (CAI, control), while the within-subjects factors were side with 2 levels (injured, uninjured) and direction with 8 levels (AL, A, AM, M, PM, P, PL, L). Tukey post hoc tests were performed to identify specific differences when significant interactions and main effects were demonstrated. We used the mean of the 3 reaches for each direction and leg for data analysis. The alpha level was set at $P < .05$ for all analyses.

RESULTS

We identified a significant side-by-group interaction ($F_{1,38} = 3.99, P = .05$) (Figure 3). Post hoc comparisons revealed an overall decreased reach in the CAI group while balancing on the injured side compared with the matched side of the uninjured group (78.6 cm versus 82.8 cm) and when compared with their own uninjured side (78.6 cm versus 81.2 cm). The Table lists the means and standard deviations for the 8 specific reach distances for both limbs of the groups. Significant differences in reach distance were found among the 8 directions when data from both limbs of both groups were pooled ($F_{1,19} = 90.8, P = .001$) (Figure 4). Post hoc testing revealed that reaches in the L direction were significantly shorter than reaches in the other 7 directions, and reaches in the AL direction were significantly less than all other directions except for L. Additionally, P and PM reaches were significantly longer than reaches in the A, AM, and PL directions.
DISCUSSION

The principal finding of our study was that subjects with CAI reached significantly less when standing on their injured limb compared with their uninjured limb and when compared with uninjured subjects. While previous investigators have estimated the reliability of the SEBTs, we focused on the ability of these tests to detect impairments in lower extremity postural stability. Some have reported no side-to-side differences among ankle-injured subjects; others have identified such differences. Differences between groups of ankle-injured and uninjured subjects were reported in 2 studies, but other studies showed no group differences. It may be that static assessment of postural control does not provide sufficient challenge to consistently detect functional deficits in subjects after LAS. Ross et al have presented preliminary results of dynamic postural-control deficits in those with CAI by measuring time to stabilization after jump landings on a single limb. While these methods hold promise as a means to quantify functional performance deficits in athletes with CAI, more research in this area is needed.

Dynamic assessment, such as time-to-stabilization measures or the SEBTs, may be better than static postural-control assessment to determine functional deficits in those with CAI. The differences between static postural-control tests and the SEBTs must be considered. Static postural control is the ability to remain as still as possible while maintaining one's balance over a stable base of support. Static postural impairment with CAI is thought to be caused by impaired proprioception and neuromuscular control. When ligaments are torn, articular receptors may be damaged and contribute to the observed postural deficits. Maintenance of balance during dynamic movements, such as those involved in performing the SEBTs, involves the ability to keep the center of gravity over the stable base of support without losing one's balance. Dynamic postural stability has been defined as the extent to which a person can lean or reach without moving the feet and still maintain balance. We believe that performance of the SEBTs challenges the subject's limits of stability as he or she maximally reaches and is, thus, at least somewhat indicative of dynamic postural stability. Although dynamic postural impairment may be influenced by impaired proprioception and neuromuscular control, other factors may contribute to this condition, including strength and range of motion.

First, strength demands are most likely greater when performing dynamic tasks compared with static tasks. Closed ki-
nletic chain motion at the ankle, knee, and hip must be ade-
quately controlled by the lower extremity musculature in order
to execute the SEBTs. Conversely, maintaining single-leg
stance while standing on a stable platform places relatively
small strength demands on the lower extremity musculature.
Second, range-of-motion requirements are greater when per-
forming dynamic tasks such as the SEBTs compared with quiet
standing tasks. Maintaining single-leg stance while performing
maximum reach with the opposite leg requires the stance leg
to have sufficient ankle, knee, and hip motion. After LAS,
joint injury resulting in decreased motion in the subtalar or
talocrural joint may affect performance on the SEBTs. Finally,
subject apprehension may be the most critical performance-
inhibiting factor. After LAS, subjects may be more hesitant to
perform a dynamic task that requires them to challenge their
limits of stability. Several of our subjects with CAI reported
feelings of apprehension when performing reaches while bal-
ancing on their injured limbs. In a balance task during quiet
standing, apprehension may be substantially less because a
subject’s limits of stability are rarely challenged.

Incorporation of the SEBTs into the clinical assessment of
patients with CAI requires an understanding of issues related
to measurement reliability and learning effects. Kinzey and
Armstrong reported intrasession reliability estimates (intraclass correlation coefficient [ICC] 2,1) between 0.67 and 0.87
for the SEBTs and recommended the performance of several
practice trials before recording baseline values because of the
motor learning associated with this novel task. As subjects in
this study were not allowed to touch down with the foot at the
point of maximum reach, the examiner was forced to estimate
a point on the floor corresponding to maximum reach distance.
This may have influenced the ICC values. Hertel et al32 slight-
ly adjusted the procedures for these tests by allowing subjects
a very brief touch down with the reach foot at the point of
maximum reach. On a second day of testing, estimates of in-
tratester and intertester reliability (ICC 2,1) for the different
reach directions ranged from 0.82 to 0.96 and 0.81 to 0.93,
respectively. They suggested that at least 6 practice trials on
each limb be allowed before any baseline values are record-
ed.32

A secondary finding of our study was that reach distances
varied substantially across the different directions in both
limbs of the 2 groups. We chose to include reach direction in
our statistical model because we were interested in identifying
whether injured subjects reached significantly less than unin-
jured subjects in any of the specific directions. In fact, reach
differences in the different directions were consistent across
both limbs of the injured and uninjured groups. This suggests
that the 8 directions of the SEBTs may be best used as a
battery of tests to identify reach distances among groups.

A potential criticism of this study is that we chose not to
exclude subjects who had mechanical instability from our CAI
group. In the sports medicine literature, separating individuals
with CAI into categories of either mechanical instability or
functional instability is a longstanding tradition; however, empirical evidence to support this somewhat arbitrary
dichotomy is lacking. An individual who possesses repetitive
bouts of ankle instability (giving way) has neuromuscular def-
cits (the principal criterion for functional instability) regard-
less of the presence or absence of pathologic laxity (the prin-
cipal criterion for mechanical instability). As the SEBTs are
an assessment of lower extremity reach and functional perfor-
ance, we chose not to assess subjects for mechanical insta-


cility. Because there is no satisfactory evidence to suggest why
subjects with mechanical instability would perform differently
than subjects without mechanical instability on tests such as
the SEBTs, we chose not to exclude subjects with mechanical
instability.

A second potential criticism of this study is the possible
role of subject height in influencing the reach distances of
subjects. Preliminary data suggest that height and leg length
are both statistically significant predictors of reach distances
on the SEBTs. While we did not normalize reach distances
to height or leg length in our study, we did match injured and
healthy subjects for height as closely as possible. Independent
\( t \) tests revealed no significant difference in height (\( P = .58 \))
or leg length (\( P = .28 \)) between injured and uninjured sub-
jects.

CONCLUSIONS

The SEBTs appear to be a promising means of identifying
functional deficits in subjects with CAI via measures of lower
extremity reach. Given the dynamic nature of this assessment
and the limited equipment needed, the SEBTs hold potential
as a cost-effective tool for assessing functional deficits in a
variety of lower extremity conditions. Future research should
examine the validity of the tests in different injured popula-
tions, such as those with anterior cruciate ligament deficiency
and patellofemoral pain syndrome. Also, comparing perfor-
ance of static postural-control tasks on a forceplate with per-
formance on the SEBTs would allow investigation of the cor-
relation between increased postural-control scores and
decreased reach distance. Thirdly, using the tests to determine
if lower extremity reach improves with rehabilitation would
be beneficial. Finally, assessing specific range-of-motion def-
cits with kinematic measures would provide insight into the
movement strategies and sources of impairment resulting in
decreased SEBTs performance in specific populations.

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Chronic Ankle Instability Does Not Affect Lower Extremity Functional Performance

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Objective: To determine if functional performance is impaired in individuals with self-reported chronic ankle instability.

Design and Setting: We used a between-groups design to assess 3 functional variables. All data were collected at a Division III college and a military academy. Before testing, all subjects performed a 5-minute warm-up, followed by a series of stretches for the lower extremity muscles. Subjects then performed cocontraction, shuttle run, and agility hop tests in a counterbalanced fashion. Three trials for each functional test were completed and averaged for analysis.

Subjects: Twenty men with a history of at least 1 significant ankle sprain and episodes of at least 1 repeated ankle injury or feelings of instability or “giving way” were compared with 20 men with no prior history of ankle injury. Subjects were matched by age, height, weight, and activity level.

Measurements: Time to completion was measured in seconds for the cocontraction and the shuttle run tests. The agility hop test was measured on an error point scale.

Results: Using 3 separate, independent, 2-tailed t tests, we found no significant difference between groups for the cocontraction (P = .452), shuttle run (P = .680), or agility hop (P = .902) tests.

Conclusions: Chronic ankle instability is a subjectively reported phenomenon defined as the tendency to “give way” during normal activity. Although athletes commonly complain of subjective symptoms associated with chronic ankle instability, our findings suggest that these symptoms do not negatively influence actual functional performance. Future researchers should evaluate other, more demanding functional-performance tests to further substantiate these findings.

Key Words: functional ankle instability, proprioception, mechanoreceptors, agility test

The ankle joint has been reported to have the highest incidence of injury in sports.1 The lateral-ligament complex is the most frequently injured structure in the ankle joint, representing approximately 85% to 95% of all ankle sprains.2-4 Chronic disability characterized by pain, swelling, and functional instability affects approximately 40% of those who suffer lateral ankle sprains.5-9 Chronic ankle instability (CAI) is a subjectively reported phenomenon that has been defined as a tendency to “give way” during normal activity and is comparable with the giving-way phenomenon that occurs in an unstable knee joint. More recently, Vaes et al10 defined functional instability as “the disabling loss of reliable static and dynamic support of a joint.” Because of the prevalence of chronic ankle instability and the disability it creates, considerable attention has been directed toward understanding the underlying cause of this phenomenon.1,2,5,11-17

Most research to date has focused on the role of proprioception and muscle function as contributing factors to CAI.6,13-17 Proprioceptive deficits after ankle injury are thought to result from damage to mechanoreceptors in the ligaments, muscles, and skin, contributing to subsequent feelings of instability.1,13 Freeman et al8 attributed this proprioceptive disability to the articular deafferentation that occurs when nerve fibers in ligaments and capsule are damaged during an ankle sprain. This contention is supported by multiple studies that link chronic instability more to deficits in proprioceptive capabilities than to deficits in muscle strength.1,13-15,18 Consequently, the relationship between proprioceptive deficits and chronic instability has been of great interest.1,5,6,11,13-15,17

Somatosensation is a complex sensory component of the neuromuscular system that encompasses the “perception and execution of musculoskeletal control and movement.”19 Proprioceptive feedback during joint motion depends not only on sensory information from joint receptors (ie, ligament and capsule) but also includes divergent information from skin, articular, and muscle mechanoreceptors.5,14,15 While researchers have demonstrated that the afferent feedback system may be interrupted after injury, how these deficits may affect actual performance on functional tasks is unknown.

The relationship of perceived CAI to actual functional-per-
formedance decrements has received minimal attention. In the few studies to date, functional-performance measures such as the shuttle run and various single-leg hopping tasks have been examined. No significant difference in any of the functional-performance tasks was found when comparing the injured with the uninjured side. At this point, no investigators have compared performance on these tasks between healthy groups and those with instability. Because of the potential cross-over effects that can occur during these functional tasks, we feel this is the next step.

A variety of functional-performance tasks have been developed to simulate, in a controlled environment, the actions and forces imposed on the ankle joint during normal athletic performance. In particular, agility tests may provide a quantitative assessment of functional performance, as they require the ability to perform skilled, multidirectional, and coordinated movements over a measurable period of time. For the purpose of this study, we chose the cocontraction, shuttle run, and agility hop tests because of the particular stresses they place on the ankle joint. Specifically, the cocontraction test reproduces rotational forces that require stabilization at the ankle joint; the shuttle run reproduces acceleration and deceleration forces normally seen in athletic competition; and the agility hop test specifically targets aspects of proprioception such as balance, coordination, and joint control.

Each of these tests has been previously used to assess functional performance in the lower extremity. Authors using these specific tests or similar tests have demonstrated that they are reliable measures. Specifically, the cocontraction and shuttle run tests have shown excellent reliability, with r ranging from .92 to .96. Pilot testing of the agility hop test during the present study demonstrated high intratester reliability (intraclass correlation coefficient 2,1 = .98).

While the complexities involved in neuromuscular feedback and its relationship to chronic instability may not be completely understood, it appears that deficits in proprioception may lead to functional instability and that coordination exercises may improve some measures of proprioception. Given these findings, one might assume that the subjective symptoms and proprioceptive deficits associated with CAI would affect functional performance, yet this has not been sufficiently evaluated or substantiated in the literature.

Therefore, our purpose was to determine if functional performance, as measured by the cocontraction, shuttle run, and agility hop tests, is impaired in those with self-reported CAI.

METHODS

Forty subjects from an all male Division III college and a military academy volunteered for this study. The CAI group included 20 men (age = 20.4 ± 2.5 years, height = 187.3 ± 7.6 cm, mass = 93.0 ± 17.9 kg) with self-reported CAI. The criteria for inclusion in the CAI group were (1) a history of at least one significant lateral ankle sprain in which the subject was unable to bear weight or was placed on crutches, (2) episodes of at least one repeated lateral ankle injury or feelings of ankle instability or “giving way,” and (3) no previous participation in a rehabilitation program. The control group consisted of 20 men (age = 19.8 ± 1.9 years, height = 186.8 ± 8.0 cm, mass = 90.6 ± 16.3 kg) with no previous history of ankle injury, who were matched to subjects in the CAI group according to height, mass, age, activity level (collegiate athlete, recreational athlete, or sedentary individual), and sport if any. We also matched the control and CAI groups for limb side, so we had equal numbers of right and left ankles in each group. No matching occurred with regard to limb dominance. All subjects read and signed an informed consent form, approved by a university committee for the protection of human subjects, before participating in the study, which was also approved by the committee.

PROCEDURES

We used 3 functional-performance tests to simulate, in a controlled environment, normal athletic stresses to the ankle joint: the cocontraction, shuttle run, and agility hop tests. Before testing, we gave subjects thorough instructions on how to perform each test, and subjects completed a 5-minute bicycle warm-up followed by three 20-second stretches for the quadriceps, hamstrings, and triceps surae muscle groups. Immediately after the warm-up, subjects performed 3 trials of each functional-performance test with a 30-second rest between trials and a 1-minute rest between tests to minimize fatigue. All tests were performed during a single session and were counterbalanced to control for order effect.

Cocontraction Test

The cocontraction test followed the same procedures described by Evans et al and Lephart et al. A 1.23-m length of heavy rubber tubing with an outer diameter of 2.5 cm was secured to a metal loop on a wall 1.52 m above the floor (Figure 1). We attached the other end of the tubing to a heavy hook-and-loop tape belt secured around the subject's waist. We also marked a semicircle on the floor with a radius of 2.44 m from the metal loop, which served as a boundary guideline for the subject to stay behind while performing the test. We instructed each subject to start on the left side of the semicircle, facing the metal loop. Using a shuffle step, in which the feet did not cross, subjects were asked to complete 5 wall-to-wall lengths as quickly as possible. Before the test, we gave each subject the following instructions: (1) begin at the command “go,” (2) use only a shuffle step, (3) do not use your hands to push off the walls, (4) keep your feet behind the marked semicircle, (5) hold the cord with both hands throughout the test, (6) face the metal loop at all times, and (7) do not pull the cord with your hands, but keep tension on the cord by bending your knees. Time began at the command.
Shuttle Run Test

To administer the shuttle run test, we marked a distance of 6.1 m on the floor with 2 separate pieces of tape. Subjects were asked to start behind the first piece of tape, then run and touch the opposite tape, completing 4 consecutive 6.1-m lengths for a total of 24.4 m (Figure 2). Time began at the command “go” and stopped when the subject crossed the final piece of tape. Subjects were instructed to change directions by pushing off the involved ankle.

Agility Hop Test

The agility hop test is a unique combination of a traditional hop test and a single-leg balance test. In this test, the participant is required to hop in many different directions and return to a stable, balanced position between hops. Scoring on the agility hop was based on an error rating scale described by Bernier and Perrin. We marked 6 spots on the floor, numbered in order (Figure 3). We instructed subjects to hop to each spot, using the involved limb or matched control, according to the following instructions: (1) begin by standing on spot #1 and hold balance for 5 seconds, hop to spot #2, regain balance and hold for 5 seconds, and continue in sequential order through spot #6; (2) immediately after each hop, bring your arms to your sides and fully extend the involved hip and knee (this forces the subject to make postural corrections at the ankle); and (3) keep the uninvolved leg directly to the side of the test leg upon landing.

We evaluated test performance according to the number of errors the subject made. The same examiner scored all trials and recorded an error for each of the following: (1) subject moved the test foot or didn’t “stick” the landing, (2) subject did not hold for the full 5 seconds on each spot, (3) subject moved arm(s) for balance, (4) subject’s contralateral leg moved away from the test leg, (5) subject touched down with the contralateral leg, or (6) subject’s body swayed excessively in any direction. All subjects were videotaped during the agility hop test to ensure that errors were correctly counted.

STATISTICAL ANALYSIS

We obtained data for the cocontraction and shuttle run tests using a stopwatch and recorded time in seconds. Data for the agility hop test were based on an error point scale. Each test was performed 3 times and the average used for data analysis. We compared performance between the CAI and control groups for each functional test with an independent 2-tailed t test. Alpha for all analyses was set at $P < .05$.

RESULTS

We found no significant difference between the CAI and control groups in the time to completion for either the cocontraction test ($t_{1,38} = .760, P = .452, 1-\beta = .115$) or the shuttle run test ($t_{1,38} = .415, P = .680, 1-\beta = .069$) (Table). We also found no significant difference in error scores between the CAI and control groups for the agility hop test ($t_{1,38} = .124, P = .902, 1-\beta = .052$).

DISCUSSION

Our primary finding was that functional performance, as measured by the cocontraction, shuttle run, and agility hop tests, was not different between the uninjured and CAI sub-
While interpreting these data, we felt it was important to explore whether our lack of significant findings was due to insufficient statistical power (ie, insufficient number of subjects) necessary to gain meaningful results. We suspected this was not the case and that the results were due to a low effect size, given the very small mean differences between the groups. We confirmed this by calculating the effect size for each test, using the standard deviation of the uninjured group. Effect sizes were .24 for the cocontraction test, .11 for the shuttle run test, and .05 for the agility hop test, which, by convention, indicate very small (unobservable) differences between the conditions.29,30 Hence, even if we were to add substantially more subjects to achieve statistically significant differences between conditions (eg, more than 300 subjects to achieve 80% power for the cocontraction test alone), the actual difference would not be of clinical importance.

We also wanted to confirm that our times for the cocontraction and shuttle run tests were consistent with previous findings. In a previous study of subjects after anterior cruciate ligament reconstruction, those who eventually returned to sport took 14.96 seconds on the cocontraction test; those who could not return took 20.70 seconds, which was determined to be significantly slower.23 On this test, our CAI and control participants took 14.99 and 14.57 seconds, respectively. In the previous study, scores for the shuttle run ranged from 7.45 seconds for the group that was able to return to activity to 9.67 for those who could not return (a significant difference).23 Our results were 6.83 seconds for the CAI group and 6.78 seconds for the control group; therefore, our times were consistent with those found in the literature for functionally active subjects.

To evaluate functional performance, we chose tests that imposed sport-specific movements and loads on the ankle joint and required the balance, coordination, and multiplanar muscular stabilization necessary for high-intensity athletic activities. While the cocontraction and shuttle run tests have been effective in identifying deficits in subjects with anterior cruciate ligament-insufficient knees,23 we were unable to detect differences in subjects with CAI. Potential reasons for our lack of significant findings may be that minimal proprioceptive deficits were present in our CAI group or that these deficits were present but compensated for by increased reliance on feedback from other joints and structures.

Functional-performance tests are very complex tasks that allow multiple joints and structures to assist in the production of movement. Previous authors have demonstrated that novel coordination exercises such as ankle-disk training may improve proprioceptive capabilities of the ankle15,27; a more functional and complex task may lead to this compensatory response. Perhaps future researchers should simultaneously assess both specific proprioceptive deficits and functional-performance capabilities to determine the extent of compensation for isolated deficits.

It is also possible that deficits were present but not apparent with the specific functional-performance tests used in this study. While subjects were matched according to affected limb side, age, height, mass, activity level, and sport when applicable, it may also be relevant to evaluate individual sports relative to the functional tests used. Lephart et al19 found that times on the cocontraction, carioca, and shuttle run tests varied among athletes in different sports and even among positions within a sport. Increasing the sport specificity of the functional tasks and the demand of the tasks to impose further stress on the ankle joint may provide more sensitivity to detect proprioceptive deficits in subjects with CAI.

A limitation of this study was the lack of information on previous rehabilitation of the CAI group. While none of these participants were involved in rehabilitation at the time of the study, historical information was not obtained. In addition, we did not know if any previous rehabilitation programs included proprioceptive exercises. It is important to note that the range and variability of scores in our CAI group were no different than in the healthy subjects. By not controlling this factor, intuitively one would expect greater response variability in this group if some had previously benefited from a rehabilitation program while others did not. In the absence of these findings, we suspect that previous rehabilitation history likely had little effect on our results. More research is needed to elucidate the effect of rehabilitation on CAI and functional performance. Future investigators should control for rehabilitation background and history as part of the screening process and may consider evaluating differences between subjects with CAI who have been through a proprioceptive rehabilitative program versus those who have not.

Another important issue is the severity of the reported CAI and the criteria for defining the instability. Definitions of CAI vary tremendously among studies,10–12,14,17,31 While the definition used in this study is widely accepted,15,17,27 the question we must address is whether a history of ankle sprains and recurrent episodes of giving way are enough to identify CAI. In future studies, we believe it would be beneficial to collect additional information from the subject, such as history, frequency, severity, and rehabilitation of ankle injuries and to correlate these factors to any deficits noted. This information would allow us to continue to analyze differences among subjects who complain of CAI and those who do not, and it would further our understanding of the effect of CAI on functional performance.

**Clinical Relevance**

Chronic ankle instability has been defined primarily as a subjective phenomenon. Subjective complaints of giving way are typically used to screen subjects for inclusion into the experimental group. While one of the primary complaints by those suffering from CAI is a feeling of giving way, it does not appear that this phenomenon has any detrimental effects on functional performance. The scoring used for each of the functional-performance tests was based solely on physical per-
formance and had no bearing on feelings of giving way by any of the subjects. Thus, while the subjective reports should not be discounted, these complaints of instability do not appear to prevent individuals from participating at an optimal level.

CONCLUSIONS

Because of the competitive nature of sports, individuals must be able to perform at an optimal level. Our findings suggest that while participants may complain of ankle instability, their proprioceptive deficits are not sufficient to result in gross decrements in performance during functional activity. These results should play a role in rehabilitation and return-to-play criteria. Continued research is necessary to define both the characteristics of chronic ankle instability and how deficits can affect actual functional performance.

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Commentary:
Functional Ankle Instability Revisited

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Chronic ankle instability is a clinical problem frequently seen in athletes. Various complicated mechanical and neuromuscular factors seem to be involved in chronic ankle instability. The purpose of this special communication is to revisit the concept of functional ankle instability and to discuss its clinical relevance. The 2 hypothesized causes of chronic ankle instability have been labelled mechanical instability and functional instability. Mechanical instability (MI) is defined as ankle movement beyond the physiologic limit of the ankle’s range of motion. The term “laxity” is often used synonymously with MI. Functional instability (FI) is defined as the subjective feeling of ankle instability or recurrent, symptomatic ankle sprains (or both) due to proprioceptive and neuromuscular deficits.

FUNCTIONAL BIOMECHANICS OF ANKLE INSTABILITY

It is not possible to discuss FI without first understanding the biomechanics related to lateral ankle instability. (Please note that the relevant anatomy has been described elsewhere in this special issue.) While the talocrural joint is often considered “the ankle joint,” it is important to recognize that the subtalar joint is critical to the mechanics of ankle instability. The subtalar joint acts functionally as a mitered hinge, allowing the leg to rotate on the weight-bearing foot. While the body’s center of gravity moves forward during walking and running, the stance limb is positioned so that the supportive area is situated beneath the center of gravity (COG). Biomechanically, the reaction force from the ground acts on the foot to create a moment acting on the subtalar joint. The position of the foot in relation to the COG affects the ground-reaction force acting through the center of pressure (COP) (Figure 1). Postural corrections at the ankle primarily occur at the subtalar joint as rotations occur around the COP. Ankle synergy is defined as postural corrections taking place at the ankle; these primarily occur through corrective motions of inversion and eversion in an effort to keep the foot stable underneath the COG. If pure ankle synergy takes place, no shear forces are produced, and any forces on the foot are counteracted by forces acting through the COG.

The relationships of the muscles around the ankle and the axes of the subtalar and talocrural joints usually define the joint’s ability to counteract external loads (torques) on the ankle. Torque around the ankles depends on the line of action of the ground-reaction force upon the subtalar-joint axis. The ground-reaction force typically acts lateral to the subtalar-joint axis and anterior to the talocrural-joint axis (Figure 2). The external load usually everts and dorsiflexes the ankle. This torque is counteracted by the strong plantar-flexor and invertor muscles.1

The subtalar-joint axis is typically 42° from the horizontal axis of the foot and 23° from the longitudinal axis of the foot, passing just medial to the anterior tibial tendon.2 Gauffin3 showed that the subtalar-joint axis moves during the stance phase of gait. When the foot is inverted, the subtalar-joint axis moves medially, and when the foot is everted, the axis moves laterally (Figure 3). The inverted, weight-bearing ankle is likely to produce an external load that further forces the foot into inversion. The evotor (or pronator) muscles are not thought to be strong enough to withstand a body-weight load acting with a lever longer than 3 to 4 cm. If a shear force is added, the torque rises rapidly and an episode of hyperinversion and subsequent “giving way” of the ankle is likely to occur.

In barefoot conditions, the ankle normally avoids an external inverting torque because the line of action of the reaction force is seldom far from the subtalar axis. The simple illustrated series (Figure 4) shows that the hyperinverted ankle has created an external inverting torque, which is potentially injurious. A shoe may make the foot more vulnerable to hyper-inversion because the added breadth of the shoe increases the length of the lever arm, and friction between the shoe and the ground adds a shear (horizontal)-force component, thus creating more torque about the subtalar joint. In a traumatic situation, an external inversion torque typically starts the mechanism of injury. If the evotor muscles cannot counteract the external inversion torque, hyperinversion resulting in trauma to the lateral ankle ligaments is likely to occur.

PREVIOUS RESEARCH ON FUNCTIONAL ANKLE INSTABILITY

The classic work of Freeman et al4 in 1965 suggested that sensory information arising from the ankle ligaments provides most of the proprioceptive information necessary to allow the body to produce appropriate motor responses to prevent or
minimize injury. It was hypothesized that injury to the ankle ligaments also resulted in damage to the sensory receptors in these ligaments. This led to the common use of rehabilitation techniques to improve coordination by improving proprioception in patients recovering from ankle sprains. Despite widespread acceptance, the theory of damage to the mechanoreceptor system and the value of rehabilitation in restoring proprioception after ankle sprain have not been confirmed through research. The concept of FI, however, should not be discounted because a purely mechanical view of chronic ankle instability seems inadequate. Rehabilitation activities designed to stimulate the proposed proprioceptive function of the ankle ligaments might be effective, but the mechanism by which this occurs is not clear.

Recent researchers have been unable to confirm that mechanoreceptors constitute the most important source of proprioceptive information from peripheral joints. Rather, current evidence suggests that information from a variety of receptor sources (cutaneous, joint, and muscular) is important for motor control. Anesthetizing the lateral ligaments of the ankle has very little effect on ankle-joint proprioception as measured by the ability to match reference positions; however, application of a simple ankle brace improves ankle joint-position sense. This suggests that cutaneous receptors may be more important than ligament receptors in providing proprioceptive information at the ankle.

Impaired postural control is a predictor for ankle injury in previously uninjured soccer players. Thus, impaired postural control, as measured by stabilometry, is a primary condition in injury-prone subjects. Proprioceptive damage caused by an ankle sprain (secondary alteration) may impair the feedback needed to retain well-functioning central motor programs. The injury might directly alter the motor programs so that abnormal, injury-related motor performance occurs when an ankle is perturbed.

Intense postural training, such as ankle-disk training, rede-
velops postural-correction patterns. With rehabilitation, Sheth et al. showed a change in pattern of muscle-reaction time such that a delay was seen for the anterior and posterior tibial muscles, which would be favorable for suitable qualitative correction of external inversion torque. This might provide a synergistic approach for avoiding inversion ankle sprains.

Patients with chronic lateral instability of the ankle have prolonged reaction time compared with healthy controls. No differences, however, were found between sides when comparing reaction times in patients with unilateral instability. A stimulus-response threshold to different degrees of ankle inversion has been found in the peroneus latency response, and the reflex pathways probably do not vary regardless of the angle of tilt.

Lentell et al. concluded that muscular weakness is not a major contributing factor in the chronically unstable ankle, but muscular imbalance has been shown to be an important predictor for injury. Ankle injuries with greater plantar-flexion strength and a smaller dorsiflexion-to-plantar-flexion ratio had a higher incidence of inversion ankle sprain. Similarly, individuals with an elevated eversion-to-inversion strength ratio had a higher incidence of ankle-inversion injury.

During the swing phase of gait, the process of neuromuscular preparation for the subsequent weight-bearing stage of the gait cycle is important to ankle stability. Although injury does not typically occur in the swing phase, inappropriate positioning of the lower limb before heel strike would appear to increase the potential for injury. Once the foot reaches the ground, the line of action of the reaction force is determined and mainly related to the position of the foot in relation to the COG and inertia. If the foot is held in an inverted position when it reaches the ground, an external-inversion load is placed upon the joint, increasing the likelihood of injury.

Once weight bearing begins, the lag time to produce an effective recovery movement via the proprioception-neuromuscular complex (mechanoreceptor response time plus the electromechanical delay) is almost as long as the stance phase of running. This suggests that the most important issue to FI might be preprogrammed motor patterns and physiologic reactions to postural perturbations. Postural control is hierarchically organized, so that complex locomotor movements are broken down into much simpler, stereotyped patterns. Nashner proposed 3 principles for postural control: (1) rapid postural adjustments organized into a limited number of synergistic arrangements and fixed patterns, each of which is movement specific; (2) synergistic organization appears to be performed automatically by local mechanisms using receptor information; and (3) adaptation of responses is due to motor training, in which voluntary control is replaced by automatic movement sequences.

Tropp and Perrin et al. emphasized the special role of the ankle in the control of both static and dynamic balance and the dominance of postural corrections at the hip joint in the presence of unstable ankles. The hip strategy of postural control includes larger corrective motions and results in higher shear forces with the ground. Stabilometry has also shown greater COP trajectories with postural corrections at the hip. This is the biomechanical expression of wide segmental motions, which usually is seen as an increase in body sway. Hip strategy creates large shear forces with the ground, which may increase ankle inversion and result in the ankle giving way.

PRACTICAL ASPECTS IN SPORTS MEDICINE

When assessing the chronically unstable ankle, it is important to differentiate between FI and MI. Instability related to pathologic laxity must be treated accordingly; however, MI lacks any clear relation to laxity. In a systematic review of the literature concerning the prevention of ankle sprain, several Swedish studies are referenced. This raises the question as to whether these results can be generalized to other sport populations and countries. Most findings suggest that special emphasis on proprioception and ankle strengthening should be considered. I suggest that coordination training should include activities that provoke ankle inversion and eversion and should be performed for at least 2 months. Such efforts are aimed at improving neuromuscular performance and reducing ankle-injury rates.

After an injury, ankle taping or bracing can be used to avoid excessive inversion of the foot during the swing phase of gait (before foot contact) or protect against inversion torque (or both). Ankle taping and bracing have been found effective for injury prevention. The mechanism could be a combination of keeping the unloaded foot in a neutral position and countering unexpected inversion torque; however, if the ankle is totally stiff, ankle synergy is prevented and hip synergy dominates. Taping or bracing may also provide protection by improving proprioception at the ankle through stimulation of cutaneous receptors. Conventional orthoses do not appear to have negative effects.

SUGGESTED DIRECTIONS OF FUTURE RESEARCH

When dealing with injuries and diseases of the locomotor system in general and bone and joint problems in particular, one is met by the message “stay active.” Our attitude toward physical activity and sports has changed. Many adults who were not raised to be active in general sports now perform various types of physical exercise. We see many ankle-joint injuries caused by jogging, aerobics, and other fitness programs. Certainly, these injuries are mostly benign and are probably counterweighted by the positive effects of exercise; however, we should find a way to decrease the incidence of such injuries.

Functional instability must be considered a viable cause of residual ankle disability and instability. Even if neuromuscular deficits are identified, the clear mechanism of injury and the best methods of prevention are yet to be elucidated. I suggest that the main factor in FI is a change in coordination, mainly due to transition from ankle synergy to hip synergy.
during postural corrections. This may be combined with a tendency to invert the foot during the swing phase of the gait cycle and an inability to handle potentially dangerous situations during the stance phase. We do not know whether a local mechanoreceptor injury or muscle-strength imbalance contributes to chronic ankle instability, but coordination training and proprioceptive training are clearly the treatments of choice and can help prevent recurrent sprains. Further studies should focus on the importance of ankle position during the swing phase of gait and potential alterations of motor programs with an increased risk for ankle-joint injuries.

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