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1. General Grants Program for 2002
2. Epidemiological Study for Pediatric Sports Healthcare
3. National High School Injury Surveillance Study Data
4. Athletic Training Outcomes Assessment Data
5. Exercise by Children and Adolescents in Warm and Hot Environments
6. Bone and Joint Decade

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Are Certified Athletic Trainers Qualified to Use Therapeutic Modalities?

David O. Draper

It is apparent that certified athletic trainers are limited in their use of therapeutic modalities by some state practice acts. I am aware of some situations in which the athletic trainer is only permitted to prepare the patient for treatment (eg, apply electrodes, prepare an area for ultrasound treatment), but the physical therapist must physically turn on the machine and perform the treatment. In other states, the certified athletic trainer (ATC) who works in a clinic setting is considered to be on the same level as a physical therapist assistant or aide, and as such, might be limited in modality use. As a researcher of therapeutic modalities for more than a decade, it troubles me that the hands of ATCs are tied with respect to modality use.

My purpose in writing this editorial is to inform the public that ATCs are skilled in the use of therapeutic modalities. I will provide both entry-level and continuing education examples.

1. How are students of athletic training being educated and trained in the proper use of therapeutic modalities?

Students of athletic training are educated in programs accredited by the Commission on Accreditation of Allied Health Education Programs (CAAHEP). In order to meet the standards of this accrediting agency, a student must complete a myriad of cognitive (22), psychomotor (10), and affective (5) domains dealing with therapeutic modalities. This is typically accomplished by completing at least one semester course on therapeutic modalities. In addition, students may receive basic instruction in the use of therapeutic modalities in their basic athletic training and rehabilitation courses.

Aside from the classroom experience, athletic training students are also provided an opportunity to use modalities on a daily basis during their year-round clinical practicums. This powerful model of education combines academics in the morning with clinical work in the afternoon and evening.

2. What does the National Athletic Trainers’ Association (NATA) offer to keep its ATCs current in the proper use of therapeutic modalities?

Certified athletic trainers are required to earn continuing education units (CEUs) to retain their certified status. A variety of continuing education opportunities exist in the area of therapeutic modalities.

Educational sessions: An entire educational session (3 hours) has been devoted to the use of therapeutic modalities at the last 4 NATA Annual Meetings and Clinical Symposia. Also, many 15-minute Free Communications research presentations and poster presentations on the topic of therapeutic modalities have been provided during the recent NATA annual meetings.

Home study courses: The NATA offers home study courses dealing with the latest techniques and research on therapeutic modalities.

Professional journal: The Journal of Athletic Training is the scholarly journal of the NATA. The Table demonstrates how the Journal of Athletic Training advances ATCs’ understanding of therapeutic modalities in comparison with 2 other journals in related fields. The Journal of Orthopaedic and Sports Physical Therapy published 1 therapeutic modalities article every 4.7 issues; Physical Therapy, 1 such article every 6 issues; and the Journal of Athletic Training, 1.5 such articles per issue.

3. Are ATCs doing research? Certified athletic trainers were authors in 65 of the 80 articles (81%) appearing in the 3 journals.

In conclusion, ATCs play a key role in assisting their patients in recovery from injury. Certified athletic trainers are provided ample opportunity to learn about therapeutic modalities during their entry-level education. They are required to earn CEUs to retain their certification status. Certified athletic trainers are very active in clinical research on therapeutic modalities, and as
Therapeutic Modality Articles in 42 Issues Each of 3 Journals

<table>
<thead>
<tr>
<th>Journal</th>
<th>No. of TM* Articles</th>
<th>No. of TM Articles by ATC Authors</th>
<th>Electric Stimulation</th>
<th>Ultrasound</th>
<th>Thermotherapy</th>
<th>Diathermy</th>
<th>Cryotherapy</th>
<th>Contrast Therapy</th>
<th>Massage</th>
<th>Magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journal of Orthopaedic and Sports Physical Therapy</td>
<td>9 (All data-based research)</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Physical Therapy</td>
<td>7 (4 Data-based research, 3 surveys or literature reviews)</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Journal of Athletic Training</td>
<td>64 (All data-based research)</td>
<td>62</td>
<td>8</td>
<td>15</td>
<td>7</td>
<td>1</td>
<td>24</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

*TM indicates therapeutic modality; ATC, certified athletic trainer.

such, are adding to this unique body of knowledge. The Journal of Athletic Training is a leading contributor to the art and science of therapeutic modalities by providing its readers with current research on the topic.

Editor's Note: David O. Draper, EdD, ATC, is an Associate Editor of the Journal of Athletic Training and a Professor of Athletic Training at Brigham Young University, Provo, UT.
Electromyographic Analysis of Single-Leg, Closed Chain Exercises: Implications for Rehabilitation After Anterior Cruciate Ligament Reconstruction

Anthony I. Beutler*; Leslie W. Cooper†; Don T. Kirkendall‡; William E. Garrett, Jr‡

*Uniformed Services University of Health Sciences, Bethesda, MD; †Community Family Practice, Indianapolis, IN; ‡University of North Carolina School of Medicine, Chapel Hill, NC

Objective: Many knee rehabilitation studies have examined open and closed kinetic chain exercises. However, most studies focus on 2-legged, closed chain exercise. The purpose of our study was to characterize 1-legged, closed chain exercise in young, healthy subjects.

Subjects: Eighteen normal subjects (11 men, 7 women; age, 24.6 ± 1.6 years) performed unsupported, 1-legged squats and step-ups to approximately tibial height.

Measurements: Knee angle data and surface electromyographic activity from the thigh muscles were recorded.

Results: The maximum angle of knee flexion was 111 ± 23° for squats and 101 ± 16° for step-ups. The peak quadriceps activation was 201 ± 66% maximum voluntary isometric contraction, occurring at an angle of 96 ± 16° for squats. Peak quadriceps activation was 207 ± 50% maximum voluntary isometric contraction and occurred at 83 ± 12° for step-ups.

Conclusions: The high and sustained levels of quadriceps activation indicate that 1-legged squats and step-ups would be effective in muscle rehabilitation. As functional, closed chain activities, they may also be protective of anterior cruciate ligament grafts. Because these exercises involve no weights or training equipment, they may prove more cost effective than traditional modes of rehabilitation.

Key Words: one-legged squats, step-ups, functional exercise

Designing an optimal exercise regimen for knee rehabilitation continues to be a prevailing focus of sports medicine and physical therapy research. Much of the controversy surrounding knee rehabilitation concerns which type of exercise is most appropriate at various stages of rehabilitation. An example of this controversy is the ongoing debate over rehabilitation after anterior cruciate ligament (ACL) reconstruction.1-7 Given the frequency of ACL reconstruction and the lengthy rehabilitation that follows, the search for an optimal recovery regimen involving the most beneficial types of exercise is an important endeavor. While many modes of rehabilitation exercise have been used, much of the current debate centers on the risks and benefits of open versus closed kinetic chain exercise.

The concept of open and closed chain kinetic exercises comes from linkage analysis in mechanical engineering. In 1955, Steindler suggested that the human body could be represented by a chain of rigid segments connected by a series of joints.8 He observed that the pattern of muscle recruitment in the leg was different when the foot was fixed than when the foot was free. The term closed chain describes exercise in which the distal appendage is fixed, as in a squat or a pull-up. Open chain refers to movements in which the foot or hand is relatively free, such as during seated knee extension or throwing a baseball.

Both open and closed chain exercises have been studied extensively to determine their proper place in rehabilitation following ACL reconstructive surgery.2-4,9,10 The results of cadaveric research,9,13 biomechanical analyses,14,15 and tibial translocation studies12 suggest that closed chain exercises result in reduced anterior tibial shear force and decreased ACL strain, while open chain exercises produce greater anterior tibial shear forces and increased ACL strain, especially at 0° to 45° of extension. Still, open chain exercise continues to be an important rehabilitation tool. Open chain isokinetic exercise is widely used in evaluating strength recovery after ACL reconstruction, and previous studies demonstrated higher levels of target muscle activation during open chain exercises than dur-
ing closed chain maneuvers. However these findings are somewhat deceptive because open chain leg extensions involve a single leg, while previously studied closed chain exercises are 2-legged activities.

The purpose of our study was to quantitatively characterize the activation of the quadriceps during 1-legged, closed chain exercises in young, recreationally athletic men and women. One-legged exercises were chosen for their potential for increased levels of muscle activation and their utility in practical rehabilitation settings. Additionally we wished to study maneuvers (1-legged squats and step-ups) that would not require the use of free weights or expensive weight-training machines.

MATERIALS AND METHODS

Subjects

Written consent in accordance with institutional review board policy was obtained from 11 men and 7 women (age = 24.6 ± 1.6 years, height = 174.2 ± 8.6 cm, weight = 67.9 ± 10.3 kg). The subjects had no history of prior knee injury or knee surgery. The institutional review board also approved the study.

Before testing, the skin surrounding the knee joint was shaved and cleaned with isopropyl alcohol to ensure adequate surface contact for electrodes. Two silver/silver chloride 3M Red Dot surface electrodes (St Paul, MN) were placed by a single investigator on the subject’s dominant side (the arm with which the subject would prefer to throw a baseball) over the muscle bellies of the vastus lateralis, vastus medialis oblique, rectus femoris, and biceps femoris using anatomical landmarks described by Perotto. The interelectrode distance was approximately 4 cm. A single ground electrode was placed on the ulnar styloid of the ipsilateral forearm. Electrical impedance was determined and verified to be less than 2 kΩ.

An electrogoniometer (Noraxon USA Inc, Scottsdale, AZ) was attached to the lateral aspect of the subject’s leg. A single investigator positioned the electrogoniometer along a line passing through the greater trochanter, the lateral femoral condyle, and the lateral malleolus. Double-sided tape was used to secure the electrogoniometer during positioning. Once in position, the goniometer was anchored more firmly to the skin using transverse strips of 3M Blenderm surgical tape. The subject was then instructed to stand upright, and the electrogoniometer was set to 0°.

For each trial, the analog data from the electromyographic (EMG) leads and the goniometer was sampled and processed with the Noraxon Telemyo System. Muscle activity signals were collected by the surface electrodes and passed to a battery-operated FM transmitter (Noraxon USA Inc) worn by the subject. The transmitter contained a single-ended amplifier that filtered the signal from analog to digital data with an analog-to-digital card. From the transmitter, the signal was sent to the computer, where the raw EMG and goniometer data were sampled at a frequency of 1000 Hz and analyzed by the Myoresearch software package (Noraxon USA Inc).

Experimental Protocol

Each subject performed 1-legged squats, step-ups, and maximum isometric voluntary contractions (MVICs). The performance order of the squats and step-ups was randomly selected using a random number table. Maximum isometric voluntary contractions were performed last. The subjects were given the opportunity to practice each exercise until comfortable with their performance. Each subject then performed the squats and step-ups in 3 sets of 1 repetition each. A rest period of 1 minute was given between sets, between exercises, and between MVICs.

One-legged squats were performed by having the subjects stand on the instrumented leg with the arms outstretched and touching a vertical pillar. The subjects were instructed to use the pillar only to aid with balance. They were then asked to squat down as low as possible and rise again to the upright position using only the instrumented leg. If subjects lost their balance, could not rise in a smooth motion, or were judged to have used the pillar to pull themselves upright, the trial was discarded and the exercise was performed again after the 1-minute rest period.

Step-ups were performed by having the subjects place the foot of the instrumented leg on a step of approximately tibial plateau height (step height was adjusted for each subject). The subjects were instructed to step up to full extension of the instrumented leg and then return to the original position using only the instrumented leg. To ensure that the subjects did not push off the contralateral leg, they were required to stand on the heel of the uninstrumented leg, maintaining the toes dorsiflexed off the ground and the uninstrumented knee locked in full extension for the entire concentric portion of the step-up. To aid in their performance of this maneuver, subjects were instructed to bend their torsos forward over the instrumented knee. If a subject did not rise in a smooth motion or was judged to have pushed off the uninstrumented leg, the trial was discarded and the exercise was performed again after the 1-minute rest period. If a subject could not perform the exercise correctly after repeated attempts, the step was lowered 3 cm and the exercises were repeated. Three subjects (1 man, 2 women) were unable to perform step-ups at tibial plateau height. Each was able to perform the exercise with the step height lowered by 3 cm.

Maximum isometric voluntary contractions were measured with the subject sitting upright on a leg exercise chair with a padded leg extension-flexion bar contacting the distal leg. Care was taken to ensure that the hinge center on the machine arm was aligned with the knee joint center. The subject was secured in the seat with thigh, hip, and shoulder straps. Quadriceps MVICs were collected by asking the subjects to extend their legs as hard as possible for 5 seconds against the extension bar, which was locked at 90° of flexion. After a 1-minute rest period, the exercise was repeated at 60° of flexion and then at 30° of flexion after an additional 1-minute rest period. Hamstrings MVICs were collected at the same degrees of knee flexion with the same equipment, with the subjects flexing their legs as hard as possible for 5 seconds.

Data Analysis

We analyzed MVICs by integrating the rectified EMG signals and finding the greatest 1 second of activation for each of the muscles during each trial (30°, 60°, and 90°). This 1 second of greatest activation for each muscle from any trial was assigned 100% of EMG activity for that muscle. The maximum integrated EMG (IEMG) of the rectus femoris and the vastii were summed to obtain a value assigned as 100% of IEMG activity for the quadriceps (quadriceps MVIC). The
**Electromyographic Analysis by Sex and Exercise**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Men</th>
<th>Women</th>
<th>All Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Squat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum knee flexion angle (degrees)</td>
<td>120 (21)</td>
<td>96 (19)†</td>
<td>111 (23)</td>
</tr>
<tr>
<td>Angle of maximum quadriceps activation (degrees)</td>
<td>103 (12)†</td>
<td>85 (17)†</td>
<td>96 (16)</td>
</tr>
<tr>
<td>Maximum quadriceps activation (% MVIC)</td>
<td>197 (71%)</td>
<td>205 (63%)</td>
<td>201 (66%)</td>
</tr>
<tr>
<td>Step-up</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum knee flexion angle (degrees)</td>
<td>108 (10)†</td>
<td>91 (79)†</td>
<td>101 (16)</td>
</tr>
<tr>
<td>Angle of maximum quadriceps activation (degrees)</td>
<td>86 (11)</td>
<td>79 (12)</td>
<td>83 (12)</td>
</tr>
<tr>
<td>Maximum quadriceps activation (% MVIC)</td>
<td>195 (42%)</td>
<td>227 (67%)</td>
<td>207 (54%)</td>
</tr>
</tbody>
</table>

*SD indicates standard deviation; MVIC, maximum voluntary isometric contraction.
†P < .05, men versus women.

maximum biceps femoris IEMG was assigned as 100% of the IEMG activity for hamstrings per second (hamstrings MVIC). We used these values to normalize the dynamic contractions recorded during the squats and step-ups. The squat and step-up data were analyzed over 10° arcs of knee flexion during the concentric and eccentric portions of exercise. The rectified EMG signals from the rectus and vastii muscles were integrated over these 10° arcs of motion and then summed to create a combined quadriceps IEMG for each arc. The quadriceps IEMG for each arc was then divided by the time-weighted quadriceps MVIC and multiplied by 100 to express the quadriceps activation for each 10° arc as a percentage of the quadriceps MVIC (MVIC%). The same methods were used to calculate the MVIC% for the hamstrings.

Data were summarized by routine descriptive statistics. Significant differences (P < .05) were determined by repeated-measures analysis of variance with 1 grouping factor (sex) and 2 repeated factors (exercise and knee angle interval).

**RESULTS**

For the squat and step-up exercises, the maximum angle of knee flexion, angle of maximum quadriceps activation, and maximum quadriceps activation are summarized in Table 1. The male versus female differences in maximum quadriceps activation were not significant. However, the differences in maximum angle of knee flexion and angle of maximum quadriceps activation were significant (P < .05). Men squatted to deeper angles of knee flexion and produced their maximum quadriceps contraction at greater knee-flexion angles than women.

For the step-up exercise, the male versus female differences in angle of maximum quadriceps activation and maximum quadriceps activation were not significant. However, the maximum angle of knee flexion was significantly greater (P < .05) for the male group.

Quadriceps activation did not differ between men and women over the arcs of motion ending at 90°, 60°, and 30°. Accordingly, the data were pooled and expressed for all subjects. Three subjects could not perform a 90° range of motion and were excluded. The quadriceps and hamstrings activation over each arc of motion with n > 14 is summarized for squats (Figure 1) and step-ups (Figure 2). The difference in quadriceps activation among 90°, 60°, and 30° was highly significant (P < .0001) for the eccentric and the concentric portions of both the squats and the step-ups. No significant difference was seen between squats and step-ups in eccentric activation at 90°, 60°, or 30°.

However, the eccentric quadriceps activation at 30° was greater for step-ups (36 ± 11% MVIC) than for squats (26 ± 12% MVIC, P = .067). In contrast, the eccentric activation at 90° was significantly greater for squats (95 ± 29% MVIC) than for step-ups (72 ± 36% MVIC, P = .045). Eccentric quadriceps activation was not significantly different (P = .185) between squats and step-ups at 60° of knee flexion.

The hamstrings electrodes of 2 subjects became detached during the exercises and were not discovered until after the test. Consequently, these data could not be reported; thus, 16 subjects had complete hamstrings data. The maximum hamstrings activation was 81 ± 74% MVIC, occurring at 86 ± 33° for squats, and 59 ± 37% MVIC, occurring at 65 ± 14°.
for step-ups. No significant differences in hamstrings data were noted between men and women.

**DISCUSSION**

The peak levels of quadriceps activation achieved by subjects in this study were 201 and 207% MVIC for squats and step-ups, respectively, approximately double the maximum activation measured during isometric exercise. Exercises that elicit maximal voluntary muscular contraction have been shown to be very effective in increasing muscular strength. The peak levels of quadriceps activation achieved in our study are more than double those reported by 

Stuart et al and Wilk et al recorded quadriceps activation during loaded, 2-legged, closed chain exercises, and the quadriceps activation achieved by subjects in our study is roughly double that reported by both groups. Some important differences in method and subject selection exist between the trials. First, both Stuart et al and Wilk et al used free weights to increase resistance during exercise; no weights were used in our study. Second, Wilk et al's subjects were trained weight lifters and Stuart et al's trial included only male subjects. Our subject pool consisted of young, recreational male and female athletes. Also interesting to note is that the quadriceps activation for 1-legged squats and step-ups remained greater than 100% MVIC at 60° of flexion in our study. Both the peak and the sustained levels of activation suggest that 1-legged squats and step-ups are effective in achieving a maximal voluntary muscular contraction and would be effective in strength building for men and women. One possible advantage is that these 1-legged exercises involve neither free weights nor weight-training equipment. Hence, they may prove more cost effective than traditional modes of rehabilitation.

A second important feature of these 1-legged exercises is that they involve closed chain joint kinetics. Closed chain exercises have been associated with decreased ACL strain. While the safe or optimal level of strain for newly implanted ACL autografts remains unknown, most physicians and therapists have assumed that exercises that effectively strengthen the quadriceps muscles while producing less ACL strain are desirable

Results of cadaveric studies by More et al, Markolf et al, and Arms et al suggest that squatting produces significantly less ACL strain than seated leg extension, especially between 0 and 30° of knee flexion. Mathematical models of the biomechanical forces occurring in the knee joint have also been used to estimate ACL shear forces. Nisell and Wilk et al concluded that open chain exercises result in anterior shear and ACL stress, with peak values approaching 700 Newtons (or 1 body weight) at approximately 30° of knee flexion. However, closed chain exercises result in posterior tibiofemoral shear forces throughout the range of motion. These results are identical with those obtained by other investigators, who also demonstrated that increasing resistance during open chain exercise led to a nonlinear increase in anterior shear force, while increasing resistance during closed chain exercise did not significantly increase tibiofemoral shear force in a recent in vivo study. Finally, studies measuring anterior tibial displacement have been used to determine ACL stress during exercise. Yack et al and Drez et al found significantly less anterior tibial translation during closed chain exercise, especially in ACL-deficient knees. Clearly, exercises with closed chain biomechanics similar to the 1-legged exercises studied here produce less anterior shear force than open chain maneuvers. In addition, the closed chain, 1-legged exercises in our study involve increased torso flexion, which has been shown to further decrease the anterior component of the tibiofemoral shear force.

Closed chain exercise also results in decreased anterior tibial shear force because the maximum quadriceps activation occurs at deep angles of knee flexion. Cadaveric analysis shows that the highly activated quadriceps can pull the tibial forward and stress the ACL between 0 and 45° of knee flexion. Studies of open chain exercises show maximum levels of quadriceps activation between 45° and 0 degrees of knee flexion. However, closed chain exercises maximally activate the quadriceps at angles of knee flexion greater than 45°.

Studies of 1-legged squats and step-ups in this study also demonstrated peak activation at knee flexion angles well away from the demonstrated "danger zone" for anterior tibial pull by the quadriceps (96 ± 16° in squats, 83 ± 12° in step-ups). Within the "danger zone," at 30° of flexion, the 1-legged squats and step-ups had relatively low quadriceps activation levels of 69% MVIC and 67% MVIC, respectively.

Another potential stabilizing force at the tibiofemoral joint is hamstring cocontraction. Most published reports show a constant, low-level hamstring activity throughout the exercise cycle in 2-legged, closed-chain exercise. We found an average biceps femoris activation of roughly 20% to 40% MVIC throughout the exercise cycle, which is consistent with these previously reported results. Our hamstrings data displayed much higher intrasubject and intersubject variability than did our quadriceps data, making further interpretation and description difficult. Typical coefficients of variation ranged from 20% to 30% for quadriceps data and from 70% to 90% for the corresponding hamstrings parameters. Additionally, our hamstrings data reflected only EMG activity monitored from electrodes placed over the biceps femoris muscle, ignoring the contribution of the lateral semimembranosus and semitendinosus muscles. We also made no effort to control for hip angle, which may be an important factor in hamstrings activation. The primary purpose of our study was to characterize quadriceps activation; the hamstrings results are reported here for completeness.

The angle required to achieve maximal quadriceps contraction with a 1-legged squat or step-up may differ among groups of individuals. During the 1-legged squat exercise, the maximum angle of knee flexion and the angle of maximum quadriceps activation were significantly greater for men (120° and 103°, respectively) than for women (108° and 86°). Yet the level of maximum quadriceps activation was not significantly different between the 2 groups (197% MVIC in men, 206% MVIC in women). These data suggest that though the female subjects did not squat as low on average as their male counterparts, 1-legged squats would be equally effective for building quadriceps strength in men and women, because both groups were exercising at close to maximum-level quadriceps capacity.

The same trend did not exist for the step-up. Although the maximum angle of knee flexion was significantly greater for men (108°) than for women (91°), the angle of maximum quadriceps activation was not significantly different between the 2 groups (men, 86°; women, 79°; P = .187). However, when performing a 1-legged squat, the subject was instructed to squat down as low as possible while still being able to arise using only that leg. When attempting the 1-legged step-ups,
subjects first attempted to step up onto a platform of knee height. If they could not perform the step-up correctly at this height, the platform was lowered until they could perform the exercise. Yet, if they were successful at knee height, no trial of increased platform height was attempted. Thus, the maximum angle and maximum angle of quadriceps activation during step-ups may exhibit a negative skew, obscuring the true difference between the 2 groups. Despite this variation in the methods, the maximum quadriceps activation was not significantly different between men (195% MVIC) and women (227% MVIC), nor was the maximum quadriceps activation significantly different between squats (201% MVIC) and step-ups (207% MVIC) for all subjects. One-legged squats and step-ups appear to be equally effective in maximally activating the quadriceps of both male and female participants.

Differences existed between the eccentric phases of 1-legged squats and step-ups. The differences in eccentric quadriceps activation at 30° and 90° likely reflect the differing patterns of eccentric “braking” that are required by the 2 maneuvers. While performing a squat, 90° of eccentric motion occurs immediately before a change of direction (ie, beginning the concentric, rising motion). Hence, a high level of eccentric activation is expected as the quadriceps slow the fall of the torso before the concentric exercise begins. However in a step-up, 90° of eccentric motion occurs just before heel strike. Logically then, less eccentric activity would be expected than in the former scenario because most of the energy of stopping is provided by the heel strike of the contralateral leg. The statistical difference at 30° is likely of less functional significance but appears to reflect an increased initial “braking” in step-ups to lessen the impact forces of the upcoming heel strike.

Closed chain exercises have also been thought to recruit muscles in functional, familiar patterns.22,28 Theoretically, this should result in less time being spent in the initial learning phase of strength building (reduction of the pretraining effect) and more rapid entry into the muscular building phase of strength training.16,29,30 Additionally, recruiting and activating muscles in such functional patterns may improve proprioception and coordination, leading to decreased rates of injury.11,12 These theoretic benefits have not been proven conclusively, since few long-term comparisons of closed and open chain rehabilitation have been reported.1,2 However, should initial studies prove correct in predicting these beneficial training effects, 1-legged exercises may also provide these benefits due to their functional, closed chain kinetics. In fact, the balance required to perform 1-legged exercises might further enhance the coordination and proprioceptive aspects of rehabilitation. More research with studies designed specifically to test these variables are needed to better understand the role of balance and proprioception in rehabilitation.

Finally, 1-legged exercises might be useful in assessing the functional recovery of a patient without isokinetic testing. With only 1 leg used to perform the exercise, functional comparisons can easily be made between the involved and uninvolved legs. The height to which a patient can step up or the angle to which he or she can squat with the involved versus the uninvolved leg may provide valuable information concerning the stage of functional recovery. Further research comparing these 1-legged exercises in normal subjects and patients with ACL reconstructions is ongoing at this time.

CONCLUSIONS

One-legged squats and step-ups in young, athletically active men and women yield levels of quadriceps activation suffi-

cently high enough for strength building. Further investigation is needed to assess these exercises in postsurgical patients and to further compare these exercises with other traditional modes of rehabilitation therapy.

ACKNOWLEDGMENTS

We thank Scott Colby, Jason Hurst, and Anthony Francisco for their technical expertise in designing and carrying out this project and Drs Michael Gross and Kevin Guskiewicz for their assistance in preparing the manuscript.

This project was supported in part by a grant from Nike Incorporated, Beaverton, OR. No author or related institution has received any financial benefit from research in this study. This project was performed in the Coach Krzyzewski Human Performance Laboratory, Department of Orthopaedic Surgery and Sports Medicine, Duke University, Durham, NC.

The opinions expressed are those of the authors and do not represent official policy of the Department of the Air Force or the Department of Defense.

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The Effects of Patellar Taping on Knee Joint Proprioception

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Objective: To evaluate the effects of patellar taping on knee joint proprioception.

Design and Setting: In a research unit, 3 proprioceptive tests were performed. For each of the tests, a standardized patellar taping technique was applied in random order.

Subjects: Fifty-two healthy volunteers (27 women, 25 men; age, 23.2 ± 4.6 years; body mass index, 23.3 ± 3.7).

Measurements: We measured active angle reproduction, passive angle reproduction, and threshold to detection of passive movement on an isokinetic dynamometer.

Results: We found no significant differences between the tape and no-tape conditions in any of the 3 proprioceptive tests (P > .05). However, when the subjects' results for active angle reproduction and passive angle reproduction were graded as good (≤5°) and poor (>5°), taping was found to improve significantly those with poor proprioceptive ability (P < .01).

Conclusions: Subjects with good proprioception did not benefit from patellar taping. However, in those healthy subjects with poor proprioceptive ability as measured by active and passive ankle reproduction, patellar taping provided proprioceptive enhancement. Further studies are needed to investigate the effect of patellar taping on the proprioceptive status of patients with patellofemoral pain syndrome.

Key Words: proprioception testing, patellofemoral pain syndrome

Although patellar taping is readily used by physiotherapists in the treatment of patients with patellofemoral pain syndrome (PFPS), doubts still exist regarding the mechanism for its success. McConnell originally described patellar taping as part of a treatment program for PFPS and theorized that this technique could alter patellar position, enhance contraction of the vastus medialis oblique muscle, and hence, decrease pain. Studies thus far on patients with PFPS have been inconclusive regarding patellar taping enhancement of vastus medialis oblique contractions and taping realignment of patellar position. However, some studies have shown that patellar taping helps to decrease pain in patients with PFPS and in patellofemoral osteoarthritis, although the mechanism for this symptomatic improvement remains unknown. Some investigators have speculated that patellar taping may perform a role in providing a sense of mechanical stability to the patella.

Proprioception is thought to play a more significant role than pain in preventing acute injury and in the evolution of chronic injury and degenerative joint disease. A recently updated paradigm described it as the acquisition of stimuli from peripheral mechanoreceptors in joints, muscles, and deep tissues (conscious) and the projection of these stimuli to the central nervous system to modify motor control (unconscious). Proprioceptive deficits have been found in anterior cruciate ligament–deficient knees, osteoarthritic knees, and knees with chronic effusions. Application of a knee brace or bandage improves the proprioceptive deficit. The only studies to date on PFPS and proprioceptive capacity have been contradictory. Prymka et al noted poorer proprioceptive capacity in patients with “chondropathia patellae” compared with healthy subjects, whereas Kramer et al could not find any proprioceptive deficits in patients with PFPS in either weight-bearing or non–weight-bearing tests. Interestingly, Prymka et al showed that an elastic knee bandage improved patients’ proprioceptive status significantly. A proposed mechanism for this finding was that the bandage stimulated rapidly adapting superficial receptors in the skin during joint motion and increased pressure on the underlying muscles and joint capsule. Jerosch and Prymka speculated that patients who experienced patellofemoral dislocation disrupted a host of neuroproprioceptive structures in the medial retinaculum, capsule, bursae, and vastus medialis. This damage to the position sense receptors may account for the knee’s poor proprioceptive status. Hypothetically, PFPS patients with more subtle forms of chronic patellar malalignment may also exhibit some dysfunction of the peripatellar plexus, detectable with proprioceptive testing. Therefore, just as the restoration to good proprioception status is widely accepted as a key component in the rehabilitation of other knee conditions, modulating proprioception in patients with PFPS may help promote normal knee function and accelerate the rehabilitation process.

Although a plethora of investigators have studied the role of elastic bandages and knee braces on proprioceptive en-
hancement in both symptomatic and asymptomatic groups, to date none have evaluated this phenomenon with patellar taping. Such a study may not only help to define the similarities between taping and bandaging but may also explain some of the mechanisms behind patellar taping. Our purpose was to determine the effect of application of patellar taping on the proprioceptive ability of the knee in a group of healthy subjects.

METHODS

Subjects

A convenience sample of 52 healthy volunteers (27 women, 25 men; mean age, 23.2 ± 4.6 years; body mass index, 23.3 ± 3.7) gave their informed consent. The study was performed in accordance with the Declaration of Helsinki. All subjects had healthy knees with no previous significant injury and were symptom free at the time of the study. Each subject served as his or her own control, with the no-tape condition being the internal control.

Materials

Testing was performed on the Biodex 2 Isokinetic Dynamometer (Biodex Corp, Shirley, NY) using this system’s goniometer, which is sensitive to 1° increments. This was calibrated before the sessions in accordance with the manufacturer’s instructions. Data were processed using the Biodex Advantage software (version 4.5). Visual cues were eliminated by blindfolds. The tape was a 10-cm-wide strip of Hypafix (Smith & Nephew, Hull, UK). A sphygmomanometer cuff was supplied to provide equal sensory input to the lower limb of each patient from the dynamometer’s tibial pad (SP Services, Telford, UK).

Procedures

Each subject was in shorts, barefoot, and blindfolded for the test and sat on the testing seat with hip flexion at 90° (Figure 1). The right limb was chosen for each subject to facilitate the testing setup and because previous studies had shown no proprioceptive differences between dominant and nondominant limbs. The tibial pad was secured to the shank of the leg 3 cm superior to the lateral malleolus. The sphygmomanometer cuff was wrapped around the tibia under the tibial pad. It was inflated to 40 mm Hg and was checked constantly to ensure equal pressure throughout the study. To avoid any learning effect, both the order of tests and the order of conditions were randomly allocated for each subject. Each of the 6 testing conditions (2 tape conditions and 3 tests) was completely randomized. After each test, the subject was instructed to leave the seat and walk around the room to reduce any possibility of proprioceptive carryover to the next test.

Measurement of Proprioception

Proprioception can be appreciated and measured consciously by sensations of movement and joint sense. To detect both these aspects and, therefore, test proprioception, methods were adopted from previous studies. The methods chosen were passive angle reproduction (PAR), active angle reproduction (AAR), and the threshold for detection of passive movement (TDPM).

Passive Angle Reproduction

Starting at 90° of knee flexion, the lever arm passively extended the test limb, without resistance to the movement, to the target angle of 45°. This angle is in the working range of the knee during daily weight-bearing activities. Passive movement was set at an angular velocity of 2°·s⁻¹ to limit reflexive muscle contractions. Subjects were instructed not to voluntarily contract their muscles, and we assumed that no muscular contraction was present. The limb was maintained at the target angle for 10 seconds to enable the subject to remember the position. After the limb was passively returned to 90°, there was a 5-second pause, and the cycle was performed again. This time the subject activated a handheld stop button when he or she felt the target angle had been achieved. Once the button had been activated, patients were not permitted to correct the angle. The angle was identified from the onscreen goniometer. Three readings were taken, and the absolute difference between the perceived angle and the target angle was calculated for each reading.

Active Angle Reproduction

In the same seated conditions, the subject actively moved the limb to the target angle of 45° of flexion. The leg was held there for 10 seconds, so the subject could memorize the position, and then returned to 90° of knee flexion. After a pause of 5 seconds, the subject moved the lower limb by active contraction at an angular velocity approximating 2°·s⁻¹ and stopped when he or she thought the target angle had been reached. Subjects were not permitted to correct the angle. The absolute difference between the perceived angle and the target angle was calculated for each trial.

Threshold to Detection of Passive Movement

In the same seated conditions, the dynamometer was set at a knee angle of 90° of flexion and the passive angular velocity at 30°·s⁻¹. The subject was asked to press the handheld stop button when he or she felt a sensation of movement or a change in the starting knee position. The onset of movement was delayed randomly by the operator. Auditory cues were masked by a set of headphones. Three consecutive trials were...
performed, with the movement in degrees from the starting position noted.

Patellar Taping

Patellar taping was applied by one of the 2 principal investigators (M.J.C. or J.S.). Practice sessions were performed to ensure a similar procedure for taping and testing. With the subject supine with a relaxed, extended knee, one strip of tape was applied without tension across the center of the patella. The center of the tape was as near as possible to the center of the patella, with its medial and lateral edges aligned with the medial and lateral joint lines. The tape was not pulled in either the medial or lateral direction because the subjects were asymptomatic and had no evidence of patellar malalignment. Care was taken with the length of tape because anthropometric differences among subjects may have meant some smaller patients received proportionally greater amounts of tape than others. Thus, the length of tape was calculated to be 50% of the total circumference of the subject’s knee as measured with a tape measure.

Data Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences for Windows (version 7.5, SPSS Inc, Chicago, IL). The data were tested using the Kolmogorov-Smirnov test and found to be not normally distributed (P > .05); therefore, separate nonparametric Wilcoxon signed rank tests were used for each measure of proprioception tested. The level of probability was set at P < .05. Each subject had 3 readings on each of the 3 tests (PAR, AAR, and TDPM) and the 2 conditions (tape and no tape). For PAR and AAR, the absolute differences between the target angle and the actual angle recorded were used. For TDPM, differences between the start and stop angles for all consecutive trials were calculated. Three readings were taken for each subject in each condition and used to calculate the difference between the actual angle and the target angle. The actual angle may have been greater or less than the target angle, but because the difference between them was the more relevant figure for analysis, the positive or negative direction was disregarded.15

RESULTS

Nonparametric test results for all methods of testing for proprioception are displayed in Table 1. The results of the Wilcoxon signed rank tests revealed no significant differences between the tape and no-tape conditions for the 3 tests (AAR, PAR, and TDPM). The medians and interquartile ranges of the degrees from the target angle for all 52 subjects in all conditions are shown in Figure 2. Parametric results are also presented in Table 2 and Figure 3. Previous researchers15 had further analyzed their data by subdividing their samples into good (<5°) and poor (>5°) proprioceptive groups. These were simply categoric names allocated according to the accuracy score and not a specific diagnosis of the subjects’ status. We also conducted this analysis on the present data to ascertain if such a division existed in our group of healthy subjects and if taping would similarly help those who displayed poor proprioception. For PAR, ac-
Figure 3. Deviation from the target angle for all tests and both conditions. 0 indicates target angle; AAR, active angle reproduction; PAR, passive angle reproduction; and TDPM, threshold to detection of passive motion.

Figure 4. Improvement in accuracy after tape for active angle reproduction test in subgroup with more than 5° difference from target angle. 0 indicates target angle; •, extreme values; and AAR, active angle reproduction.

PAR >5° (no tape)
PAR >5° (tape)

Figure 5. Improvement in accuracy after tape for passive ankle reproduction test in subgroup with more than 5° difference from target angle. 0 indicates target angle; PAR, passive angle reproduction.

PAR >5° (no tape)
PAR >5° (tape)

The improvement in accuracy for the whole group in our study was not statistically significant, although the value of muscular, and cutaneous structures, the improvement in knee joint proprioception was due to augmented afferent input via enhancement of cutaneous stimulation from a neoprene sleeve. Barrett et al11 used a similar explanation for improvement in osteoarthritic knees with an elastic bandage. A comparable knee bandage has been previously investigated in patients with patellar dislocation and proven proprioceptive deficit.19 The proprioceptive enhancement demonstrated in that study indicated that such deficits could be rectified by stimulating skin during motion and by pressure on underlying muscles and the joint capsule. This was the basis for our investigation into patellar taping, and we speculate that similar mechanisms accounted for our results in poor-proprioception subjects on the AAR and PAR tests.

We hypothesized that patellar taping would enhance proprioception in healthy subjects using 3 common measures of proprioception. Taping did improve the proprioceptive status of those categorized as having poor proprioception but not those with good status as measured by AAR and PAR. In previous studies involving the application of various types of knee braces and bandages, knee joint proprioception has improved on both static21 and dynamic18 proprioception tests. This has been attributed more to a sensory function than a purely mechanical one. Lephart et al22 speculated that because proprioception is mediated by afferent input from articular,
1.4° was very similar to the findings of Birmingham et al\textsuperscript{21} on the open kinetic chain active reproduction test (1.2°) using a neoprene sleeve, which were statistically significant. The difference in statistical significance is probably due to the use of parametric statistical analysis by Birmingham et al\textsuperscript{21} with greater dispersal about the means and smaller SDs. Furthermore, they averaged their absolute differences in 5 attempts over 5 different target angles. In contrast, we used nonparametric analysis and had large interquartile ranges, reflecting overlapping medians. Categorizing the present data into poor and good subjects\textsuperscript{15} revealed that patellar taping significantly improved the proprioceptive ability of those with an AAR score of more than 5°. In contrast, patellar taping had no effect at all on those whose AAR score was 5° or less. Reasons for this are discussed in the context of PAR testing.

Passive Angle Reproduction

The difference from the target angle in our study between tape and no-tape conditions was 0.8°. This figure is similar to that of Perlau et al\textsuperscript{15} who noted a difference of 1° using an elastic knee sleeve at 5°-s\textsuperscript{-1}; the sleeve markedly improved the PAR results of subjects with poor proprioceptive ability (≥5° from a target angle), but there was no demonstrable effect on their subjects with good proprioception (≤5°). They did not put their data to formal statistical analysis. With the same 5° angle criterion to separate the data, our formal statistical analysis concurs with the descriptive analysis of Perlau et al\textsuperscript{15}, statistically significant improvements with the tape for those in the poor group. Interestingly, those with good proprioception were actually made significantly worse by patellar taping (P = .004), although the difference of 1.1° is far smaller than any of the other taping effects. Perlau et al\textsuperscript{15} speculated that afferent stimuli enhanced by external appliances, although helpful to some subjects whose proprioceptive status for PAR is classified as poor, can be unhelpful or even confusing to subjects with better proprioceptive status. Our results seem to enforce this theory in both the good PAR (worse) and the good AAR (no help).

Threshold to Detecting Passive Motion

One possible reason for this test's inability to show any differences may have lain more with the insensitivity of the Biodex dynamometer than the ineffectiveness of the tape. The onscreen goniometer was only sensitive to 1° increments, compared with other studies that used more sensitive devices or electrogoniometers. This device limitation means that proprioceptive differences of less than 1° would not be detected. During the feasibility phase of this study, we used a testing angular velocity of 2°-s\textsuperscript{-1}, which was within the usual range of angular velocities of 0.2°-s\textsuperscript{-1} to 5°-s\textsuperscript{-1}.\textsuperscript{23} This angular velocity range has been recommended to minimize the contribution of musculotendinous mechanoreceptors in providing the central nervous system with information regarding limb position and movement. At 2°-s\textsuperscript{-1}, we noted that subjects were able to detect motion but registered very little variation on the onscreen goniometer. An increase in angular velocity to 30°-s\textsuperscript{-1} allowed more variation among subjects' scores, but this was far in excess of the recommended angular velocity for this type of test, and its reliability and validity have not been addressed. We found a very small worsening of 0.3°, similar to that of Beynnon et al\textsuperscript{20} who found a difference of 0.28°. Although this initially may be considered of doubtful clinical significance, it is possible that in real life, with the limb moving at great velocity and subjected to high forces, this small value takes on greater clinical significance than first thought. We recommend that careful consideration be given to using a commercial dynamometer, such as the Biodex, for the TDPM test. A purpose-built device\textsuperscript{20,23} or electrogoniometry\textsuperscript{14,18} may be more sensitive methods for detecting threshold to passive motion.

The taping was applied by senior outpatient clinicians who run regular courses on patellar taping for graduate physiotherapists. To ensure that their technique was consistent, a simple method was used, with the tape applied directly over the patella of the extended, relaxed knee. Although more complex variations of patellar taping have been advocated, this study was performed on asymptomatic subjects who had no abnormality to correct. Furthermore, the amount of skin covered was considered more important than the number of tape layers over the same area of skin. Our findings also suggest that care should be taken when using a group of healthy subjects to establish normative data. In the PAR test, exactly 50% of the subjects were classified as having poor proprioception according to the criteria of Perlau et al\textsuperscript{15}. In the AAR test, 37% of the subjects were classified as poor using the same criteria.

Limitations of the Study

Although the sample size of 52 is considerably larger than any other study we have cited except for Perlau et al\textsuperscript{15} (N = 54) and Birmingham et al\textsuperscript{21} (N = 59), and our mean values are comparable with those of many other studies, our subjects exhibited larger variance around the mean, resulting in the study's low power. For example, for the tape and no-tape conditions (N = 52), the AAR test had a power of 0.12; the PAR test had a power of 0.15 (P < .05). Put another way, with the mean differences and the variance exhibited by our patients, we would have needed 664 patients to detect a meaningful difference in the AAR test and 461 for the PAR. We recommend that future investigators consider this aspect carefully by performing proper calculations for the sample size.

The power calculation at P < .05 for the poor AAR group (n = 19) was 0.57 and for the poor PAR group (n = 26) was 0.69. It was not possible to determine sample power from the data reported in Perlau et al\textsuperscript{15} but we calculated that although Birmingham et al\textsuperscript{21} had excellent power (0.99) for AAR, power for PAR was only 0.47 (P < .05).

The TDPM test was conducted at an angular velocity in excess of that recommended by other researchers in this field.\textsuperscript{18} We accept this limitation and acknowledge that the results for this particular test should be interpreted with caution. The sensitivity of the Biodex goniometer could also be construed as a limitation, because the 1° increments may be insensitive to more subtle differences among subjects or between taping conditions. Some clinicians may argue that the taping technique was not specific enough to reflect different clinical situations or abnormalities of PFPS. Our methods were designed to facilitate technique between the authors and control for variable skin coverage. Furthermore, the subjects had neither PFPS nor abnormalities of the patella.

CLINICAL IMPLICATIONS

The clinical implications of these findings are that poor proprioceptive status can be enhanced by a simple patellar taping..."
technique. Clinicians using patellar taping need not apply a complex technique to achieve an improvement in proprioception. Healthy subjects with poor proprioception may be at enhanced risk for PFPS. As with other knee conditions, applying an external appliance such as tape may reduce the risk of injury by enhancing proprioception. Proprioception in PFPS is underresearched, and further study is necessary to investigate this phenomenon and also the effect of patellar taping on the proprioceptive status of patients with PFPS.

CONCLUSION

Knee proprioception measured by AAR, PAR, and TDPM did not change significantly when healthy subjects received patellar taping. The improvement achieved with patellar taping reached statistical significance, however, when applied to those subjects with poor knee joint proprioception (>5° accuracy) in the AAR and PAR tests.

ACKNOWLEDGMENTS

We are grateful for the cooperation of the Schools of Physiotherapy at the Universities of Manchester and Bradford, UK, to Bradford Hospital NHS Trust, and to Dr Julie Winstanley for statistical analysis.

REFERENCES

Cryotherapy and Transcutaneous Electric Neuromuscular Stimulation Decrease Arthrogenic Muscle Inhibition of the Vastus Medialis After Knee Joint Effusion

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Objective: Arthrogenic muscle inhibition (AMI) is a presynaptic, ongoing reflex inhibition of joint musculature after distension or damage to the joint. The extent to which therapeutic interventions affect AMI is unknown. The purpose of this study was to verify that the vastus medialis (VM) is inhibited using the knee joint effusion model and to investigate the effects of cryotherapy and transcutaneous electric nerve stimulation (TENS) on AMI using this model.

Design and Setting: A 3 × 6 analysis of variance was used to compare Hoffmann-reflex data for treatment groups (cryotherapy, TENS, and control) across time (preinjection, postinjection, and 15, 30, 45, and 60 minutes after injection).

Subjects: Thirty neurologically sound volunteers (age = 21.8 ± 2.4 years; height = 175.6 ± 9.6 cm; mass = 71.5 ± 13.3 kg) participated in this study.

Measurements: Hoffmann-reflex measurements were collected using a percutaneous stimulus to the femoral nerve and surface electromyography of the VM.

Results: Hoffmann-reflex measurements from the cryotherapy and TENS groups were greater than measurements from the control group at 15 and 30 minutes after injection. Measurements from the cryotherapy group were greater than for the TENS group, and measurements for the TENS group were greater than those for the control group at 45 minutes. At 60 minutes, the cryotherapy group measurements were greater than the TENS and control group measures. Measurements at 15, 30, 45, and 60 minutes after injection were reduced compared with the preinjection and postinjection measurements in the control group. Measurements in the cryotherapy group at 30, 45, and 60 minutes were greater than the preinjection, postinjection, and 15-minute data. No differences between time intervals existed in the TENS group.

Conclusions: Artificial knee joint effusion results in VM inhibition. Cryotherapy and TENS both disinhibit the quadriceps after knee joint effusion, and cryotherapy further facilitates the quadriceps motoneuron pool. Cryotherapy treatment resulted in facilitation of the VM motoneuron pool during the post-treatment phase. The TENS treatment failed to disinhibit the VM motoneuron pool by 30 minutes postinjection.

Key Words: Hoffmann reflex, joint effusion, neuromuscular...
to a mixed nerve, resulting in depolarization of large afferents and, ultimately, depolarization of motoneurons in the anterior horn of the spinal cord. This results in a twitch contraction of the effector muscle, which can be measured by electromyography (EMG). As the stimulus is increased, more afferent fibers reach threshold, and more motoneurons are recruited within the motoneuron pool. This is represented by an increased amplitude in the twitch contraction.

The difference between the maximum baseline H-reflex measurement and postinjury measurement represents inhibition caused by excitation of mechanoreceptors within the knee joint capsule and stimulation of the Ib inhibitory interneurons. Inhibition, or a decrease in the availability of motoneurons within a pool, is reflected by a decreased H reflex, while facilitation is represented by an increased H reflex. The effusion model allows for mechanical inhibition in the absence of perceived pain. Pain is a confounding variable in injury that is difficult to control.

Despite evidence that AMI exists, few clinicians or researchers have even attempted to suggest ways to overcome or neutralize AMI in a clinical setting. Cryotherapy or transcutaneous electric nerve stimulation (TENS) may be effective therapeutic interventions in slowing or modifying AMI. According to Knight, ice not only decreases general nerve conduction velocity, muscle spasm, and pain, but it has a definite slowing and blocking effect on sensory nerve fibers at certain nerve tissue temperatures (10°C). The relationship appears to be linear; the cooler the nerve becomes, the more slowly the impulse is carried. It seems that any cooling of a mixed nerve would have the same effect on both motor and sensory nerves, but the results of studies exploring the effects of cryotherapy on strength and torque output are varied. Furthermore, cryotherapy seems to have no effect on more functional measures such as agility. Clinically, cooling an acutely sprained ankle improves the patient’s ability to perform active exercise. These factors suggest that cooling has a greater effect on the sensory function of the peripheral nervous system than on the motor component.

Transcutaneous electric nerve stimulation is an intervention that could reduce AMI by postsynaptically inhibiting the Ib inhibitory interneurons. This process would decrease activity of the interneurons responsible for mediating inhibition of the motoneuron pool and decrease AMI. Iles reported that stimulation of cutaneous nerve branches reduced presynaptic inhibition of the soleus muscle. Transcutaneous electric nerve stimulation has been shown to produce a small increase in quadriceps maximum voluntary contraction after anterior cruciate ligament reconstruction and after open meniscectomy. Arvidson et al attributed this effect to a small decrease in pain, but Stokes et al showed some dissociation between pain and AMI.

The purpose of this study was to verify that the quadriceps are inhibited as measured by H reflex using the knee joint effusion model and to investigate the effects of cryotherapy and TENS on AMI using this model.

**METHODS**

A 3 × 6 factorial design was used to compare treatment groups across time intervals. The independent variables included treatment groups (cryotherapy, TENS, and control) and measurement intervals (pretreatment, post-treatment, and 15, 30, 45, and 60 minutes post-treatment). The dependent variable was the H reflex. Control variables included surface temperature measurements of the knee and EMG electrode sites.

**Subjects**

Volunteers (age = 21.8 ± 2.4 years; height = 175.6 ± 9.6 cm; mass = 71.5 ± 13.3 kg) were 30 (19 male, 11 female) neurologically sound, physically active college students with no lower extremity conditions resulting in surgery in the last 2 years, no lasting lower extremity pathology in the previous 6 months, and a measurable vastus medialis (VM) H-reflex measurement. Each subject was determined to be free from neurologic disorders and symptoms through a preparticipation questionnaire. A preparticipation questionnaire and an H reflex screening were used to assess other inclusion criteria. Thirty-two subjects were excluded because a measurable VM H reflex could not be obtained due to instrumentation limitations. Subjects gave informed consent to participate in this study. Human subject approval was obtained from the School of Health and Human Performance Human Subjects Committee at Indiana State University.

**Instrumentation**

H-reflex measurements were collected using surface EMG (MP100, BIOPAC Systems Inc, Santa Barbara, CA). Signals were amplified (DA100B, BIOPAC Systems Inc) from disposable, pregelled Ag-AgCl electrodes. The EMG measurements were collected at 2000 Hz. The BIOPAC stimulator module (STM100A, BIOPAC Systems Inc) was used with a 200-volt (maximum) stimulus isolation adapter (STMS0B, BIOPAC Systems Inc) and a shielded bar electrode (ELS03, BIOPAC Systems Inc).

Surface temperature measurements were collected using a portable Datalogger (MSS-3000, Commtest Instruments Ltd, Christchurch, New Zealand) with 30-gauge, exposed-junction thermocouples with Kapton insulated leads (TX-31, Columbus Instruments, Columbus, OH).

**Orientation**

A 30-minute orientation and screening was held for all volunteers approximately 1 week before testing. A general explanation of the study and its significance was given, along with an explanation of the measurement protocol. Vastus medialis H-reflex measurements were recorded to ensure that the volunteer had a measurable H reflex for data collection. If a maximum measurable H reflex was obtained, all risks involved in the study were explained, and the subject was randomly assigned to a group (control, cryotherapy, or TENS). If no measurable H reflex could be obtained, the subject was dismissed.

**Subject Preparation**

Two locations were shaved, debrided (abraded with fine sandpaper), and cleaned with isopropyl alcohol for application of the EMG electrodes (10-mm Ag-AgCl, BIOPAC Systems Inc) for each volunteer. Surface electrodes were centered on the greatest bulk of the VM, superomedial to the patella, as found during an isometric contraction. The electrodes were placed in line with the muscle fibers and spaced 2 cm apart from center to center. The ground location was on the ipsilateral malleolus.

A stimulating electrode was placed over the femoral nerve.
in the femoral triangle of the test leg. First, the femoral pulse was located. The electrode was then placed over the femoral nerve, located just lateral to the femoral artery. Adhesive collars were applied to each pole of the stimulating electrode to maintain the position over the nerve for the duration of the data collection. An elastic wrap was applied over the electrode and around the waist to apply pressure and to hold the electrodes in place during measurements.

Thermocouples were placed on the center of the patella and on the skin lateral to the junction of the 2-surface EMG electrodes. The thermocouples were held in place with a 4-cm strip of athletic tape.

**H-Reflex Procedure**

The volunteer was positioned supine with the knee and hip slightly flexed and the heel of the involved leg resting in a secure pad, designed to keep the heel stable and the lower extremity in a fixed position while at rest. Factors such as head position, eye position, and hand movements may affect H-reflex amplitude.\(^{32}\) For this reason, every attempt was made to control positions and movements of the entire body. Subjects placed their open hands at their sides. They focused on a small picture on the ceiling with their heads forward, and they listened to wave sounds through headphones. In previous work on soleus H-reflex measurements, this protocol resulted in excellent reliability (intraclass correlation coefficient \(r = 0.938\))\(^ {33}\).

A series of short duration (0.3-millisecond), high-intensity (100 to 200 V) stimuli with 20-second rest intervals was delivered to the volunteer with varying amplitudes in order to find the maximum H-reflex. These stimuli were delivered using a trial-and-error method for finding the peak H-reflex. Stimuli were increased in 2-volt increments. The number of trials necessary to find a maximum H-reflex ranged from 5 to 12. A maximum H-reflex was present (Figure 1) in the near absence of a direct motor response (M response), and as the M response increased, the H reflex decreased. The peak of the H reflex was between 19 and 23 milliseconds, while the M response was between 8 and 15 milliseconds (Figure 1). With the stimulating amplitude set at the maximum H-reflex level, 5 measurements were taken, with a 20-second rest period between measurements.

**Joint Effusion Procedure**

An area superolateral to the patella was cleaned with alcohol and Betadine (Purdue Frederick Co, Norwalk, CT). Using a sterile, disposable syringe, a physician injected 2 cc of lidocaine subcutaneously for anaesthetic purposes. With a second disposable syringe, 60 mL of sterile saline was injected into the superolateral knee joint capsule. The physician performed an effusion wave and ballotable patella test to ensure that the effusion was within the knee joint capsule. The physician wore a new pair of sterile disposable gloves for each volunteer. All materials were disposed of in the proper containers according to Occupational Safety & Health Administration guidelines.\(^ {34}\)

**Testing Procedure**

Three volunteers, 1 from each treatment group (control, cryotherapy, and TENS), reported for each injection session. Electrode-placement sites were prepared as previously de-
superior anterolateral and anteromedial and the inferior anterolateral and anteromedial areas of the knee with approximately 5 to 7 cm distance between them, forming a square around the patella. A typical TENS protocol was used, including a continuous, asymmetric, biphasic square-pulse wave with a pulse width of 100 and a pulse rate of 120. The stimulus intensity was increased until a visible contraction of the VM was apparent. The intensity was then decreased until no contraction was seen or felt by the volunteer. The treatment session lasted 30 minutes, with measurement intervals mimicking those of the cryotherapy treatment. The TENS treatment was briefly terminated during the 15-minute measurement so it would not interfere with the H-reflex amplitude.

**Control Group**

Measurements were recorded at each of the intervals (preinjection, postinjection, and 15, 30, 45, and 60 minutes postinjection). Subjects in all groups remained in a supine position on the treatment table throughout the entire data-collection session. No treatment or intervention was applied to the control group.

**Statistical Analyses**

Means were computed from the 5 trials of each measurement for statistical analysis. A 2-way analysis of variance with repeated measures on time was performed to test for overall differences between treatment groups over time, and the Tukey honestly significant difference test was used for post hoc comparisons ($P < .05$ for all tests). Descriptive statistics were computed for temperature data.

**RESULTS**

H-reflex (V) means for each time interval and treatment group (Table) are expressed as percentage change from the preinjection measurement (Figure 2). An overall difference was detected in H-reflex measures between treatment groups over time ($F_{10.135} = 13.68, P \leq .0001$). At 15 and 30 minutes, the control group had lower H-reflex amplitudes than the cryotherapy and TENS groups (Tukey, $P < .05$). At 45 minutes, H-reflex amplitudes of all groups were different; cryotherapy was greater than TENS, which was greater than control (Tukey, $P < .05$). At 60 minutes, the H-reflex amplitudes of the cryotherapy group were greater than those of the TENS and control groups (Tukey, $P < .05$). The 15-, 30-, 45-, and 60-minute H-reflex measurements decreased compared with the preinjection and postinjection measurements in the control group (Tukey, $P < .05$). H-reflex measurements at 30, 45, and 60 minutes increased compared with the preinjection, postinjection, and 15-minute measurements in the cryotherapy group (Tukey, $P < .05$). No differences were found between time intervals in the TENS group.

Descriptive statistics of surface temperature measurements from the anterior surface of the knee and from the EMG electrode site (Figure 3) suggest that the temperature remained constant at the EMG electrode sites, ensuring that the EMG measurement was not affected by possible cooling of the tissue beneath the electrodes.

**DISCUSSION**

Knee effusion has been shown to cause inhibition of the quadriceps muscle. Our control group data support this finding (Figure 2). This inhibition is likely the result of increased activity of slowly adapting Ruffini endings in the knee joint capsule. Activity from these receptors stimulates Ib inhibitory interneurons, resulting in inhibition of the quadriceps motoneuron pool and facilitation of the hamstring and triceps surae. The Ib interneurons seem to be the integration point for sensory information received from joint mechanoreceptors, resulting in AMI.

H-reflex measurements were used in this study to compare the availability of motoneurons within the quadriceps motoneuron pool before effusion and over a period of time after joint effusion. A change in the excitability of the motoneuron...
pool is represented by a change in H-reflex amplitude as more or fewer motoneurons are stimulated from a given stimulus intensity. The H-reflex measurement, which was taken at rest, was very reliable within (ICC[3,1] = .94) and between (ICC[3,1] = .93) sessions using our protocol. This measurement does not directly equate to changes in functional strength, but it does equate to state changes to the motoneuron pool, which affect strength, muscle wasting, and mobilization.

The effusion model was chosen to mimic injury without the effects of perceived pain. Pain is often blamed for inhibition. While pain undoubtedly plays some role in AMI, the joint effusion model demonstrates that quadriceps inhibition occurs in the absence of pain. In previous work, mean pain scores after knee joint effusion were 1.18 ± 0.82 out of 78 possible points using the McGill pain questionnaire. Two of the McGill pain questionnaire terms that could be selected to describe pain and was the term chosen most often. These data were collected after the injection of saline at each H-reflex measurement. They were not representative of the injection itself, only the effusion created by the injection. The knee effusion model allows for “mechanical” inhibition of the quadriceps in the absence of pain. Pain can be a difficult variable to quantify and interpret in studying joint injury. Therefore, this model reduces any variability that may be associated with pain.

The postinjection measurement from the control and cryotherapy groups demonstrated an excitatory trend in the cryotherapy and control groups (Figure 2). The TENS group did not display this same effect. While these data seemed to be inconsistent, occurring in fewer than half of the volunteers, they are worthy of explanation. The volunteers who showed this increased measurement after injection of saline into the knee joint seemed the most anxious and nervous about the injection. This nervousness or anxiety could result in an increased H-reflex measurement. A sympathetic response, triggered by hypothalamic stimulation, would include such physiologic effects as increased heart rate, increased heart contractility, increased blood flow to somatic muscles, sweat, pupil dilation, and increased salivary secretion. These physiologic reactions could easily increase the variability in the measurement. The only explanation as to why the TENS group postinjection measurement did not increase compared with the other groups is that those randomly assigned subjects may not have been as anxious or nervous about the injection of saline.

Data from the TENS group showed no change from the preinjection measurement over time (Figure 2). TENS decreased the amount of inhibition resulting from knee effusion (disinhibition) during and shortly after the treatment (15-, 30-, and 45-minute intervals). Clinical evidence supports a small increase in voluntary activation of the quadriceps from TENS after ACL reconstruction and meniscectomy. While TENS dis inhibited the quadriceps motoneuron pool during the treatment phase (Figure 2), it seemed to become less effective after treatment. This is evident by the downward trend at 45 and 60 minutes. The mechanism by which TENS reduces inhibition caused by joint effusion is not known. Because it caused measurements to return only to baseline levels, and it resulted in disinhibition during the treatment followed by an inhibitory trend, it seems likely that TENS primarily affects inhibition by having a direct effect on the interneuron that mediates the process. Afferent activity from TENS may result in inhibition of the Ib inhibitory interneuron. TENS could also cause excitation of the Ib excitatory interneuron, resulting in an excitatory potential at the motoneuron pool. Lastly, TENS could stimulate supraspinal centers to negate the effects of AMI through descending inhibitory fibers synapsing on the Ib interneuron. Each of these explanations is a possible mechanism for TENS-induced disinhibition of the VM after knee joint effusion. More data are needed to determine the exact mechanism.

Placing ice on an effused knee resulted not only in disinhibition but facilitation of the motoneuron pool beyond baseline measures (Figure 2). This facilitation continued for up to 30 minutes even after the ice was removed, a finding supported by data previously collected in our laboratory on healthy subjects. Cooling has a slowing effect on nerve conduction velocity of sensory afferent fibers. Cooling also slows the discharge rate of mechanoreceptors in muscle. Joint mechanoreceptors should react to cooling in the same way. Several authors have shown a decrease in intra-articular temperature during application of ice. Oosterveld et al reported a decrease of 9.4°C in intra-articular temperature after a 30-minute application of chipped ice. They noted that even though the ice was removed at 50 minutes, intra-articular temperatures continued to decrease for up to 45 minutes. A decrease in nerve conduction velocity and a slowing in discharge rate of joint mechanoreceptors would result in less information being delivered to the spinal cord in a given period of time, and therefore, a decrease in inhibition.

Since cryotherapy stimulates cutaneous receptors, including mechanoreceptors (pressure) and thermoreceptors, these receptors may play a role in facilitating the quadriceps motoneuron pool. Quickly adapting mechanoreceptors excite the Ib interneurons, resulting in excitation of the quadriceps motoneuron pool. This mechanism would counteract inhibition mediated through the Ib interneurons. Perhaps large amounts of information reaching the spinal cord from several different sensory receptors, stimulated by the effusion and the ice, create an environment in which supraspinal centers intercede. Additionally, since the quadriceps motoneuron pool was facilitated beyond the baseline measurement, supraspinal activity is likely involved. A decrease in inhibition would return H-reflex values to a baseline (preinjection) level. Measurements above the baseline level must be modulated by factors outside the reflexive loop.

Supraspinal pathways generally modulate spinal reflexes. In other words, reflexive activity produced from afferent traffic is reduced by supraspinal pathways to allow for controlled movement. Perhaps this tonic activity is reduced during cryotherapy treatment, allowing for less supraspinal control over reflexive activity. Cervero et al discussed a descending tonic spinal inhibition that occurs as a mechanism limiting the amount of motoneuron inhibition caused by trivial environmental stimulation of cutaneous and subcutaneous mechanoreceptors. This idea is contrary to that discussed previously. They reported that, during joint injury, descending tonic spinal inhibition is reduced, allowing for increased AMI. In this case, since descending tonic spinal inhibition is thought to be initiated by environmental factors, ice could increase this process, thereby decreasing AMI. Further study is needed to better understand the supraspinal influences and the process by which ice facilitates motoneuron recruitment within the VM motoneuron pool.

Clinical observation provides support for cryotherapeutic facilitation of the motoneuron pool. During cryokinetics, in-
jured athletes seem able to perform exercises that were not possible before a cryotherapy treatment. Knight\textsuperscript{22} attributed this finding to a decrease in residual pain from the injury. However, these data show that changes to the motoneuron pool take place after knee effusion and cryotherapy treatment, and previous work suggested that this model facilitates the process in the absence of pain.\textsuperscript{2} Ice has a direct effect on diminishing AMI, not just pain.

The results of studies investigating the effects of cryotherapy on strength vary, with studies showing increased,\textsuperscript{54,55} decreased,\textsuperscript{25,27} and unchanged\textsuperscript{56,57} force production. These decreases in strength after cryotherapy were a product of cooling muscle, not the joint. Ruiz et al\textsuperscript{27} reported that isokinetic concentric and eccentric strength decreased immediately after cryotherapy treatment. However, there were no decreases in concentric strength at 20 and 40 minutes post-treatment. The differences reported in strength measurements after cooling were a product of variability in the type of measurement and the times and temperatures at which the measurements were taken. Additionally, each of these studies was conducted using healthy subjects. A population with abnormal joints may respond differently.

Functional measures of motor activity may decrease\textsuperscript{25} or be unaffected\textsuperscript{28} by cryotherapy. Cross et al\textsuperscript{55} reported that vertical jump decreased and shuttle run times increased immediately after ice immersion (foot and ankle). However, vertical jump was decreased by 1.1 cm and shuttle run times increased by 0.2 seconds. These small changes could have been due to a number of factors, including the temporary stiffness often experienced immediately after ice immersion.\textsuperscript{22} Our data suggest that recruitment within the motoneuron pool increases during and immediately after joint cooling and continues to increase during the post-treatment phase. Knee extensor torque decreases after knee effusion,\textsuperscript{14,39} which corresponds to our H-reflex measures in the control group. However, this is not a direct indication that a more functional measure of motoneuron pool recruitment would increase with cryotherapy, TENS treatments, or both. Further study is needed to determine if H-reflex measurement changes correspond to functional changes in force output over the same period of time in injured subjects.

Since cooling the skin may affect the electrical conductance properties of the tissue, it was necessary to measure surface temperatures at the site of the recording EMG electrodes to maintain the integrity of our measurement (Figure 3). Temperatures at the EMG electrode sites remained constant throughout the treatment (15 minutes, 31.52 ± 1.79°C, and 30 minutes, 31.49 ± 1.80°C) and post-treatment periods (45 minutes, 31.23 ± 1.84°C, and 60 minutes, 31.44 ± 1.69°C). Knee surface temperature measurements were also collected, showing a normal\textsuperscript{22} decline in temperature during the cooling phase and a rise in temperature during the post-treatment phase. With these data, we are confident that cooling the knee did not affect our measurements from the VM.

More than 53% of the screened subjects were excluded because we could not measure a maximum H reflex. A stimulator that produces a high voltage stimulus (100 to 200 V) with a pulse duration of at least 1.0 milliseconds would be ideal for the H-reflex measurement. Because our stimulator could only produce a pulse duration of 0.3 milliseconds at that intensity, we were unable to measure a maximum H reflex before the stimulator reached its maximum intensity. Larger amounts of subcutaneous fat in some subjects also made it difficult to obtain a stimulus intensity great enough to elicit a maximum H-reflex measurement.

In conclusion, the knee joint effusion model allows for investigation of neuromuscular changes associated with joint injury. The quadriceps motoneuron pool is inhibited in the absence of muscular injury or pain. Cryotherapy and TENS effectively dis inhibit the quadriceps motoneuron pool after knee joint effusion, and cryotherapy further facilitates the motoneuron pool. Reduction of AMI by these therapeutic modalities may permit earlier activation of musculature during joint rehabilitation, allowing for active exercise and its positive effects on healing and the rehabilitation process. Further work will allow us to determine if a reduction in AMI allows the injured athlete to return to competition faster and with less susceptibility to further injury.

References

Temporal Pattern of the Repeated Bout Effect of Eccentric Exercise on Delayed-Onset Muscle Soreness

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Objective: To determine the temporal pattern of the repeated bout effect of eccentric exercise on perceived pain and muscular tenderness associated with delayed-onset muscle soreness (DOMS).

Design and Setting: Subjects completed 2 identical eccentric exercise bouts separated by 6, 7, 8, or 9 weeks. The experiment was conducted in a biokinetics research laboratory.

Subjects: Sixteen male and 15 female untrained subjects (age = 24.59 ± 4.42 years, height = 171.71 ± 7.81 cm, weight = 73.00 ± 11.20 kg).

Measurements: Two physiologic characteristics of DOMS were measured immediately before and 0, 24, 48, and 72 hours after each eccentric exercise bout. Perceived pain was measured using a visual analog scale (VAS), and muscular tenderness was measured using a punctate tenderness gauge (PTG).

Results: Two 4 × 2 × 5 (group × bout × time) analyses of variance with repeated measures on the bout and time factors were performed on the VAS and PTG data. Significant (P < .05) main effects were found for group, bout, and time for the VAS and the PTG data. No significant interactions were detected. Post hoc analysis revealed significantly less perceived pain for the 9-week group than the 8-week group. The 7-week group had significantly less and the 8-week group had significantly more muscular tenderness than any other group. Perceived pain and muscular tenderness were significantly less after exercise bout 2 than after exercise bout 1. All subjects had significantly less perceived pain and muscular tenderness pre-exercise than 0 and 24 hours after the eccentric exercise bouts.

Conclusions: An effective prophylaxis for perceived pain and muscular tenderness associated with DOMS is the performance of an eccentric exercise bout 6 to 9 weeks before a similar exercise bout.

Key Words: musculoskeletal injury, eccentric exercise, repeated bout effect, visual analog scale

Delayed-onset muscle soreness (DOMS) affects most active people at some point in their lives. DOMS is a common ailment that in many cases impedes an athlete's performance. As part of a muscle tissue damage continuum, DOMS represents a limited form of muscle tissue damage that, on a larger scale, involves the entire functional muscle unit. DOMS presents with a dull, aching pain that develops 24 to 48 hours after a novel or unaccustomed exercise bout. The pain typically peaks between 24 and 72 hours postexercise when the muscles are tender and swollen. The deleterious effects of DOMS are well documented, yet there is no standard treatment or prophylaxis for the condition.

The effects of DOMS are alleviated when a soreness-producing exercise bout is preceded by a similar soreness-producing exercise bout. An adaptive response to one or more bouts of eccentric exercise has been termed the repeated bout effect and appears to be the best known prophylaxis for DOMS. The time frame of the adaptation remains enigmatic. Performance of a single eccentric exercise bout has been shown to reduce muscle soreness after a similar exercise bout up to 6 weeks but not beyond 9 weeks. The extent of the diminished prophylactic response over time is still unknown. Our purpose was to determine the temporal pattern of the repeated bout effect of eccentric exercise on perceived pain and muscular tenderness associated with DOMS when 2 identical exercise bouts were separated by 6, 7, 8, or 9 weeks.

METHODS

Research Design

The study consisted of 3 independent variables and 2 dependent variables. Independent variables were exercise group...
Subjects’ Age, Height, and Weight by the 6-, 7-, 8-, and 9-Week Groups (Mean ± SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-week (n = 7)</td>
<td>23.86 ± 5.61</td>
<td>171.63 ± 8.15</td>
<td>75.43 ± 11.90</td>
</tr>
<tr>
<td>7-week (n = 8)</td>
<td>23.38 ± 1.92</td>
<td>175.80 ± 9.36</td>
<td>80.29 ± 14.59</td>
</tr>
<tr>
<td>8-week (n = 8)</td>
<td>25.75 ± 7.21</td>
<td>167.96 ± 8.84</td>
<td>65.13 ± 7.44</td>
</tr>
<tr>
<td>9-week (n = 8)</td>
<td>25.38 ± 2.92</td>
<td>171.45 ± 4.90</td>
<td>71.16 ± 10.93</td>
</tr>
</tbody>
</table>

(6 weeks, 7 weeks, 8 weeks, or 9 weeks), bout (exercise bout 1 or 2), and time (immediately before or 0, 24, 48, or 72 hours after exercise). Dependent variables were perceived pain as measured via a visual analog scale (VAS) and muscular tenderness as measured via a punctate tenderness gauge (PTG). The study was conducted at the Temple University Biokinetics Research Laboratory.

Subjects
Sixteen male and 15 female Temple University students volunteered to participate in the study. Subjects’ mean age was 24.59 ± 4.42 years, height was 171.71 ± 7.81 cm, and weight was 73.00 ± 11.20 kg (Table). Subjects were screened and admitted for study participation based on the absence of current upper body weight training, upper extremity injury within one year of the study, and predisposing cardiovascular or cardiopulmonary conditions. Subjects were asked to refrain from performing upper body stretching and exercises, treating the affected arm, and taking anti-inflammatory medications during the data collection periods. One subject did not return to complete the second exercise bout and was dropped from the study. In accordance with the Temple University Institutional Review Board, which approved the study, appropriate subject consent was obtained before data collection.

Instrumentation and Equipment
Isokinetic Dynamometer. The Biodex B-2000 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY), was used to perform the exercise bouts, which consisted of eccentric contractions of the wrist extensor muscles of the subject’s nonwriting forearm. The dynamometer was calibrated by the primary investigator at the beginning of each data collection session according to the manufacturer’s guidelines. Mechanical reliability is 1.0 for eccentric peak torque, average power, and total work, and physiologic reliability ranges from 0.94 to 0.99 for eccentric peak torque, average power, and total work of the quadriceps and hamstrings muscle groups.

Visual Analog Scale. A variation of the VAS developed by Melzak was used to quantify the general level of soreness of the subjects. The VAS consists of a 10-cm line, with no soreness on the left end of the line and extreme soreness on the right end of the line. Subjects were asked to place a slash mark on the line according to the general level of perceived soreness at the time of assessment. A blank scale was used each time to avoid bias from preceding measurements. The slash mark was measured from the left end of the line to the nearest 0.1 cm. Scores were recorded as a value between no soreness (0) and extremely sore (10). The VAS is easily and quickly administered and has been used as a reliable measurement for determining the intensity of human pain.

Punctate Tenderness Gauge. Newham et al developed a method to measure tenderness upon palpation using a variation of the PTG. The PTG (Technical Products Co, Caldwell, NJ) used in this study consists of a 2-mm hemispheric metal probe attached to a strain gauge. A plastic grid with holes at 10 evenly spaced sites was placed over the subject’s experimental forearm with the elbow flexed to 90° and the forearm fully pronated. The proximal end of the grid was placed snugly in the subject’s cubital fossa, with the corners of the grid positioned over the medial and lateral humeral epicondyles and secured with self-adhesive strips. The PTG was inserted into each hole and depressed until the subject reported that the sensation of pressure changed to discomfort or pain. The criterion measure was the amount of pressure required to elicit the response and was recorded in pounds of pressure. Muscular tenderness, as measured using the PTG, and pounds of pressure are inversely related (ie, the more muscular tenderness, the less pressure required to elicit a response). This method of PTG application is comparable with weights traceable to the National Bureau of Standards (r = .99, intraclass correlation coefficient [2,1] = .98 lb; standard error of the mean = .03 lb) (D. C. Meserian, unpublished data, 1987 to 1991).

Data Collection
Group Assignment and Pre-Exercise Measurements. Each subject was randomly assigned to one of 4 exercise groups: 6 weeks, 7 weeks, 8 weeks, or 9 weeks. The 6-week group performed the second exercise bout 6 weeks after the initial exercise bout, while the 7-, 8-, and 9-week groups performed the second exercise bout 7, 8, or 9 weeks after the initial exercise bout, respectively. The VAS and PTG were administered before the exercise bout.

Exercise Positioning and Stabilization. Subjects were seated upright on the dynamometer accessory chair with the experimental (nonwriting) forearm on the padded armrest, which was positioned immediately proximal to the ulnar styloid process. The forearm was fully pronated and the triceps brachii was aligned with the dynamometer axis. The elbow was flexed to 90° with the forearm positioned in the horizontal plane. The start position was verified goniometrically by the primary investigator, who performed all goniometric measurements (intratester reliability, r ≥ .81). Straps were positioned across the subject’s pelvis, chest, and forearm to ensure stabilization of the arm and elbow during exercise. A folded towel was placed in the axilla to facilitate the adducted position and to allow for greater arm and elbow stabilization. Range-of-motion limits were set by the investigator at 60° of extension and 70° of flexion with 10% range limits in each direction.

Exercise Bout 1. Standardized instructions were read to each subject before the warm-up and exercise bouts. The warm-up consisted of 5 submaximal and 4 maximal eccentric repetitions, followed by exercise bout 1, which consisted of 5 sets of 50 maximal eccentric repetitions of the wrist extensor muscles with a 60-second rest period between sets. The dynamometer was set in the passive mode to allow the subject to actively resist wrist flexion, producing eccentric tension. After the exercise bout, the subject was instructed to relax and allow the dynamometer to return the wrist to the extended starting position to eliminate concentric work. Total work as a relative measure of muscular effort for the exercise protocol was determined from the computer output and recorded upon completion of the initial exercise bout.
Figure 1. Average perceived pain (cm) for 6-, 7-, 8-, and 9-week groups. *Significantly less perceived pain (P < .05) was found for the 9-week group than for the 8-week group.

Figure 2. Average perceived pain (cm) at exercise bouts 1 and 2. *Significantly less perceived pain (P < .05) was found for exercise bout 2 than for exercise bout 1.

Figure 3. Average perceived pain (cm) at pre-exercise and 0, 24, 48, and 72 hours. *Significantly less perceived pain (P < .01) was found at pre-exercise than at the 0- and 24-hour tests.

Figure 4. Average muscular tenderness for 6- and 9-week groups.

Figure 5. Average perceived pain (cm) at 0, 24, 48, and 72 hours. *Significantly less perceived pain (P < .05) was found for exercise bout 2 than for exercise bout 1.

Figure 6. Average muscular tenderness at 0, 24, 48, and 72 hours. *Significantly less muscular tenderness (P < .01) was found after exercise bout 2 than after exercise bout 1.

Visual analog scale and PTG tests were administered immediately after exercise bout 1. Subjects were reminded not to massage, stretch, or treat the exercised arm in any way and to refrain from taking anti-inflammatory medications for 3 days postexercise. Subjects returned to the laboratory 24, 48, and 72 hours postexercise for follow-up VAS and PTG administrations. Once the 3 days of follow-up data were obtained, the subjects were scheduled to return to the laboratory 6, 7, 8, or 9 weeks after the initial exercise bout, depending on group assignment.

Exercise Bout 2. Subjects returned to the laboratory for exercise bout 2 after the assigned number of weeks. The VAS and PTG were administered, and then subjects were positioned, stabilized, and exercised as they had been for exercise bout 1. Exercise bout 2 was terminated when the subject had produced the same total work as that of exercise bout 1. Total work output for each subject during exercise bout 2 duplicated the total work recorded for exercise bout 1. The VAS and PTG were administered immediately upon completion of the exercise bout and 24, 48, and 72 hours postexercise.

Data Analysis
Two 4 × 2 × 5 (group × bout × time) analyses of variance with repeated measures on the bout and time factors were performed on the VAS and PTG data. The Biomedical Data Program Statistical Software (University of California Press, Berkeley, CA) was used for data analyses. We performed Tukey HSD post hoc tests to determine where the significant differences occurred. The alpha level was set at P ≤ .05, and all hypothesis testing was completed in the null form.

RESULTS
Significant main effects were found for group, bout, and time for the VAS and PTG (Figures 1 and 2). No significant interactions existed. Post hoc analysis revealed that the 9-week group had significantly less perceived pain (F3,27 = 3.12, P < .05) than the 8-week group as measured via the VAS (Figure 1). Significantly less perceived pain (F1,3 = 5.18, P < .05) was found after exercise bout 2 than after exercise bout 1 as measured via the VAS (Figure 2). The time data revealed significantly less perceived pain (F4,12 = 28.39, P < .01) for the pre-exercise test than for the 0- and 24-hour tests as measured via the VAS (Figure 3).

Post hoc analysis of the PTG data revealed that the 7-week group had significantly less and the 8-week group had significantly more muscular tenderness (F3,27 = 3.35, P < .05) than any other group (Figure 4). Significantly less muscular tenderness (F1,3 = 62.49, P < .01) was found after exercise bout 2 than after exercise bout 1 as measured via the PTG (Figure 5). Significantly less muscular tenderness (F4,12 = 7.47, P < .01) was found for the pre-exercise test than for the 0-hour and 24-hour tests (Figure 6).

DISCUSSION
The expected temporal pattern of DOMS during the 72 hours immediately after the exercise bout is consistent with observations of others. Perceived pain and muscle tenderness were both significantly greater than baseline values at 24 and 48 hours after the exercise bout, with the DOMS resolving by 72 hours (Figures 2 and 5). The acute postexercise discomfort associated with DOMS was most likely due to structural and biochemical changes. Mechanical forces associated with the intense eccentric exercise bout of the present study likely damaged muscle proteins and connective tissue, leading to edema and an inflammatory reaction that caused secondary biochemical damage. Several mechanisms may be responsible for the...
adaptive effect observable 6 to 10 weeks after an eccentric exercise perturbation. Healing is usually observable by 72 hours after tissue injury, which may be responsible, in part, for the decreases in both perceived pain and muscle tenderness. The formation of protective proteins such as desmin or titin during healing may have been responsible for the attenuation of DOMS after the second exercise bout (Figures 1 and 4). Collagen deposition in the myotendinous junction and perimysial areas during maturation and remodeling would increase the strength of connective tissue surrounding the myofiber, providing an additional protective effect. Finally, repair of the sarcoplasmic reticulum and sarcotendinous apparatus, increasing their resistance to damage, would further reduce the calcium-mediated damage and efflux of intramuscular proteins after an eccentric exercise bout.

We expected progressively higher levels of perceived pain and muscular tenderness when an exercise bout was repeated after 6, 7, 8, and 9 weeks. Group data in the present study revealed differences in the magnitude of the average perceived pain and muscular tenderness incurred by the subjects. Significantly less perceived pain was found for the 9-week group than for the 8-week group (Figure 1). While randomization of subject group assignment would have negated individual variations in the exercise bout response, the relatively small sample size may account for the unexpected results in perceived pain and muscular tenderness of the 7- and 8-week groups.

The exercise bout data in our study were consistent with the expected outcome. Regardless of group, less perceived pain and muscular tenderness occurred after exercise bout 2 than after exercise bout 1. Similarly, Byrnes et al found that repeating a bout of downhill running after 3 and 6 weeks resulted in significantly less perceived soreness for the second exercise bout when compared with the first exercise bout. After 9 weeks, perceived soreness ratings for the second exercise bout exceeded those for the first exercise bout. The downhill running was performed at a variable treadmill speed with a constant heart rate (170 beats per minute) and constant duration (45 minutes) for each subject. Nosaka et al also found significantly less perceived muscle soreness when an eccentric exercise bout using the elbow flexors was repeated after 6 weeks. No significant decrements in perceived soreness ratings were found when the second exercise bout was performed 10 weeks after the first exercise bout. A similar constant workload was performed during each of the eccentric exercise bouts of the elbow flexors. Additionally, Newham et al found progressively more soreness when eccentric exercise bouts of the elbow flexors were repeated every 2 weeks for 6 weeks. Elbow flexors were exercised at a constant workload for all exercise bouts. We used the wrist extensor muscles because these were not eccentrically trained, were used minimally in activities of daily living, and would not incapacitate the subject with pain and reduced function. The relative workload was designed to exactly duplicate the amount of tension produced by the muscles and was measured by the isokinetic dynamometer for each exercise bout for each subject.

Figure 4. Average muscular tenderness (pounds of pressure) at 6-, 7-, 8-, and 9-week groups. *Significantly less muscular tenderness (P < .05) was found for the 7-week group than for any other group. †Significantly more muscular tenderness (P < .05) was found for the 8-week group than for any other group. Note: values are inversely related to muscular tenderness.

Figure 5. Average muscular tenderness (pounds of pressure) at exercise bouts 1 and 2. *Significantly less muscular tenderness (P < .01) was found for exercise bout 2 than for exercise bout 1. Note: values are inversely related to muscular tenderness.

Figure 6. Average muscular tenderness (pounds of pressure) at pre-exercise and 0, 24, 48, and 72 hours. *Significantly less muscular tenderness (P < .01) was found at pre-exercise than at the 0- and 24-hour tests. Note: values are inversely related to muscular tenderness.
CONCLUSIONS

Perceived pain and muscular tenderness associated with an eccentric exercise perturbation can be reduced by performing similar exercise 6, 7, 8, or 9 weeks before beginning an exercise program. Most individuals engaging in physical activity and rehabilitation program noncompliance are often attributed to the discomfort associated with DOMS. Performance of an eccentric exercise bout up to 9 weeks before beginning an exercise program can reduce delayed postexercise muscle pain and tenderness. Preseason conditioning may begin up to 2 months before intense physical activity, resulting in reduced delayed muscle pain and tenderness during the first weeks of a competitive sports season. Reduced muscle pain, tenderness, stiffness, and weakness associated with DOMS may help improve performance and reduce injury due to unsound biomechanical compensations early in a competitive sports season. Sports medicine personnel must emphasize the importance of the prophylactic benefits of the repeated bout effect on DOMS to individuals who are involved in novel or unaccustomed physical activity. Further research is needed to determine other methods of reducing the severity of the signs and symptoms associated with DOMS.

ACKNOWLEDGMENTS

We thank Carl Mattacola, PhD, ATC, for reviewing the manuscript.

REFERENCES

The Carry-Over Effects of Diathermy and Stretching in Developing Hamstring Flexibility

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Objective: To compare the effects of low-load, short-duration stretching with or without high-intensity, pulsed short-wave diathermy on hamstring flexibility.

Design and Setting: We used a single-blind, repeated-measures design (pretest and posttest for all treatments) that included a placebo. The 3 independent variables were treatment mode, pretest and posttest measurements, and day. Treatment mode had 3 levels: diathermy and stretching, stretching alone, and control. The dependent variable was range of motion. Subjects were randomly assigned to the diathermy and stretching, stretching-only, or control group. Subjects were treated and tested each day (at approximately the same time) for 5 days, with a follow-up test administered 72 hours later. Hamstring flexibility was tested using a sit-and-reach box before and after each treatment. Diathermy and stretching subjects received a 15-minute diathermy treatment on the right hamstring at a setting of 7000 pulses per second, with an average pulse width of 95 μsec. Stretching-only subjects received a 15-minute sham diathermy treatment. Both diathermy and stretching and stretching-only subjects then performed three 30-second stretches (short duration) before being retested. Control subjects lay prone for 15 minutes before being retested.

Subjects: Thirty-seven healthy college students (11 men, 26 women, age = 20.46 ± 1.74 years) volunteered.

Measurements: Hamstring flexibility was measured using a sit-and-reach box before and after each treatment.

Results: The average increases in hamstring flexibility over the 5 treatment days for the diathermy and stretching, stretching-only, and control groups were 6.06 cm (19.6%), 5.27 cm (19.7%), and 3.36 cm (10.4%), respectively. Three days later (after no treatment), the values for the diathermy and stretching, stretching-only, and control groups were 8.27 cm (26.7%), 6.83 cm (25.3%), and 4.15 cm (14.2%), respectively. No significant differences in hamstring flexibility were noted among the groups.

Conclusions: Diathermy and short-duration stretching were no more effective than short-duration stretching alone at increasing hamstring flexibility. The effects of diathermy with longer stretching times need to be researched.

Key Words: heat, stretch, injury treatment

Heat and stretching are often used by clinicians to increase flexibility and restore lost range of motion.1-9 Vigorous heating (>4°C over core temperature) increases collagen tissue extensibility and decreases tissue viscosity10-13 and tension.11 High-intensity, pulsed short-wave diathermy can produce vigorous heating over large areas14 and, in so doing, induce muscle relaxation,15 decrease muscle spasm,13 and decrease joint stiffness.13

Both isometric contraction (muscle contraction against a stable force that is followed by relaxation) and passive stretching increase joint range of motion.1 Passive stretching, however, appears to be the safest and best stretching method3 because prestretch isometric contractions may promote lingering facilitation of the contracted muscles16 and thus produce more tension and a greater risk of injury.2

In animal studies, researchers discovered that stretching a tendon while it was being heated increased tendon length more than stretching alone.11 Low-load, long-duration stretching performed once the tissues reached significantly elevated temperatures, however, resulted in the greatest increases in residual tissue length12 and produced the least amount of damage17 when compared with tissues stretched at lower temperatures with higher loads.12,17

Two groups of investigators3,4 reported that deep heat (ultrasound) and low-load, long-duration stretching of human triceps surae muscle (dorsiflexion) resulted in small, short-term increases (1.2° to 3°) in flexibility. Their conclusions, however, are debatable due to the methods used: (1) the area treated with ultrasound was so large that deep heating probably did not occur;3 (2) there was no control for the stretching used;4 and (3) the muscle studied was not necessarily tight, possibly possessing a significant range for improvement in flexibility.3,4

Once muscle has been vigorously heated with high-intensity, pulsed short-wave diathermy, the intramuscular temper-
ature remains vigorously heated for approximately 5 minutes. We believe that stretching should be performed immediately after the diathermy treatment in order to effectively increase tissue extensibility.

To date, no researchers have investigated the effects of using high-intensity, pulsed short-wave diathermy and passive stretching on improving flexibility. Our objective was to determine if this method of heat and stretching would increase hamstring range of motion more than stretching alone in uninjured subjects.

METHODS

We used a single-blind, 2×3×6 factorial design with repeated measures. The dependent variable was range of motion. The 3 independent variables were treatment mode, pretest and posttest measurements, and day. Treatment mode had 3 levels: diathermy and stretching, stretching alone, and control. Measurements were taken for 6 days.

Subjects

Thirty-seven healthy, college students (11 men, 26 women, age = 20.46 ± 1.74 years) volunteered to participate. Subjects were excluded from the study if (1) their straight-leg, hip-flexion range of motion was greater than 100°, (2) they had a history of either hamstring or lower back injury, (3) they had metal pins, plates, or screws in the right femur, (4) they were or could possibly be pregnant, or (5) during the study, they reported any discomfort that the researchers deemed to be more than the normal sensation of stretched tissue. The study was approved by the university’s institutional review board. All participants signed a consent form after being informed of the risks involved with participation. All participants continued their daily routine without altering their stretching or exercise habits throughout the course of the study.

Instruments

We used a Magnatherm SSP (International Medical Electronics, Ltd, Kansas City, MO) diathermy unit with an operating frequency of 27.12 MHz. The unit houses dual 200-cm² induction drum coil electrodes with 2-cm space plates. The unit was calibrated before the study.

A standard plastic goniometer (Fred Sammons Inc, Bissell Healthcare Corp, Brookfield, IL), marked in 1° increments, was used to initially screen subjects’ straight-leg, hip-flexion range of motion. Hamstring range of motion was tested with a Figure Finder Flex-Tester sit-and-reach box (Novel Products Inc, Rockton, IL).

Procedures

We tested hamstring flexibility before and after each treatment session using a sit-and-reach box equipped with a 5.08-cm (2-in) diameter tube at its base. Subjects sat barefoot with their legs under the ledge of the sit-and-reach box with the right (treatment) leg extended, the heel against the tube, and the left leg slightly bent (Figure 1). The right foot was plantar flexed (but relaxed) over the tube to remove any effect of triceps surae muscle tightness. Subjects then slowly stretched forward as far as the right leg would allow. The distance that the subjects’ fingers reached along the sit-and-reach box was recorded. We used the best of 3 trials for statistical analysis.

Subjects lay prone on a treatment table with their feet off the end of the table for 15 minutes (Figure 2). One of 3 treatments was then applied. Subjects in the diathermy and stretching group had their hamstrings dried with a towel to remove any sweat that might have accumulated on the area. The diathermy drums were placed over the belly of the hamstrings and the posterior aspect of the distal hamstrings and musculotendinous junction at the knee. We applied diathermy at a setting of 7000 pulses per second with an average pulse width of 95 µsec. At the completion of the treatment, we turned off the diathermy unit.

The procedure for the stretching group was identical to that of the diathermy and stretching group; however, this diathermy unit caused no heating of the tissues. Before the study, we unhooked the power output leading to the diathermy drums. The lights turned on, but no heat entered the tissues, thus creating a sham diathermy treatment. Subjects in the control group simply lay prone on the treatment table (with the feet off the end of the table) for 15 minutes before being tested (Figure 2).

Immediately after the heat treatment, the diathermy and stretching and stretching-alone subjects performed three 30-second stretches. Subjects stood on the left foot (toe turned out laterally approximately 25° from midline) in front of a table 0.762 m (2.5 ft) high (Figure 3). The distance between the left foot and the table was measured by a tape measure fixed to the floor to ensure that all of the stretches were performed identically. The subject placed the right leg on the
Table 1. Sit-and-Reach Measurements (Mean ± SD in cm)

<table>
<thead>
<tr>
<th>Day*</th>
<th>Diathermy and Stretching</th>
<th>Stretching Only</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pretest 31.1 ± 6.4</td>
<td>26.9 ± 9.0</td>
<td>28.9 ± 7.7</td>
</tr>
<tr>
<td></td>
<td>Posttest 35.3 ± 6.0</td>
<td>30.0 ± 8.3</td>
<td>30.0 ± 8.5</td>
</tr>
<tr>
<td>2</td>
<td>Pretest 33.1 ± 5.9</td>
<td>28.4 ± 8.1</td>
<td>29.9 ± 7.3</td>
</tr>
<tr>
<td></td>
<td>Posttest 36.7 ± 5.8</td>
<td>31.8 ± 8.2</td>
<td>30.8 ± 6.5</td>
</tr>
<tr>
<td>3</td>
<td>Pretest 34.6 ± 5.8</td>
<td>29.8 ± 7.9</td>
<td>29.9 ± 7.0</td>
</tr>
<tr>
<td></td>
<td>Posttest 38.5 ± 5.4</td>
<td>33.1 ± 7.5</td>
<td>31.6 ± 7.0</td>
</tr>
<tr>
<td>4</td>
<td>Pretest 35.9 ± 5.3</td>
<td>30.9 ± 8.4</td>
<td>31.7 ± 6.8</td>
</tr>
<tr>
<td></td>
<td>Posttest 39.1 ± 4.9</td>
<td>34.2 ± 7.9</td>
<td>33.0 ± 6.4</td>
</tr>
<tr>
<td>5</td>
<td>Pretest 37.1 ± 5.4</td>
<td>32.2 ± 7.6</td>
<td>31.8 ± 6.3</td>
</tr>
<tr>
<td></td>
<td>Posttest 40.3 ± 5.2</td>
<td>35.1 ± 7.2</td>
<td>33.0 ± 6.2</td>
</tr>
<tr>
<td>8</td>
<td>Pretest 39.3 ± 5.6</td>
<td>33.8 ± 7.1</td>
<td>33.0 ± 6.4</td>
</tr>
</tbody>
</table>

*Both the diathermy and stretching and the stretching-only groups showed significant changes in range of motion each day within groups but no significant changes between groups.

RESULTS

The 3 groups began the study with slightly different but not statistically different amounts of hamstring range of motion as measured by the sit-and-reach box (Table 1). There was no difference among treatment groups (F2,34 = 2.36, P = .11) or interactions for day-by-group (F8,136 = 1.2, P = .28), day-by-pretest or posttest (F4,136 = .525, P = .72), or day-by-pretest or posttest-by-group measurements (F8,136 = .405, P = .92). All of the subjects improved their flexibility over the 6-day test period (F4,136 = 42.6, P = .001). Immediate effects (pretest and posttest) (F1,34 = 152.4, P = .001) and pretest or posttest-by-group interactions (F2,34 = 11.3, P = .001) were significant. Both the diathermy and stretching and stretching-alone groups had significantly greater immediate effects in range of motion than the control group; however, there was no difference between the diathermy and stretching and the stretching-alone groups (Tukey < .05).

There was a carry-over, or chronic, effect for days (F4,136 = 47.93, P = .001) (Table 2 and Figure 4), but no difference among groups (F2,34 = 1.51, P = .24) or in day-by-group interaction (F8,136 = 1.63, P = .12). Days 4 through 6 were different from days 2 and 3, and days 5 and 6 were different from day 4.

DISCUSSION

Our results support previous findings that stretching increases flexibility.1,2,6,7,16 Researchers in 2 studies determined that
Table 2. Chronic Effects of Stretching (Change in Pretest from Day 1)

<table>
<thead>
<tr>
<th>Group</th>
<th>Diff (cm)</th>
<th>% Change</th>
<th>Diff (cm)</th>
<th>% Change</th>
<th>Diff (cm)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diathermy and</td>
<td>2.0 ± 2.5</td>
<td>6.4</td>
<td>1.4 ± 3.3</td>
<td>5.2</td>
<td>1.0 ± 3.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Stretching*</td>
<td>3.5 ± 3.2</td>
<td>11.3</td>
<td>2.9 ± 4.6</td>
<td>10.8</td>
<td>1.1 ± 2.9</td>
<td>3.8</td>
</tr>
<tr>
<td>Stretching Only*</td>
<td>4.9 ± 3.8</td>
<td>15.6</td>
<td>4.0 ± 6.3</td>
<td>14.9</td>
<td>2.9 ± 3.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Control</td>
<td>6.1 ± 3.6</td>
<td>19.6</td>
<td>5.3 ± 5.5</td>
<td>19.7</td>
<td>3.0 ± 3.4</td>
<td>10.4</td>
</tr>
<tr>
<td>Day</td>
<td>8.3 ± 3.5</td>
<td>26.7</td>
<td>6.8 ± 5.4</td>
<td>25.3</td>
<td>4.1 ± 3.9</td>
<td>14.2</td>
</tr>
</tbody>
</table>

*Both the diathermy and stretching and the stretching-only groups showed significant changes in range of motion each day within groups but no significant changes between groups.
†Mean ± SD. Diff indicates difference.

Figure 4. Residual effects (change in range of motion from day 1). Treatments were applied on days 1 through 5.

Our results do not support previous reports that deep heat and stretching cause greater increases in flexibility than stretching alone in the short term.19 Warren et al18 noted that the greatest increases in residual tissue length in rat-tail tendons occurred when low-load, long-duration stretching was performed once the tissues had reached significantly elevated temperatures.12 Tendon properties change under mechanical stress at temperatures greater than 37°C.19 With increased temperatures, the microstructure of collagen changes such that the stress-relaxation property increases (greater relaxation), which permits deformation when stretched.19 When collagen is heated, it undergoes a number of thermal transitions. These transitions cause increased extensibility and allow plastic deformations of the tissue when it is stretched.19,20 These studies,10-12,18-21 however, were all performed on rat-tail, kanga-
Limitations

The first limitation to our study involves the use of the sit-and-reach test to measure hamstring length. Past research has shown that the back-saver sit-and-reach test has good test-retest reliability (r = 0.90) and has compared favorably with the Leighton Flexometer (Leighton Flexometer, Inc, Spokane, WA) and goniometer measurements. Some researchers, however, argue that due to spinal and pelvic movement, the sit-and-reach test is not sensitive enough to isolate hamstring flexibility and have replaced it with the active knee-extension test.

A second limitation of our study was the method of stretching. Our method of bending at the waist and reaching for the toes posteriorly rotates the pelvis. Researchers have shown that keeping the pelvis in anterior rotation, with a more upright position of the trunk, actually increases flexibility more than when stretching with the pelvis rotated posteriorly.

Another limitation is the duration of our stretch (3 stretches for 30 seconds each, daily for 1 week). After this study, we completed another study that used a 10-minute stretch during pulsed short-wave diathermy treatment daily for 3 weeks. The group with diathermy increased flexibility significantly more than the sham group. Apparently a heat and stretching routine is more effective when long-duration stretching is employed and repeated for longer than a week.

Another limitation involved our measuring the range of motion of the control group on a daily basis. We did not know that this short exercise would actually increase range of motion. We suggest that the control group should be tested only on the first and last day of the experiment to avoid the stretching and increased flexibility gained during the intermediate sit-and-reach measurements.

A last limitation is that we did not use a randomized-block design so that subjects were similar in initial flexibility. Subjects in our diathermy and stretching group began with better hamstring flexibility than those in the stretching-only and control groups, leaving more room for improvement in the last 2 groups. If all groups began with similar flexibility, our results might have been different.

CONCLUSIONS

In our study, flexibility increased in all of our subjects. Although numerically different, the increases in flexibility between the diathermy and stretching, stretching-only, and control groups were not statistically significant. No group outperformed another.

Our study is important and adds to the knowledge base of athletic training. First, we have learned that the sit-and-reach test not only measures flexibility but also increases it, and as such, flexibility studies should not measure daily range of motion of a control group. Second, our results support previous research that stretching increases flexibility. Last, our findings do not support previous reports that deep heat applied before stretching techniques.

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Pulsed Shortwave Diathermy and Prolonged Long-Duration Stretching Increase Dorsiflexion Range of Motion More Than Identical Stretching Without Diathermy

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Objective: To compare the effects of 3 treatments on ankle dorsiflexion range of motion: prolonged long-duration stretching, pulsed shortwave diathermy followed by stretching, and pulsed shortwave diathermy, stretching, and ice combined.

Design and Setting: A 2 x 5 x 15 repeated-measures (on 2 factors) design guided this study. Range-of-motion change in triceps surae flexibility was the dependent variable. The 3 independent variables were treatment group, pretest and posttest measurements, and day. Treatment group had 4 levels: control, stretching (10 minutes of stretching via the weight and pulley), diathermy and stretching (20 minutes of diathermy and 10 minutes of stretching), and diathermy, stretching, and ice (20 minutes of diathermy, 10 minutes of stretching applied after 15 minutes of diathermy, and 5 minutes of ice applied during the last 5 minutes of stretching). Each subject received 14 treatments throughout 3 weeks, with a follow-up measurement taken 6 days after the last treatment.

Subjects: Forty-four healthy college-student volunteers not involved in any flexibility program.

Measurements: We measured ankle dorsiflexion using a digital inclinometer before and after treatment.

Results: After 14 days of treatment, the range-of-motion increase was greater after heat and stretching than after stretching alone. After 6 additional days of rest, the heat and stretching range-of-motion increase was greater than that for stretching alone.

Conclusion: Pulsed shortwave diathermy application before prolonged long-duration static stretching was more effective than stretching alone in increasing flexibility throughout 3 weeks. After 14 treatments, prolonged long-duration stretching combined with pulsed shortwave diathermy followed by ice application caused greater immediate and net range-of-motion increases than prolonged long-duration stretching alone.

Key Words: ice, deep heating, flexibility

Flexibility programs are used clinically for their many benefits, including muscle relaxation, posture improvement, body symmetry, relief of low-back pain, relief of muscle cramps and soreness, and injury prevention. To improve the effects of stretching, combinations of heat and stretching have been used by clinicians in a variety of ways. Deep vigorous heating in combination with stretching requires a temperature increase of more than 4°C over core temperature at a depth of 3 to 5 cm without damaging superficial tissue. Deep heating is thought to lessen nerve sensitivity, increase blood flow, increase tissue metabolism, decrease muscle spindle sensitivity to stretch, cause muscle relaxation, and increase tissue flexibility. It is assumed that, when used in conjunction with stretching, the benefits of deep vigorous heating allow greater tissue flexibility than stretching alone.

Researchers previously studied heat and stretching techniques by using hot packs, whirlpools, and ultrasound as thermal agents. Ice has been applied after stretching in an effort to cool tissues in their elongated state. These studies on animals and humans have produced mixed results.

Pulsed shortwave diathermy is used for deep vigorous heating. Used clinically, it heats tissue at depths of 3 to 5 cm by transferring energy into deep tissue through high-frequency current. Tissue temperature is controlled by the length of application, with maximum increases of 4°C to 6°C. Diathermy heats large areas of muscle and, as such, may be more suitable than ultrasound for improving flexibility in large muscles.

The purposes of our study were to compare the effects of combining pulsed shortwave diathermy, with or without ice, with prolonged long-duration calf stretching on (1) daily (short-term) changes in flexibility, (2) day-to-day (long-term) changes in flexibility, and (3) retention of flexibility 6 days after cessation of treatment.

METHODS

A 2 x 5 x 15 repeated-measures (on 2 factors) design guided this study. Triceps surae flexibility, measured by range-of-motion (ROM) change, was the dependent variable. The 3
Figure 1. Bottom view of the weight and pulley used to apply a constant, low-load, prolonged stretch.

The independent variables were treatment mode, pretest and posttest measurements, and day. Change in ROM was affected by one independent variable: the treatment mode. Treatment mode had 5 possible interventions, including control, control with measurements, stretching only, diathermy and stretching, and diathermy, stretching, and ice. Each independent variable was compared with the control group.

Subjects

Sixty healthy college students volunteered to participate and gave informed consent after being advised of their rights and risks of participation. Forty-four subjects (21 men, 23 women; age, 22.5 ± 2.0 years; height, 171.0 ± 9.0 cm; weight, 72.6 ± 12.8 kg) completed the study. We instructed subjects to continue their normal daily routine or exercise habits throughout the study. We excluded subjects if they were involved in any flexibility or strength training for the calf, had a recent ankle injury or history of ankle injury that would be adversely affected by static stretching, had metal plates or screws in the right leg, were pregnant, or had any allergies to cold. The university institutional review board reviewed and approved this study.

Procedures

Subjects were randomly assigned to 1 of 5 groups: control 1, control 2, stretching, heat and stretching, and heat, stretching, and ice. The control 2 group was not stretched and was measured twice: at the beginning and end of the study. Subjects in the control 1, stretching, heat and stretching, and heat, stretching, and ice groups were stretched 14 times in 3 weeks, once daily except for weekends. In these latter 4 groups, ROM was measured before and after each treatment and 6 days after the last treatment. Subjects reported at the same time every day for their treatments and measurements.

We measured ankle position on a treatment table set up with a weight-and-pulley system so that constant tension could repeatedly be applied to the triceps surae (Figure 1). To place each subject in a consistent position for each measurement, the subjects lay prone on the treatment table, with their feet hanging over the edge. We placed reference marks, used to take measurements, with a permanent ink pen. The first mark was placed on the lateral side of the calf 10 cm proximal from the middle of the lateral malleolus. The second mark was placed on the posterior side of the calf, forming a line that connected the first and second reference points and was perpendicular to the line connecting the lateral malleolus and the first reference mark. The third reference mark was placed on the flattest part of the plantar aspect of the heel of the subject’s shoe. We secured the subject to the table with a strap to prevent sliding due to the pull of the weights. Next, we applied the stretching to the subject’s foot using a rope and pulley with approximately one third of the subject’s body weight attached. We instructed the subject to relax while we lined up the digital inclinometer with the first mark and allowed it to stabilize. Then we zeroed the device and moved it to the second reference point on the heel of the subject and allowed it to stabilize before taking the reading (Figure 2A and B). The elapsed time from applying tension until the measurement was recorded was less than 30 seconds.

The stretching group received a 10-minute static stretch on the table with the weight and pulley. We previously performed a pilot study to determine how much weight to apply. Our pilot study revealed that applying the same weight to subjects for 10 minutes was uncomfortable for some subjects and ineffective for larger subjects. Using our pilot study data, we chose to apply approximately one third of the subject’s body
weight to the calf. The only time we strayed from this formula was when this weight was too difficult for the subject. Our procedure was similar to that of Wessling et al,3 who applied a 23.1-kg load for 1 minute.

During treatment session 1 of the stretching, weight was adjusted in 5-lb (2.27-kg) increments until it was one third of the subject's body weight. If the subject could not tolerate this much weight, we decreased it until the subject could tolerate it while feeling a firm stretch of the triceps surae. By treatment 2, subjects were being stretched for 10 minutes total, with approximately one third of their body weight applied by the pulley apparatus. The heat and stretching group received a 20-minute diathermy treatment while lying on the table. With the skin dried to remove excess moisture, the diathermy drum was placed over the musculotendinous junction of the triceps surae (Figure 3). The pulsed shortwave diathermy output was set at 800 bursts per second, 400-microsecond burst duration, 800-microsecond interburst interval, with a peak root mean square amplitude of 150 W per burst and an average root mean square output of 48 W.12,13 At the 15-minute mark, we applied the stretching (one third of body weight) for 10 minutes. The heat, stretching, and ice treatment plan repeated the heat and stretching treatment plan except that at the end of 20 minutes of diathermy, a 1-kg ice bag was applied to the musculotendinous junction with an elastic wrap for 5 minutes.

Instruments

We used 2 Megapulse (Accelerated Care Plus, Sparks, NV) shortwave diathermy machines operating at a frequency of 27.12 MHz. The units housed a 200-cm² induction coil with an air space plate of 2 cm. The manufacturer calibrated both machines before we began our study.

We used a Dualer Electronic Inclinometer (Jtech Medical Industries, Heber City, UT) for all ankle measurements. The electronic inclinometer used eccentric encoding wheels that were accurate to ±1° and had a repeatability of ±1°. We followed the manufacturer's instructions at all times to ensure accuracy. The measurement was reliable (r = 0.99; intraclass correlation coefficient [ICC] of the control pretreatment and posttreatment measurements).

The stretching equipment consisted of weights in 5- to 10-lb (2.27- to 4.54-kg) increments attached to 4 rope-and-pulley sets constructed by the researchers. All 4 sets applied equal tension on the subjects.

Statistical Analysis

We used the raw data in degrees to look at several differences. Pretreatment to posttreatment was the difference between the measurements taken before and after treatment each day. Days was the difference between the measurements taken before treatment each day. Group was the difference between the groups. We calculated the mean changes in ankle position from the 14 single-treatment sessions for the control 2, stretching, and ice treatment plan repeated the heat and stretching, and heat, stretching, and ice groups.

To test for main and interaction effects, we used a 2 X 5 X 15 analysis of variance (ANOVA) (pretreatment to posttreatment, days, groups) with raw scores (α < .05). Because there were interactions in the overall ANOVA, we performed a series of simple main-effects tests. We performed a 2 X 2 ANOVA (control 1, control 2, first and last day) to see what effect taking measurements every day would have on ankle position. Because there was no difference, we eliminated control 2 from subsequent analysis. To measure the effect of our treatments, we performed a 4 X 15 ANOVA (groups, days) with pretreatment scores. To measure changes immediately after treatment, we performed a 4 X 14 ANOVA using the differences between the pretreatment and posttreatment measurements. We used a series of Scheffé post hoc tests to test for simple effects.

We performed further Scheffé post hoc testing to determine if individual comparisons were significant for the differences between groups and days using raw scores, change scores, and pretreatment to posttreatment scores. Using the same test, we compared the difference between pretreatment and posttreatment on each day for each group and the pretreatment to posttreatment means of all groups.

RESULTS

Results are displayed in Figure 4. Ankle position in the control 1 and treatment groups was approximately 96° to 101° (or 6° to 11° beyond neutral) at the beginning of the experiment and increased to 99° to 105° after the last treatment and 98° to 107° after a week of no treatment (Table 1). The ROM was not different between the 2 control groups (F1.31 = 0.13, P = .72, power = 0.06), indicating that daily measurements...
in the first control group did not induce changes. Therefore, the control 2 group was eliminated from further analysis.

Overall, ankle position differed among groups (F3,32 = 2.92, P = .049, power = 0.639, $\eta^2 = .215$), days (F13,416 = 16.03, P = .001, power = 1.00, $\eta^2 = .334$), and pretreatment to posttreatment (F1,416 = 163.63, P = .001, power = 1.00, $\eta^2 = .836$). Also, the interactions among groups and days (F39,416 = 1.48, P = .036, power = 0.994, $\eta^2 = .122$), groups and pretreatment to posttreatment (F3,32 = 15.54, P = .001, power = 1.00, $\eta^2 = .593$), and days and pretreatment to posttreatment (F13,416 = 2.22, P = .008, power = 0.962, $\eta^2 = .065$) were significant.

The immediate effects of treatment (pretreatment to posttreatment or intrasession ankle-position changes) were different among groups (F3,32 = 15.54, P = .001, power = 1.00, $\eta^2 = .593$) and days (F14,416 = 6.76, P = .008, power = 1.00, $\eta^2 = .334$), but the interaction among groups and days was not significant. Daily changes in the control 1 group ranged from $-0.25^\circ$ to $0.30^\circ$ per day, which was significantly less than those in the 3 treatment groups, which ranged from $1.25^\circ$ to $4.38^\circ$ per day (stretching-alone average, $2.47^\circ$/d; heat and stretching, $2.94^\circ$/d; heat, stretching, and ice average, $3.24^\circ$/d) (F3,32 = 15.5, P = .001, power = 1.00, $\eta^2 = .593$). There was no difference among the 3 treatment groups (Scheffé P > .05).

Net effects of treatment (cumulative, residual, or intersession ROM changes) were analyzed using pretreatment measurements. There was a day-by-group interaction (F42,448 = 1.43, P = .043, power = 0.995, $\eta^2 = .118$), so further analysis involved simple main-effects testing. Net ROM did not change in either the control or stretch groups (Scheffé P < .05) but was significantly different in the heat and stretching group between days 1 and 18 and in both the heat and stretching and heat, stretching, and ice groups between days 1 and 25.

Analysis of differences in net ROM among groups was complicated by differences in initial ankle position. Net ankle position on the first day was less in the control 1 group ($96.9^\circ \pm 6.9^\circ$) than in the 3 treatment groups ($99.8^\circ \pm 3.2^\circ$ to $101.4^\circ \pm 5.4^\circ$, Scheffé P < .05). Ideally, all groups would have the same ROM at the start. We computed change scores by subtracting day 1 pretreatment scores from each subsequent day pretreatment score (Table 2) and used these change scores for analysis. There were no differences among groups (change scores) on days 1 through 17 (Scheffé P > .05). On days 18 and 24, ROM changes were greater in the heat and stretching group ($7.25^\circ \pm 4.5^\circ$) than in either the control 1 ($2.5^\circ \pm 2.6^\circ$) or stretching-only group ($4.18^\circ \pm 2.82^\circ$; Scheffé P < .05) groups but not different than the heat, stretching, and ice group ($4.89^\circ \pm 3.22^\circ$, Scheffé P > .05).

### DISCUSSION

#### Prolonged Stretching Defined

The terms short-duration stretching, long-duration stretching, and prolonged stretching have been used in the research literature without specific definitions. We present the following definitions for our article and as a point of departure for discussion and debate concerning these terms.

- **Short-duration stretching:** lasts less than 1 minute
- **Long-duration stretching:** lasts longer than 1 minute
- **Prolonged stretching:** extends throughout several days

So the term prolonged stretching should be used only in combination with short or long duration, such as prolonged long-duration stretching.

We selected 1 minute as the demarcation between short duration and long duration because previous researchers have tested stretches with durations of 15 seconds, 30 seconds, 60 seconds, 120 seconds, 8 minutes, 10 minutes, and 3 sets of 5 minutes. Readers should note that these are general descriptors, and individual treatments should include the duration (seconds, minutes) of the stretching and the number of sessions.

Using a heat-and-stretching regimen (with high-intensity,
pulsed shortwave diathermy) for 3 weeks may result in greater changes in ROM than stretching alone. Our results concur with those of Lentell et al\textsuperscript{7} and Wessling et al\textsuperscript{3} while contradicting others\textsuperscript{14,17} (Table 3). Discrepancies among these studies may be the result of differences in any one or a combination of several variables: application of heat and the duration, intensity, and frequency of stretching.

**Application of Heat**

Our results and those from other studies suggest that vigorous deep heating combined with prolonged long-duration stretching is more effective than prolonged long-duration stretching alone in increasing flexibility throughout 3 weeks.\textsuperscript{18} Several areas of research on human and animal subjects form the nucleus of this idea. Static stretching is an effective method for increasing flexibility.\textsuperscript{8-10} Animal tendon properties change when put under a static stretch at temperatures greater than 37°C.\textsuperscript{10,11} This change in tendon properties allows for increased extensibility and plastic deformation of the stretched tissue.\textsuperscript{11,18-22} Wessling et al\textsuperscript{3} and Lentell et al\textsuperscript{7} reported that vigorous heating combined with static stretching was more effective than stretching alone in human subjects; however, they heated tendon only, whereas we heated a combination of tendon and muscle tissue. It is possible that the net ROM gains came primarily from the increased tendon flexibility that results from vigorous heating and stretching as shown with animal tendons.\textsuperscript{18-22}

Despite evidence supporting the heat and stretching theory, research has not been conclusive. Draper et al\textsuperscript{17} reported no significant differences in immediate and net ROM between a heat and stretching group and a stretching-alone group. Draper et al\textsuperscript{4} reported that ROM was significantly greater in an ultrasound heat and stretching group than in a stretching group after 3 treatment sessions but not significantly different after 9 treatment sessions. It is possible that the type of heating modality used and other factors, such as the intensity, duration, and frequency of stretch, may be responsible for these apparent contradictions.

Pulsed shortwave diathermy appears to be a more appropriate modality than ultrasound for heating tissues before stretching.\textsuperscript{4} First, pulsed shortwave diathermy not only heats tissues to similar peak temperatures as ultrasound, but it heats a much larger area of tissue.\textsuperscript{13} The Megapulse used in our study offered a heating area of 200 cm\textsuperscript{2}, whereas ultrasound heads are typically 3 to 10 cm\textsuperscript{2}.\textsuperscript{13} Second, tissue heated with pulsed shortwave diathermy retains heat 3 times longer than that treated with ultrasound.\textsuperscript{12}

**Table 2. Differences in Range of Motion From Day 1 (Degrees; Mean ± SD)**

<table>
<thead>
<tr>
<th>Day</th>
<th>Control 2</th>
<th>Control</th>
<th>Stretching</th>
<th>Heat and Stretching</th>
<th>Heat, Stretching, and Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-0.50 ± 2.78</td>
<td>0.91 ± 2.81</td>
<td>0.38 ± 2.33</td>
<td>-0.89 ± 2.32</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-1.63 ± 3.02</td>
<td>0.20 ± 2.34</td>
<td>-0.75 ± 1.49</td>
<td>0.89 ± 2.76</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-0.38 ± 2.72</td>
<td>1.81 ± 2.56</td>
<td>1.75 ± 2.55</td>
<td>1.78 ± 3.63</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.13 ± 3.18</td>
<td>0.82 ± 3.49</td>
<td>3.25 ± 2.49</td>
<td>0.56 ± 3.91</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.25 ± 2.96</td>
<td>0.27 ± 2.94</td>
<td>2.25 ± 2.55</td>
<td>2.33 ± 3.12</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1.38 ± 3.16</td>
<td>0.27 ± 2.80</td>
<td>2.50 ± 2.73</td>
<td>2.11 ± 2.03</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.88 ± 1.96</td>
<td>0.82 ± 2.89</td>
<td>1.75 ± 3.49</td>
<td>2.67 ± 3.50</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2.38 ± 2.97</td>
<td>1.82 ± 3.82</td>
<td>2.00 ± 2.93</td>
<td>1.44 ± 1.81</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1.75 ± 2.60</td>
<td>2.00 ± 2.72</td>
<td>2.75 ± 2.92</td>
<td>2.11 ± 1.83</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1.25 ± 2.43</td>
<td>2.34 ± 3.44</td>
<td>4.00 ± 2.51</td>
<td>2.67 ± 2.45</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2.13 ± 2.53</td>
<td>2.27 ± 3.47</td>
<td>3.25 ± 2.66</td>
<td>1.56 ± 2.83</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>2.25 ± 2.71</td>
<td>2.36 ± 3.29</td>
<td>4.38 ± 3.46</td>
<td>3.56 ± 2.56</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>1.75 ± 2.25</td>
<td>1.91 ± 4.39</td>
<td>4.75 ± 4.53</td>
<td>3.22 ± 2.54</td>
<td></td>
</tr>
<tr>
<td>→ 24</td>
<td>1.6 ± 2.34</td>
<td>2.50 ± 2.67</td>
<td>4.18 ± 2.82</td>
<td>7.25 ± 4.50</td>
<td></td>
</tr>
</tbody>
</table>

→ No treatment or measurements for the weekend.
⇒ No treatment or measurements for 6 days.

**Duration, Intensity, and Frequency of Stretching**

We believe that a low-load, long-duration stretch in place of a high-load, brief stretch is required to take advantage of the responses of connective tissue under tensile deformation while being heated. Warren et al\textsuperscript{10} reported that the greatest residual increases in rat-tail tendon ROM occurred after a low-load, long-duration static stretch was applied while the tissue was vigorously heated. Previous studies by Draper et al\textsuperscript{16} (20-second static stretch), Wessling et al\textsuperscript{3} (1-minute static stretch), and Draper et al\textsuperscript{17} (30-second static stretch) did not use a low-load, long-duration static stretch. All 3 sets of investigators used a large-force, short-duration static stretch. However, Lentell et al\textsuperscript{7}, who used a low-load, long-duration stretch, reported that combining superficial heat and low-load, long-duration stretching resulted in significantly greater increases in ROM than low-load, long-duration stretching without preheating.

Little prior research has indicated how much weight to apply to the calf to create a low-load, long-duration stretch. Lentell et al\textsuperscript{7} applied 0.5% body weight to the subject's shoulder to increase external rotation ROM. Wessling et al\textsuperscript{3} applied a 23.1-kg load for 1 minute, using a method similar to ours. Our pilot study revealed that applying the same weight to subjects for 10 minutes was uncomfortable for some subjects and ineffective for larger subjects. Using our pilot study data, we combined the previous 2 studies' methods and chose to apply approximately one third of the subject's body weight to the calf. The only time we strayed from this formula was when this weight was too difficult for the subject.

The time required to cause tensile deformation of tissue varies according to the type and duration of the force applied.\textsuperscript{10,11} A low-force stretching method requires more time to produce the same amount of elongation as a higher-force
Table 3. Research Comparing Stretching Alone with Heat and Stretching

<table>
<thead>
<tr>
<th>Authors</th>
<th>Tissue Studied</th>
<th>Location</th>
<th>Thermal Modality</th>
<th>Number of Treatments</th>
<th>Type of Stretching</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Load, Prolonged Stretching Studies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wessling et al (1987)8</td>
<td>Human muscle &amp; tendon</td>
<td>Calf</td>
<td>Ultrasound</td>
<td>1 (1 min)</td>
<td>Low-load, prolonged (23.1 kg)</td>
<td>Heat combined with static stretching increases range of motion more than static stretching alone.</td>
</tr>
<tr>
<td>Lentelli et al (1992)9</td>
<td>Human muscle &amp; tendon</td>
<td>Shoulder</td>
<td>Hot pack</td>
<td>3 (three 5-min stretches)</td>
<td>Low-load, prolonged (0.5% of subject’s body weight)</td>
<td>*Short term: heat and stretching range-of-motion increase is greater than stretching alone. Long term: heat and stretching range-of-motion increase is greater than stretching alone.</td>
</tr>
<tr>
<td>Lehmann et al (1970)10</td>
<td>Animal tendon</td>
<td>Rat tail</td>
<td>Water bath</td>
<td>1 (variable)</td>
<td>Low-load, prolonged (variable)</td>
<td>Combining heat with low-load prolonged stretching increases range of motion more than stretching alone. Low-load prolonged stretching produces greater range-of-motion increase than high-load short duration heat and stretching range-of-motion increase is greater than stretching alone. A low-load prolonged stretch should be used at the highest temperature possible.</td>
</tr>
<tr>
<td>Present study</td>
<td>Human muscle &amp; tendon</td>
<td>Calf</td>
<td>Pulsed short-wave diathermy</td>
<td>14 (10 min)</td>
<td>Low-load, prolonged (approximately ½ of subject’s body weight)</td>
<td>*Short term: heat and stretching range-of-motion increase is greater than stretching alone. Long term: heat and stretching range-of-motion increase is greater than stretching alone.</td>
</tr>
<tr>
<td>High-Load, Short-Duration Stretching Studies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Short term indicates the results immediately after the end of the treatment or treatments. Long term indicates the results 3 to 7 days after the end of the treatment or treatments.
method; however, the proportion of tissue lengthening that re­
mains after tensile stress is removed is greater for the low­
load, long-duration stretching method.\textsuperscript{11,17} Higher-force, short­
duration stretching favors recoverable, elastic-tissue de­
formation, whereas low-load, long-duration stretching en­
hances permanent, plastic deformation.\textsuperscript{10,11} Sapega et al\textsuperscript{18} wrote that this principle does not necessarily rule out combin­
ing higher forces with a long duration of stretch, but in the
clinical setting, high-force application has a greater risk of
causing pain and possibly tissue rupture. In addition, labo­
atory studies\textsuperscript{10,11,29} indicated that when connective tissue struc­
tures are permanently elongated, some degree of mechanical
weakening takes place, even though outright rupture does not
occur. The amount of weakening depends on the manner and
degree of tissue stretching. Of particular interest is that, for
the same amount of tissue elongation, a high-force stretching
method produces more structural weakening than a low-force,
slower method. Apparently a low-load, long-duration static
stretch is effective and safe.\textsuperscript{10,11,20}

Researchers\textsuperscript{3,4} have reported that heat and stretching can
cause significant ROM changes in human tissue after just one
treatment. However, these studies involved high-load, short­
duration stretching, and investigators did not record ROM af­
after the last treatment and after a period of rest to measure
net gains. Only Lentell et al\textsuperscript{7} showed significantly greater ROM
after one treatment using heat and stretching than stretching
alone in combination with a low-load, long-duration stretch.
Animal tendon research\textsuperscript{9–11} with heat and low-load, long-du­
r duration stretching supports the findings by Lentell et al.\textsuperscript{7} Our
study contradicts these findings: the heat and stretching group
did not have significantly greater ROM than the stretching
group until after treatment 13.

Questions

Based on previous research, we could not explain some of
our results. First, why did the control 2 group increase in
ROM? Although this was a cause for concern, the ROM in­
crease was not statistically significant. Also, this small increase
was possibly due to the increased activity of the students
during the spring months when we conducted the study.

Second, why did ROM increase in each of the treatment
groups during the 6 days of rest? We noticed this phenomenon
in another one of our studies\textsuperscript{23} and can only speculate that the
increased flexibility during the 6 days of rest might be due to
reduction in muscle guarding. Even though our technique in­
volved prolonged long-duration stretching, the force of one
third of the body weight might have been more than subjects
were accustomed to. The 6 days of rest was apparently enough
time to wash out the effects of muscle guarding, leading to
increased ROM.

Third, although the heat, stretching, and ice group produced
the same ROM gains as the heat and stretching group after
treatment, why were those gains not retained? Previous re­
searchers have shown that cold application may benefit ROM
in short-term treatment by reducing muscle spasm and painful
inhibition.\textsuperscript{16,24} These effects, however, have not been found to
last very long.\textsuperscript{25}

Perhaps other questions can be answered by further research
incorporating some of the following modifications:

1. A randomized block design would allow the different
groups to start at approximately the same ROM.
2. To more precisely determine the net changes in ROM,
future researchers should begin treatment on the second
day (ie, only take a pretreatment measurement on the first
day) and should have a posttreatment measurement 24
hours after the last day to determine the net effect of the
last treatment.
3. Researchers could attempt to compare longer or shorter
stretching times with a weight-and-pulley system as used
in this study.
4. These methods could be applied to other parts of the body,
such as the hamstrings, where a greater increase in ROM
is possible.
5. Further research is needed to compare different lengths of
diathermy treatments and numbers of treatments to find
out which combination yields the greatest flexibility gains.
6. Further research is needed to address why the greatest
ROM increases occurred 6 days after the last treatment.
Investigators should look at various rest periods after
training (stretching) and at various rest periods after stan­
ard training periods. One possibility is to train (stretch)
different groups of subjects for 1 to 4 weeks and to test
the effect of the different rest periods on net increases in
ROM.
7. Finally, more research needs to be performed on the effect
of prolonged long-duration stretching combined with thermal
modalities on subjects who have connective tissue
changes due to aging or pathologic conditions.

Limitations

When studying the effect of pulsed shortwave diathermy on
prolonged long-duration stretch, it is important to be able to
ensure even heating throughout all of the subjects. A limita­
tion in this study is that we do not know how much temperature
increase occurred inside the muscle because we did not mea­
sure intramuscular temperature. Our protocol was based on
reports by Draper et al\textsuperscript{12} and Garrett et al,\textsuperscript{13} who produced
temperatures of more than 40°C. Also, although shortwave
diathermy with induction drum electrodes penetrates fat fairly
well, varying thicknesses of the subcutaneous layer of fat
around the calf of the individual subjects may have produced
slightly higher muscle temperatures in lean individuals.\textsuperscript{12} A
third limitation of this study is our inability to control the
activity level of the subjects. Although we did not allow sub­
jects who were regularly participating in a flexibility or
strength training program involving the calf to join in our
study, we were unable to control the daily activity level of
those who participated. Increasing level of activity, begin­
ing new activities, or varying the time of day of activity may
have affected the temperature and stiffness of the subject’s calf
at the time of treatment.\textsuperscript{18} An additional limitation of this study
is that prolonged long-duration stretching is most often used
by clinicians with patients with ROM loss due to injury, sur­
gery, or another pathologic condition. This study was per­
formed on young, healthy college subjects; these results cannot
be applied to older or injured subjects without further research.
Finally, this stretching technique was performed with subjects
non–weight bearing on the triceps surae, which is primarily
involved in weight-bearing motor function. It is unclear how
many of these flexibility gains would have been present if the
subjects were tested in the weight-bearing position.

CONCLUSIONS

After 3 weeks of pulsed shortwave diathermy and prolonged
long-duration stretching applied to the calf, ankle ROM in-
creased more than with prolonged long-duration stretching alone. Pulsed shortwave diathermy before stretching is a safe and effective protocol for increasing tissue extensibility. However, a weight-and-pulley system may not be a practical way to stretch the triceps surae in the athletic training room setting. Ice has been shown to increase ROM by reducing pain and spasm in acute cases. Ice application after heat and stretching may not be of much benefit for increasing ROM due to chronic adhesions and muscle shortening.

REFERENCES

The Bactericidal And Cytotoxic Effects Of Antimicrobial Wound Cleansers

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**Objective:** Wound care is a part of daily activity for many athletic trainers. Knowing which cleansers are effective against the bacteria that most commonly cause infection and whether they are toxic to healthy cells enables athletic trainers to make educated decisions on which cleanser to use. We compared the bactericidal effectiveness and cytotoxicity to human fibroblast cells of 4 cleansers at various dilutions.

**Design and Setting:** A 4 x 4 factorial design was used for the cytotoxicity testing. The independent variables were type and dilution of cleanser. The dependent variable was cell viability of the human fibroblast cells. We used a 2 x 3 x 4 x 4 factorial design for the bacterial testing. The independent variables were type and dilution of bacteria and type and dilution of cleanser. The dependent variable was the bactericidal action of the cleanser on the bacteria.

**Subjects:** Human foreskin samples were used to obtain a line of fibroblast cells. Bacterial samples were obtained from an athletic training clinic, isolated from swabs of a whirlpool water supply valve (Pseudomonas aeruginosa) or skin surface (Staphylococcus aureus).

**Measurements:** We obtained bactericidal measurements by testing isolated Gram-negative (Pseudomonas aeruginosa) and Gram-positive (Staphylococcus aureus) bacteria. Minimum and maximum concentrations were identified according to bactericidal effectiveness. Cytotoxicity measurements were obtained from spectrophotometer readings of a neutral red assay for fibroblast cell viability. Final dilutions tested were determined by pilot testing.

**Results:** At the 1:5 dilution of product in sterile 0.9% saline, both Cinder Suds and Nitrotan and hydrogen peroxide were different from the control with regard to *Pseudomonas aeruginosa*. At the 1:10 dilution, both Betadine and hydrogen peroxide were different from the control with regard to *Pseudomonas aeruginosa*. These 2 cleansers were also different from each other. At the 1:10 dilution, only Betadine was not different from the control for the cytotoxicity testing.

**Conclusions:** Betadine was both effective against bacteria and not harmful to human fibroblast cells at a 1:10 dilution of a commercially purchased solution.

**Key Words:** wound cleansers, cytotoxicity, bactericidal, antimicrobial
(Betadine, hydrogen peroxide, Cinder Suds and Nitrotan, and 0.9% saline as the control), and the dilution (1:5, 1:10, 1:50, and 1:100 product in saline). The dependent variable was bacterial toxicity.

We used a 4 × 4 factorial design for the cytotoxicity assay. The independent variables were the type of cleanser and the dilutions of the cleansers tested (1:5, 1:10, and 1:50).

Subjects

Human fibroblast cells were obtained from the Indiana University School of Medicine Department of Dermatology. The primary cell line of fibroblasts was established as an explant from human foreskin samples. Once the flasks were confluent with a monolayer of cells (the bottom of the flask fully covered), the cells were harvested and some were frozen for later use. The fibroblast cells were used for all human cytotoxicity determinations. Exemption from the Human Subjects Committee was obtained because primary human cell cultures were used for all testing measures.

Instruments

We used a spectrophotometer (Model #U-2000, Hitachi Ltd., Tokyo, Japan) to measure cell viability via neutral red bioassay. The spectrophotometer measures light absorbency at set wavelengths. An inverted phase-contrast microscope (Model ELWD 0.3, Nikon Corp., Tokyo, Japan) was used to detect cell confluence and growth in tissue culture flasks. A light microscope (Model ATC 2000, Nikon Corp., Buffalo, NY) was used for cell counting. A 37°C incubator supplied with 5% CO₂ (Model 023, Forma Scientific, St. Louis, MO) provided optimal growing conditions for fibroblast cells. A laminar flow hood (LabGard Model NU427, NuAire Inc., Plymouth, MN) was used to ensure sterile working conditions. A centrifuge (Model GPR, Beckman Instruments Inc., Palo Alto, CA) was used for collecting cells from various cultures by centrifugation.

Testing Procedures

The Cinder Suds and Nitrotan wound cleansers were donated by the manufacturer; we purchased the other cleansers commercially. The manufacturer’s suggestion is to use Cinder Suds to assist with cleansing of the wound and then to saturate a sterile gauze pad and lay it on the wound for several minutes. This allows the ingredients to seep into the skin and the wound. All cleansers were diluted in cell culture medium for the fibroblast testing and in saline for all bacterial testing.

Tissue Culture

Tissue culture methods and neutral red bioassay were modeled after Cooper et al.12 Human fibroblasts were isolated from human foreskin samples. The tissue sample was minced in a sterile 0.15 M saline solution containing 1% trypsin for enzymatic separation of epidermis from dermis. To isolate individual human fibroblasts, 0.025% trypsin + 0.01% ethylenediaminetetraacetic acid (EDTA) was used. The human fibroblasts were grown in complete Dulbecco’s Modified Eagle’s Medium (DMEM) Gibco BRL, Bethesda, MD) containing 10% fetal bovine serum (FBS) 10 ng/mL epidermal growth factor (Imcera Inc, Terre Haute, IN), and penicillin (10 000 U/mL)-streptomycin (10 000 mg/mL) as an antibiotic. To ensure that the pH of the cleanser did not interfere with cell viability, pH measurements were obtained for each agent as well as for the control (media with no cleanser added).13,14

Cytotoxicity Determination Procedure

The neutral red assay was chosen because previous testing has demonstrated it to be a sensitive measure of cell viability.15–17 Subconfluent human fibroblasts (2 × 10⁵ cells/mL) were grown in secondary cultures in complete DMEM + 10% FBS (without antibacterial agents). The human fibroblasts were harvested and placed into 96-well, flat-bottom tissue culture plates and incubated for 3 days to establish cell confluence. Antibacterial agents were diluted in DMEM + 10% FBS (growth medium) and placed into the wells. The diluted cleansers were allowed to remain in contact with the cells for 15 minutes, and then the medium was removed. Neutral red (3-amino-7-dimethylamino-2-methylphenazine hydrochloride) was added to each well, and the plates were placed in the incubator for 3 hours. The cells were then washed with formol-calcium (10 mL 40% formaldehyde, 10 mL 10% anhydrous calcium chloride, and 80 mL water) and fixed using an acetic acid-ethanol mixture (1.0 mL glacial acetic acid in 100 mL 50% ethanol), the dye extracted using a repeating pipetter, and the absorbency at 540 nm measured (A₅₄₀) using a spectrophotometer. The uptake of neutral red is proportional to the number of viable (live) cells.18 The control was medium without an added test agent.

Bactericidal Procedures

Serial dilutions of each agent were made in filtered sterile saline. Two log concentrations were tested at half-log intervals. Concentrations of 1:5, 1:10, 1:50, and 1:100 were tested.

The method used by Lineaweaver et al14 was modified for this experiment. Samples of bacteria were obtained from one of the whirlpools in an athletic training room. Pure cultures were evaluated by Gram staining with microscopic evaluation and biochemical species identification. Paired bacterial suspensions (each containing 1 × 10⁷, 1 × 10⁸, or 2.5 × 10⁸ organisms) of P aeruginosa and S aureus were cultured separately in nutrient broth. Bacteria were suspended in 3.0 mL of either a topical agent or saline for 15 minutes. The suspensions with either topical agent or saline were then centrifuged at 2000 × g for 5 minutes and resuspended in 3.0 mL of saline. The suspensions were plated on nutrient agar culture medium (Difco Labs, Bethesda, MD) and incubated for 24 hours at 37°C. Colonies present after the 24-hour culture were counted. Colony counts were coded (0 = no growth, 1 = 1 to 30 colonies, 2 = 31 to 100 colonies, 3 = 101 to 200 colonies, 4 = 201 to 300 colonies, and 5 = >300 colonies), and the coded data was used for statistical analysis. Concentrations as specified for each test agent were used to determine maximal and minimal bactericidal concentrations.

STATISTICAL ANALYSIS

We used an analysis of variance to test for statistical significance of cytotoxicity. We also used univariate F tests and the Tukey procedure for post hoc testing. Results for the bactericidal study were coded and analyzed using the Kruskal-Wallis test. Post hoc testing was done using the Mann-Whitney U test. A probability level of P ≤ .05 was set for all tests.
Table 1. Results of Bactericidal Testing

<table>
<thead>
<tr>
<th>Agent</th>
<th>Control</th>
<th>1:5</th>
<th>1:10</th>
<th>1:50</th>
<th>1:100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5.0 ± 0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Betadine</td>
<td>0.0 ± 0.0*</td>
<td>0.0 ± 0.0*</td>
<td>1.8 ± 1.3*</td>
<td>3.7 ± 2.5*</td>
<td></td>
</tr>
<tr>
<td>Hydrogen peroxide</td>
<td>2.6 ± 2.1</td>
<td>3.2 ± 2.5</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td></td>
</tr>
<tr>
<td>Cinder Suds and Nitrotan</td>
<td>2.2 ± 2.5*</td>
<td>3.6 ± 1.6</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td></td>
</tr>
</tbody>
</table>

*Significantly different from control bactericidal results (P ≤ .05).

Table 2. Cytotoxicity Results

<table>
<thead>
<tr>
<th>Agent</th>
<th>pH</th>
<th>pH Control</th>
<th>1:5</th>
<th>1:10</th>
<th>1:50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.5</td>
<td>0.2776 ± 0.0062</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Betadine</td>
<td>7.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen peroxide</td>
<td>7.6</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Cinder Suds and Nitrotan</td>
<td>7.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significantly different from control cytotoxicity results (P ≤ .05).

RESULTS

Bactericidal Results

We found no differences among the bacterial concentrations tested (Table 1). Differences were found between bacterial growth and dilution of cleansers ($X^2_4 = 14.9$, $P = .005$) and between bacterial growth and type of cleanser ($X^2_3 = 13.0$, $P = .005$). No differences were found for S. aureus at any of the dilutions and for P. aeruginosa at dilutions 1:50 and 1:100. Statistically significant differences were revealed for P. aeruginosa between the dilutions of 1:5 ($X^2_3 = 7.8$, $P = .05$) and 1:10 ($X^2_3 = 7.6$, $P = .05$).

Post hoc testing using the Mann-Whitney U test for non-parametric data revealed no differences at the dilution 1:5 between Betadine and Cinder Suds and Nitrotan, Betadine and hydrogen peroxide, Betadine and control, and Cinder Suds and Nitrotan and hydrogen peroxide. Statistically significant differences at the 1:5 dilution were found between Cinder Suds and Nitrotan and control ($U < .001$, $P = .03$) and hydrogen peroxide and control ($U < .001$, $P = .03$). No differences were found at the 1:10 dilution between Betadine and Cinder Suds and Nitrotan, Cinder Suds and Nitrotan and hydrogen peroxide, and Cinder Suds and Nitrotan and control. There were statistically significant differences at the 1:10 dilution between Betadine and hydrogen peroxide ($U < .001$, $P = .03$), Betadine and control ($U < .001$, $P = .03$), and hydrogen peroxide and control ($U < .001$, $P = .03$).

Cytotoxicity Results

Cytotoxicity testing showed an interaction between type and dilution of cleansers (Table 2; $F_{4,23} = 7.4$, $P = .001$). Simple main-effects testing revealed that at a 1:5 dilution, Betadine ($F_{3.9} = 18.5$, $P = .01$), hydrogen peroxide ($F_{3.9} = 18.5$, $P = .002$), and Cinder Suds and Nitrotan ($F_{3.9} = 18.5$, $P < .001$) were all different from the control. At the 1:10 dilution, hydrogen peroxide ($F_{3.9} = 13.2$, $P = .002$), and Cinder Suds and Nitrotan ($F_{3.9} = 13.2$, $P = .002$, $SE = .047$) were both different from the control. Betadine was not different from the control at the 1:10 dilution. At the 1:50 dilution, there were still significant differences between the Cinder Suds and Nitrotan and the control.

DISCUSSION

Previous research has shown that if an antimicrobial wound cleanser does not kill bacteria, the risk of infection is significantly higher. We used a Gram-negative (P. aeruginosa) and a Gram-positive (S. aureus) bacterium for bactericidal testing procedures. The bacterial samples were obtained from an athletic training room whirlpool and skin surfaces. Pure cultures were verified by Gram staining, and the bacteria were identified using biochemical testing. We chose these 2 bacteria for several reasons. First, together they represent a large spectrum of the bacteria that cause skin wound infections. S. aureus is present as a normal flora organism on the skin surfaces of most healthy humans. P. aeruginosa is a ubiquitous environmental organism associated with whirlpool folliculitis, an infection caused by immersion in contaminated water. Athletic trainers may encounter wound infections caused by either of these common bacteria that are representative of the 2 main bacterial categories. In addition, the cell walls of the 2 bacteria are very different. Each has a peptidoglycan protective layer, but in P. aeruginosa, this layer is only 10 nm thick, whereas in S. aureus, it is 80 nm thick. The thicker this peptidoglycan layer, the more resilient the bacteria are to surface-active antimicrobial agents. Because we found no significant differences among any of the cleansers for the S. aureus bacteria, we can hypothesize that the cleansers may not contain strong enough ingredients to be effective against Gram-positive bacteria. Both the hydrogen peroxide and the Cinder Suds and Nitrotan were more specifically bactericidal for the P. aeruginosa; that is, they were more effective at killing that bacterial type versus the S. aureus. Betadine was equally effective against both bacteria. Although not statistically significant, there were numeric differences in Betadine’s effectiveness against the 2 bacteria versus the other cleansers.

We chose the cleansers to be tested based on our experience in the athletic training environment and from the results of the Goldenberg study. Goldenberg showed that many athletic
trainers are currently using Betadine and hydrogen peroxide for wound cleansing.¹ Cinder Suds and Nitrotan were chosen because they are marketed specifically to athletic trainers in various catalogues. The chosen cleansers have a variety of different active ingredients. Betadine contains 10% povidone iodine, which is equivalent to 1% available iodine in the marketed, undiluted product. Hydrogen peroxide solution contains 3% stabilized hydrogen peroxide. Cinder Suds contains water, soap, isobutene, and propane. Nitrotan contains picric acid (0.2% vol/vol), tannic acid (1.5% vol/vol), benzyl alcohol (6.1% wt/vol), and isopropyl alcohol (62% wt/vol). Finally, Betadine was the only cleanser that was similar to the control at the 1:10 dilution for cytotoxicity testing. It was also bactericidal at this concentration. This is the ideal combination for an antimicrobial wound cleanser. It kills the bacteria that cause infection, but even more importantly, it is not toxic to the fibroblast cells critical to the healing process. This could be a result of the active ingredient; none of the other cleansers tested have povidone iodine as an active ingredient.

Betadine was safe at a diluted concentration. At a 1:5 dilution, it was toxic to the human fibroblast cells in this study, and by extrapolation, the commercially purchased concentration would be toxic to human fibroblast cells as well. Thus, it is important to note that in order for Betadine to be nontoxic for human fibroblast cells, it must be diluted. For a 1:10 dilution, I part Betadine and 9 parts sterile saline should be mixed. This dilution is beneficial in many ways. Not only does it create an optimal healing environment by killing bacteria while sparing fibroblast cells, but a single purchase also lasts much longer. This lowers costs, as it is somewhat expensive to use concentrated Betadine and few athletic training budgets are unlimited.

The literature is currently divided as to the effectiveness of these antimicrobial cleansers. Some researchers²,⁴ suggest that Betadine at certain concentrations is very effective and causes minimal damage to healthy tissue. However, others⁴,⁶,⁷,¹⁴,¹⁵,²¹ believe that Betadine’s toxicity against the healthy tissue is greater than its bactericidal effectiveness. Hydrogen peroxide’s effectiveness is under discussion as well. Several investigators²,¹⁴,²²,²³,²⁵ have demonstrated that hydrogen peroxide’s bactericidal effectiveness is minimal, while its cytotoxicity is very high. Others³,²⁶ have suggested that at higher dilutions, it may not be as toxic to the healthy tissues but most likely is still ineffective against bacteria. Our study is the first to address bactericidal effectiveness and cytotoxicity of Cinder Suds and Nitrotan, although Nitrotan is advertised to “prevent infection and promote healing.”

Clinical Relevance

As health care professionals, athletic trainers need to be aware not only of the bactericidal effects of an antimicrobial wound cleaner but also of the cytotoxic effects on healthy human cells. Our results demonstrate that Betadine in saline at a 1:10 dilution of the commercially purchased solution was effective in killing both Gram-positive and Gram-negative bacteria, yet it was not harmful to normal fibroblast cells. As such, we recommend this 1:10 dilution be used in practice to provide the optimal balance between the bactericidal and cytotoxic effects. Further, this dilution is an excellent cost-cutting measure.

REFERENCES

The Development of Expert Male National Collegiate Athletic Association Division I Certified Athletic Trainers

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*California State Polytechnic University, Pomona, CA; †McGill University, Montreal, Quebec, Canada; ‡California State University, Fresno, Fresno, CA

Objective: To identify the major influences in the development of expert male National Collegiate Athletic Association (NCAA) Division I certified athletic trainers. 

Design and Setting: The participants were individually interviewed, and the data were transcribed and coded.

Subjects: Seven male NCAA Division I certified athletic trainers, who averaged 29 years of experience in the profession and 20 years at the Division I level.

Results: We found 3 higher-order categories that explained the development of the certified athletic trainers and labeled these meaningful experiences, personal attributes, and mentoring. The growth and development of the athletic trainers were influenced by a variety of meaningful experiences that began during their time as students and continued throughout their careers. These experiences involved dealing with challenging job conditions, educational conditions, and attempts to promote and improve the profession. The personal attributes category encompassed the importance of a caring and service-oriented attitude, building relationships with athletes, and maintaining strong bonds within their own families. Mentoring of these individuals occurred both inside and outside the athletic training profession.

Conclusion: We provide a unique view of the development of athletic trainers that should be of interest to those in the field, regardless of years of experience.

Successful individuals in any field seek environments that are congruent with the characteristics that allow them to express their attitudes and values while best using their skills and abilities. Although the discipline of athletic training has many positive attributes associated with it, athletic trainers must deal with a number of stressors that may include dual responsibilities (e.g., head athletic trainer and curriculum director), lack of resources, and high athlete-to-athletic trainer ratios. The demands can make it difficult for the athletic training professional to stay excited and motivated for an extended period. The question then becomes, "What can be done in the profession of athletic training to ensure that those people who enter the profession are prepared for what awaits them?" Our study is an attempt to address this issue.

Krumboldtz and Worthington outlined some factors that can help ease the transition for students who are entering the workplace, including the importance of a knowledgeable and respected counselor or mentor. Under the tutelage of this leader, a student's abilities and skills are refined or expanded (or both) in areas such as organization, interpersonal communication, and reasoning. After acquiring these skills, students can work specifically in their field of interest, such as health care, electronics, or engineering.

Research in athletic training has also supported the importance of mentoring with respect to career transition of young professionals. For example, Curtis et al. found that the clinical experience became more meaningful and beneficial when a supervising athletic trainer or mentor provided guidance and understanding in a given situation. Moreover, the interaction between the student and supervisor positively affected the career development of the student.

During the last 2 decades, studies on the career development patterns of certified athletic trainers (ATCs) have been sparse. Quantitative studies in career development issues have focused on topics such as the quality of supervision in athletic training education programs, factors that affect the professional lives of athletic trainers, and the importance of selected employment characteristics. An alternative method of data acquisition involves using qualitative research methods to emphasize the processes and meanings that are not examined in terms of quantity, amount, intensity, or frequency. Qualitative researchers seek to capture the richness and complexity of individual experiences. For example, why are so many ATCs burning out so early in their careers, or what attracts individuals to the athletic training profession? The answers to these types of questions can be collected using a number of different qualitative research methods, such as observations, narratives, semiotic analyses, and interviews.
The purpose of our study was to conduct an in-depth examination of male National Collegiate Athletic Association (NCAA) Division I ATCs who have been identified as leaders in their field based on their longevity and contributions to the field of athletic training. In particular, what factors helped contribute to their rise to prominence? A qualitative method was used to help meet the goals of the study. This allowed the ATCs an opportunity to describe their experiences from a phenomenologic perspective and, thus, maximized the opportunity for them to accurately describe their experiences and for the research team to capture the complexity of this topic.

METHODS

Participants

The criteria for identifying our expert ATCs were in agreement with previous research on expert performers in other domains, in which a minimum of 10 years of experience or more than 10,000 hours of concerted time in the field was required.8,9 These criteria were used as minimum requirements, because the focus was to formulate a sample with more than 25 years of experience as an athletic trainer. A panel of 3 ATCs who were familiar with possible candidates generated a list of 23 potential male subjects from various universities across the United States. Each candidate was then contacted by telephone and given a brief explanation of the study. The final group of 7 participants from 6 different states was determined by their willingness to participate in the study and their availability to meet for an interview before or at the National Athletic Trainers’ Association Convention in Kansas City, MO, June 16–19, 1999.

The participants averaged 29 years of experience as professionals in the field of athletic training and 20 years of experience at the Division I level. The participant group also included District and National Athletic Trainers’ Association Hall of Fame members. The institutional review board at California State University, Fresno, approved this study, and each participant read, agreed to, and signed a consent form before the interview began.

Interview Technique

We used an open-ended, unstructured interview format. This format allowed the researcher to suggest the topic for discussion and provided the interviewee with the opportunity to answer freely, with few restrictions.7,10 Unlike quantitative methods, which attempt to capture precise data of a codable nature to describe behavior within preestablished categories, qualitative methods are used in an attempt to understand the complex behavior of members of society without imposing strict guidelines that may limit the field of inquiry.7 This type of interview allowed the subjects to stress points they believed were most important in their career development, rather than relying on the investigators’ notions.

The interview was enhanced through a technique known as probing. Probes can be used to complete or clarify answers by requesting examples and evidence, by asking the interviewee to finish a thought or answer, or by indicating that the interviewer is following the conversation.10,11 For example, several participants mentioned the names of individuals who influenced their careers. The researcher followed these statements with a probe such as, “Could you tell me more about his/her influence on you?” or “You mentioned your family; would you mind sharing more about that part of your life?”

The participants were asked to share examples of specific situations that they felt enhanced their development as ATCs. No leading questions with hints about desired answers or topics were asked. For example, the term “mentoring” was not suggested to the interviewee at any time. The interviewer always began by saying, “Tell me when you first considered becoming an athletic trainer, what path you took to reach your current position, and what your major influences were.” The interviewee was allowed the latitude to answer in any way he chose. All interviews were tape recorded, and each interaction lasted an average of 50 minutes.

Data Analysis

A full verbatim transcription of each interview was typed at the completion of the interviews. Before any form of analysis began, each transcript was returned to the subject to verify content and accuracy. Minor editing, such as removing names, was performed by the research team to protect the anonymity of the participants. Brackets were used to clarify ambiguous segments of text.

The qualitative analysis was based on the guidelines of Côté et al.12 The process was inductive in that the information emerged from the data rather than being determined before data collection and analysis. First, the text was divided into pieces of information called meaning units.12,13 Tesch defined a meaning unit as a comprehensible idea or item that can stand alone. Seven interview transcripts were analyzed, resulting in a total of 281 meaning units. The 3-step process of analysis outlined by Côté et al12 was then followed: (1) creating tags, (2) creating properties, and (3) creating categories.

Each meaning unit was labeled with a tag; each tag described the information contained in each meaning unit. Similar information was given the same tag. A total of 45 tags were created to explain the various developmental patterns, characteristics, and major influences in the lives of the participants.

Similar tags were assembled into higher-order groups called properties. Properties were coded based on the features within the tags and meaning units. For example, loyalty, generosity, independence, and integrity were tags that were regrouped into the higher-order property called personal characteristics. Ten properties were identified for the 45 tags.

The properties were ultimately assembled into the highest-order group called categories. For example, the properties of personal characteristics, personal philosophies, and personal relationships were placed into a higher-order category called personal attributes. The merging of the 10 properties formed 3 categories. The inductive process was considered complete at the category level when no additional meaningful groupings emerged. A complete list of properties and categories is found in the Table.

Trustworthiness of Data Analysis

We used a number of methods to ensure that the conclusions made by the research team were trustworthy.11,14,15 Some examples were peer debriefing, prolonged engagement, and member checking. Peer debriefing refers to a method of analysis verification whereby a second inquirer probes the researcher’s biases and explores and clarifies meanings and interpretations.15 In the current study, the debriefer (an ATC
knowledgeable in qualitative analysis) checked 25% of the total meaning units for appropriate placement of tags.14 This debriefer was provided with a list of 45 tags and approximately 70 randomly selected meaning units for tagging. The meaning units were provided separately from the tags to eliminate the bias of the researcher. A 91% agreement match was established between the researcher and the second investigator. Discrepancies among researchers were restudied until an agreement was reached regarding the tagging of the meaning units. This assured the research team that the meaning units were placed in the appropriate sections.

Prolonged engagement refers to gaining the knowledge and understanding of the investigated “culture” to detect misinformation introduced by the investigator or the respondents.15 The primary investigator of the current study (R.M.) has been a member of the athletic training “culture” for 5 years. The familiarity of the researcher to the profession helped gain the trust of the participants and avoided the distortion or misinterpretation of information. It also allowed the researcher to understand the context of the information.

Sparkes14 listed member checking as the most crucial technique for establishing credibility. This is a method by which data, interpretations, and conclusions are tested with the participants from whom the data were originally collected.12,15 Feedback from the participants served to ensure the credibility of the analysis. The current study used this technique, and each subject was asked to evaluate a summary of the findings. The summary (2 pages in length) was sent to each of the 7 participants, and 5 were returned. The participants were asked to make any changes, corrections, or revisions to ensure accuracy of the information. All 5 of the participants made positive comments regarding the accuracy and content of the summary. This process provided strong corroboration that the career development paths of expert male ATCs were captured.

Nature of the Data

Although the categories and properties emerged from all 7 athletic trainers, the number of meaning units varied slightly in frequency, ranging from 32 to 56. The difference in the number of meaning units was a result of the open-ended nature of the interviews and does not reflect the knowledge level of the participants in the current study. As well, the higher number of meaning units in the category called meaningful experiences does not mean that it is more important than the other 2 categories. It may, however, relate to the complexity of the category.

Meaningful Experiences

The meaningful experiences category presents a unique look at the personal and professional history of participants by providing them with a foundation of knowledge on which to build their careers. Five properties emerged from this analysis; they were labeled athletic background, career experiences, job conditions, educational conditions, and additional responsibilities.

Athletic Background. All of the participants were involved in sports as youths and in high school. Although they all achieved different levels of success in their chosen sport, all of their athletic careers came to an end due to injury or their inability to be competitive at the next level. As ATC 2 said, “I was involved in athletics in high school. My junior year in high school, I injured my knee. It was a triad injury. In those days, if you tore your anterior cruciate ligament, it was career ending.” In addition, ATC 7 said, “I played high school football and baseball. I didn’t consider myself a bad athlete, but when I saw the environment in college, I found out that physically I couldn’t match up. It was the first time in my life where I couldn’t compete.”

The participants wanted to stay involved in athletics after they were through competing. They all found the ability to do so in some capacity. According to ATC 7, “A freshman football coach told me that there was an opportunity for me to be part of athletics without participating as an athlete. He was the one who got me involved in athletic training. Even though he wasn’t an athletic trainer, he taught the athletic training classes at the university.” In addition, ATC 4 said, “I had completed my sophomore year at a junior college as wrestler. An athletic trainer from a local university asked me if I was going to continue to compete. I said, ‘No, but I want to stay involved

## RESULTS

The results of the study revealed 3 higher-order categories that significantly influenced the development of expert male NCAA Division I ATCs. They were labeled as meaningful experiences, personal attributes, and mentoring. A description of each category will precede a presentation of supporting citations on the career experiences and major influences of the participants.

### Frequency of Meaning Units Within Each Property and Category by Certified Athletic Trainer (ATC)

<table>
<thead>
<tr>
<th>Category and Property</th>
<th>ATC 1</th>
<th>ATC 2</th>
<th>ATC 3</th>
<th>ATC 4</th>
<th>ATC 5</th>
<th>ATC 6</th>
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</thead>
<tbody>
<tr>
<td>Meaningful experiences</td>
<td>128</td>
<td>12</td>
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in athletics. He asked me if I would be interested in becoming a student athletic trainer. I began attending the university and working for him as a student athletic trainer.

**Career Experiences.** The opportunity to become involved in athletic training came about differently for each of the participants. Some of the ATCs became involved in the profession with other goals in mind, such as coaching. Others became involved through association with other student athletic trainers. According to ATC 3, "I decided that what I wanted to do was go into coaching. Since I had a number of injuries by the time I got into college, I decided to take some athletic training classes. I wanted to become proficient in athletic training and understanding injuries so that when I became a coach, I could help kids avoid suffering like I did." Also, ATC 6 said, "While working as a student manager, I got to know some of the student trainers that were working with the different teams on campus. I became interested in athletic training and started work as a student athletic trainer. I enjoyed the science aspect of things as well as the athletic side of things."

**Job Conditions.** Becoming involved in a developing profession is not always easy. Work conditions were very demanding. One athletic trainer (ATC 3) described his experience as a senior in college:

My senior year in college, the football team had triple-a-day practices. I did the athletic training and the equipment and all the washing for three practices a day. We didn’t have a lot of duplicate equipment, so I had to pull things out of lockers just to have enough clothes for practice. It was a busy time. I became proficient enough in the taping aspect that by the time the [staff athletic trainer] would get to practice, I would already have the team taped and prepared for practice. I took pride in that.

教育上，很少有学校设有运动训练课程。一位运动治疗师（ATC 6）表示，

Back at that time, structured education for athletic training was just beginning. I tried to set up my course of study as close to that as possible. I ended up becoming a biology major. I created my own program by combining classes like anatomy, physiology with some physical education courses. I then coupled the classroom education with my experiences as a student athletic trainer.

Accepting a great deal of responsibility in their first job out of college was a common trait among the participants. They were suddenly accountable for the medical care for an entire athletic program. According to ATC 1, "I learned a real respect for what some of the other athletic trainers had accomplished. Here I am, seeing kids with broken collarbones, fingers, all kinds of wild stuff that I didn’t have the chance to see at the university, and I had to be responsible for them. It was my job to take care of them. I wanted to do it and I enjoyed doing it.” Another athletic trainer (ATC 7) stated,

It was the first time that I was handling a collegiate program on my own. It also started me in a role of teaching and organizing my own athletic training program. All of a sudden, the entire collegiate athletic program was on my shoulders rather than one sport. I had to learn how to balance football, baseball, basketball, track, and women’s sports, while also teaching classes. I never had to do all of those things at the same time before.

**Educational Conditions.** Educational changes and certification requirements have become more demanding during the last 2 decades. Today’s ATCs must be more knowledgeable from an academic standpoint than their predecessors. According to ATC 2,

The level of knowledge that’s expected from us is much higher than it was 20 years ago. Twenty years ago you were expected to tape, evaluate an ankle sprain, and give an ultrasound treatment. Now, when you look at the competencies that are required for entry-level athletic trainers, I don’t know if I could be an athletic trainer. Educationally, today’s students are more qualified to do a lot of things that I’m expected to do at this time.

**Additional Responsibilities.** The ATCs also took on the responsibilities of understanding the history of the profession and doing their part to improve and promote athletic training. One athletic trainer (ATC 6) said the following:

I developed a real keen sense of the importance of the association and the history of the association. I learned about the evolution of athletic training. Unfortunately, the growth of the profession has made its history less well known. Now, when you go to a convention with 10,000 people, you could walk by Paul Grace or Lindsy McLean and not know who they are or what their importance is to the association.

This profession grew on the hard work of a lot of individuals working full-time jobs and donating their time to make the profession better. The full-time positions on the boards of today used to be held by practicing athletic trainers. In order for the profession to grow, the athletic trainers of today have to be involved and help lead the profession forward. If things aren’t going the way they want, then they have a legitimate right to complain. If they sit back and don’t get involved then they have no right to say anything.

The athletic trainers looked to make an impact by educating the community. As ATC 4 said,

Realizing that the coaches and administrators had little understanding of what we were doing, I put on an educational workshop for local coaches and administrators. The first year attendance was about 30 people. By the fourth year, we had over 100 people. I brought people in to speak and paid for their expenses through sponsorships. These workshops got a lot of positive publicity in the local area.
The development of athletic trainers is not limited to their career experiences. Personal attributes contribute to their success. The next section identifies characteristics that have enhanced the professional aptitude of the participants.

**Personal Attributes**

A second higher-order category called personal attributes details the individual nature of ATCs. In particular, this category identifies their personal characteristics, their philosophies, and their relationships both inside and outside the athletic training domain.

**Personal Characteristics.** Characteristics such as loyalty, generosity, and a strong work ethic helped these individuals succeed in a field where they must put others above themselves. According to ATC 1, “One of the things that I pride myself on is being loyal. If someone works for me and does a good job, I’ll do anything I can to help them for the rest of my life. I make that promise to them. If they’re loyal, then I return that to them as many times as I can.” In addition, ATC 7 said, “I’ve had a unique opportunity to give something back to the school. At the same time, the institution has come back and done some things for me. So, it became a 2-way street. I guess my final goal at [the university] would be to make sure that I left this place in a better condition than when I came.”

**Personal Philosophies.** The work ethic and philosophies of the participants have resulted in the development of a great passion for their work. As ATC 2 said, “For the last 15 years, I haven’t worn a watch. The job has never been about how much time I spend at work. I go to work, do my job, and go home when everything is done. If you start looking at the clock and worrying about the fact that you’re putting in 14 to 15 hours a day, you won’t last very long.” Another athletic trainer (ATC 7) said, “Years ago the philosophy was that the job wasn’t done until the job was done and practice wasn’t over until everyone went home. Now because of clinical environments and educational controls, the ‘good old boys’ have lost some of that.”

The athletic trainers truly cared about the athletes. As ATC 1 said, “To me, and I mean this with all my heart, an athletic trainer is a person who cares more about the athlete than he does himself. The athlete comes first over you. That doesn’t mean he’s first over your religion or your family; it means he’s first over you. Athletes know if you really care. I take my time and pay attention to them.”

The athletic trainers made their availability to the athletes a priority. Their professional philosophies were based on a service-oriented concept. As ATC 1 explains, “I’ve been an athletic trainer a long time now, almost 30 years, and I haven’t missed a day of work, not one. My responsibility is to be there for those athletes, and that’s my job. They expect me to be there to them all the time.” According to ATC 2,

I went in and opened the training room at 7 in the morning and closed at 7 or 8 at night. The coaches thought the sun rose and set with me. It wasn’t because I knew everything but it was because I was willing to put in the time. I think that’s true with most successful athletic trainers. I think you can make up for what you don’t know by working hard and being interested. Spending time with kids and being available to them is very important.”

The personal characteristics of the participants have made their careers more successful and fulfilling. However, the ATCs could not have accomplished everything alone. They received support and direction from the personal relationships they have created inside and outside the sporting environment.

**Personal Relationships.** The development of a bond between the ATC and the athlete is inevitable while working in an athletic training environment. There is a mutual respect for one another. Relationships that are created can last a lifetime. The following are statements made by ATC 1 and 2, respectively:

As a student, I noticed how much the athletes respected our head athletic trainer, and I noticed how much he cared for them in return. I thought the way they treated him, and the fact that athletes would come back years later to see him, was something special. There was a special bond that he had with the athletes. He taught me to respect the athletes and care for them. The very special bond that we have with athletes as athletic trainers is hard to find anywhere else. I’m not sure everybody has that bond, but I think some of us do.

Being involved with the athletes on a day-to-day basis is what keeps me going. That has made it really easy to stay interested and motivated. It’s certainly not money, glamour, or prestige. When a kid comes back on campus and the first place that he comes into is the athletic training room, it says a lot. That’s what I will miss the most. Having that relationship with the athletes where they depend upon you and respect you. It’s always been a family to me. They become my children.

In a profession where a great deal of time is spent with others, the demanding work environment can limit the time that is spent at home. As ATC 7 states,

Growing up in a small community, my children respected what I did and at the same time resented what I did. I was there at the big events, but the day-to-day battles and struggles in their lives were basically handled by their mother. We always went on the basis that what I brought was quality and not quantity. I would have liked to spend some more time with them so they could understand better where I was coming from. They had the opportunity to get an education. I think they had a good support structure, and they both turned out to be good kids.

Some of the ATCs made special compromises to accommodate both family and work as illustrated by the following statement by ATC 2: “I have 3 boys, and they are very much a part of what I do. They can come in and spend time with dad. They love to do that. Sometimes they come out to the field for practice. So even though I’m working 90 hours a
week, they are not spent exclusively away from the family. My family is very much involved in a lot of what I do."

One athletic trainer (ATC 4) has changed his views on the amount of time spent at work versus time spent at home.

I don’t feel that putting in over 70 hours a week is the way to function anymore. There is more to life than work. It was fine when it was just me or my wife and I, but when you start a family you have a commitment to them as well. In order to be able to give of yourself to them, something has to be sacrificed. I have lessened my availability in the athletic training room to be available to my family. When you look at things in proper perspective, the first thing is your faith, then your family, and then your job. If you keep life in that perspective something has to give, so I started altering that in my life. I do my job to the best of my ability. I try to be honest and fair with my athletes and my coaches. I think it is important to keep your life in balance.

Meaningful experiences and personal attributes can be influential in the development of an athletic trainer. Without direction, however, these experiences and qualities can go undeveloped. All of the participants had the benefit of a number of mentoring role models to guide, encourage, and teach them.

The next section will describe the final higher-order category, mentoring, in greater detail.

Mentoring

Mentoring involves the educational and developmental relationship between a trusted supervisor and a less experienced individual. Mentors provide their protégés with the opportunity to learn and grow throughout their careers.

Ways of Learning. The participants had the ability to gain knowledge from a number of resources. Most of their knowledge was gained through experience and opportunities working with other ATCs, coaches, or classroom teachers. As ATC 7 explains,

[My head athletic trainer’s] influence was really straightforward and very simple. What he gave me was an academic and practical view of athletic training that I never had. He was a real professional. He became a real educational avenue and a professional role model for me. He was a neat man in that he taught me what I wanted to know. I’ve tried to model myself after him. He didn’t spoon feed it. He sat back and let you get into a problem and then tried to help you solve it, if you could. I liked his teaching method because he never browbeat you and he never spoon fed you. I thought that was good. I learned a lot about intensity from all of our coaches. As we moved up in level, the intensity moved up. Your knowledge of what people can and can’t do changes with experience. That was a learning experience from coaches, not the players.

Another athletic trainer (ATC 2) stated, “One instructor I had in high school, who taught music of all things, had a significant passion for what he did. He loved doing what he did and it came through when he dealt with students. He could motivate students to do better than they could do otherwise. That was a significant influence for me.”

Ways of Teaching. The participants promoted learning environments that allowed their students to grow in the profession. The participants taught young athletic trainers by allowing them to make their own mistakes and guiding them back into the right direction, as the following statements by ATCs 3, 6, and 5, respectively, illustrate.

I give people enough freedom to either lengthen their stride or fail. Some athletic trainers like things to be extremely structured. They like to have everything done a certain way all the time. I like to sit down with my students and talk about what direction we are going to take. I’m very strict about the emergency medical stuff and those parameters, but as far as day-to-day operations and assignments, what I do is I step back and I give my graduate assistant the responsibility. I say, “Here are the guidelines and parameters in which we need to stay as far as legality and organization. This is what I have to have done; figure out how to do it.”

Because of the opportunities that I’ve had, I try to make sure that my students and staff have that same type of opportunity in the program I now run. There are many different ways of doing things, and I let them try their way. They may stumble on to the fact that the way I do it is the better way, but that’s for them to learn and not necessarily for me to tell them.

I’m going to make sure that all of our student athletic trainers get tons of experience. I want them to feel like they are getting the experience that they need. I’m not just going to have people move around from sport to sport every 2 weeks. I want them to feel like they are part of the one team. I want them to get to know the players and feel the same things I’ve felt.

DISCUSSION

Providing an account of the career development experiences and major influences of expert ATCs is a necessary step in documenting the progression of the discipline of athletic training. Before this study, such information had never been the focus of an empirical research study. Our results contribute both theoretically and practically to the athletic training domain. In the former, the results extend research on career development issues to the field of athletic training. In the latter, the results focus on aspects of the profession that are not covered in most university courses but should be of interest to those in the field, regardless of years of experience.

The results of our study are in agreement with the assumptions of the person-environment fit theory reviewed by Swan-son and Fouad. For example, individuals seek environments that allow them to use their abilities. The theory also assumes...
that the process is reciprocal in that the person shapes the environment as the environment shapes the person. The ATCs in our study developed their skills and gained experience in athletic training while simultaneously promoting and changing the profession in a positive direction through mentoring and hard work. Working within an “industry-specific” training program\(^3\) gave the participants the education and practical skills they needed to function at high levels as ATCs.

Many of the personal attributes of expert athletic trainers were also found in Salmela’s\(^16\) research on expert coaches. We compared our results with expert coaches rather than with other health care professionals because of the similar time demands and daily contact with athletes. Salmela\(^16\) found that expert coaches understood that to reach a high level of success in their profession, they had to work long hours and make personal sacrifices. These coaches demonstrated a genuine concern for their athletes as people. It is possible that some personal elements of coaching and athletic training, such as caring about athletes, exhibiting a passion for one’s job, and exuding a strong work ethic, are crucial for achieving success in these domains.

It seems reasonable to conclude that part of the success of the ATCs can be traced to their genuine concern for the well-being of each of their athletes. Although the knowledge of many athletes is limited in relation to anatomy and athletic training, they do know when you care and when you don’t. Injuries can occur at any time. When these injuries take place, the athlete becomes vulnerable and seeks an athletic trainer for help, one who cares about him or her a great deal.

Research has shown that mentorships play an important role in the career progression and development of many professionals.\(^17\)–\(^20\) Most research in this area, however, has focused on mentoring in education and business. Only recently has research been performed on mentoring in sport and athletic training. The development of the ATCs in the present study, particularly early in their careers, was greatly enhanced by more experienced individuals. Our results are in agreement with Curtis et al.\(^4\) who found that student athletic trainers benefited greatly from the guidance and direction of a mentor. Our results extend their research by providing a qualitative framework so that the participants could explain how their careers were enriched. For example, our ATCs learned from a number of different sources, including classroom teachers, other expert ATCs, and coaches. The phenomenon of being mentored by individuals outside the profession is a rare finding that has not been previously addressed in other mentoring research.

**Limitations**

Although our study enhances the understanding of the career development experiences of ATCs, some limitations must be addressed. An obvious one is that only male ATCs were sampled in the current study. Female ATCs were not included for 2 main reasons. First is the hypothesized differences that are believed to exist between male and female ATCs. Second, we were unable to acquire a sufficient list of female ATCs with the same level of experience. Future research that examines the career development patterns of female ATCs is recommended.

Certainly, differences face today’s ATCs compared with those individuals in our study. For example, the current educational status, increases in sexual equality, and expansion into other nontraditional roles are just some examples. Despite this, we believe that the results of the current study are still very applicable to modern-day athletic training professionals. We strongly believe that a passionate, service-oriented, caring, and hardworking attitude will always be associated with the athletic training profession and is something that needs to be documented. It is possible that possessing these variables is as important or more important than the academic knowledge and resources available to today’s ATCs. Along the same line, our intent was not to suggest that the career development paths of the athletic trainers in this study are the best or only ways to become successful in this field. Rather, the intention was to summarize the information from a sample of professionals who have made, and continue to make, a positive contribution to the profession of athletic training.

A final point must be addressed in this section. Unfortunately, it is difficult to translate to the reader the excitement and the passion in the voices of these participants as they shared their thoughts and knowledge with us. More specifically, it was especially rewarding to hear their love for the profession of athletic training.

**CONCLUSIONS**

In summary, we attempted to examine an area that has received limited empirical attention in the athletic training literature. Although many individuals have been working in the athletic training profession for years, few have actually documented the steps that took them to the top of their profession. It was our desire to begin an exploration and exchange of information about this area of importance. We believe that our study has contributed to the understanding of the career experiences of expert male Division I ATCs. It also provided a unique appreciation for anyone involved in the profession of athletic training, particularly those experts who perform at the highest level. We hope this article will bring attention to this topic and encourage other practitioners to conduct research in this fascinating area of athletic training. We also strongly support the use of innovative and creative methods to study this area.

**ACKNOWLEDGMENTS**

We thank Rose M. Lyon, Paul Schechter, and those athletic trainers who participated in this study.

**REFERENCES**

The Professional Socialization of Certified Athletic Trainers in the National Collegiate Athletic Association Division I Context

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Objective: To describe the professional socialization process of certified athletic trainers (ATCs) in National Collegiate Athletic Association (NCAA) Division I to guide athletic training education and professional development.

Design and Setting: We conducted a qualitative study to explore the experiences related to how participants were socialized into their professional roles in Division I.

Subjects: A total of 16 interviews were conducted with 11 male (68.75%) and 5 female (31.25%) participants who were either currently or formerly affiliated with an NCAA Division I athletic program.

Data Analysis: The interviews were transcribed, coded, and analyzed inductively using a modified grounded theory approach. Trustworthiness was obtained by peer review, data source triangulation, and member checks.

Results: We identified a discernible pattern of socialization experiences and perceptions among the participants. The professional socialization processes of Division I collegiate ATCs is explained as a 5-phase developmental sequence: (1) envisioning the role, (2) formal preparation, (3) organizational entry, (4) role evolution, and (5) gaining stability.

Conclusions: Examining the professional socialization process provides insights into the experiences of Division I collegiate ATCs as they prepare for their job responsibilities and develop professionally. Appropriate socialization tactics, such as the use of a structured mentoring experience, formal orientation, and staff development programming, can be implemented to promote effective professional development. Additionally, undergraduate students may be well served if they are educated to better use informal learning situations during their initial socializing events.

Key Words: professional development, qualitative research, anticipatory socialization, organizational socialization

Professional socialization serves as a driving influence that has a profound impact on one’s professional development. It is also primarily involved with the growth and change of one’s thoughts, feelings, attitudes, purpose, and spirit as a professional. A better understanding of socialization provides an essential first step to identifying educational strategies to improve the undergraduate education and professional development of certified athletic trainers (ATCs).

Attempting to understand professional socialization as a process has given rise to several phase or stage models in other disciplines. These models have described the experiences that professionals endure as they learn a particular role. Generally, the professional socialization process is divided into 2 aspects, anticipatory and organizational. Anticipatory socialization includes aspects of socialization before entering a work setting or organization, whereas organizational socialization entails processes that occur after entering the work setting or organization.

The professional socialization process involves learning particular skills, values, attitudes, and norms of behavior and is considered to be a key component of professional preparation and continued development in health and allied medical disciplines. Although the professional socialization process has been systematically studied from a multitude of perspectives by researchers throughout the 20th century, to date we are unaware of any research reported on the professional socialization of ATCs. Socialization has been known to be both important and inevitable, and in recent years it has been viewed as having the power to effect either negative (ie, burnout) or positive (ie, personal enrichment) results for health care professionals.

The purpose of our study was to gain insight and understanding about the professional socialization process of National Collegiate Athletic Association Division I (NCAA DI) collegiate ATCs. Three research questions guided this aspect of the study: (1) What informal and formal processes socialize ATCs into their professional role at the NCAA DI level? (2) How do ATCs perceive their experiences during their first several years of practice? (3) Do these experiences change over time in a detectable pattern?

METHODS

A qualitative method was used to understand the experiences of ATCs in the NCAA DI context. Qualitative research is
an interpretation of data based on the meaning that individuals give to their experiences. According to Boyle, qualitative research is well suited to study individuals who share similar social and cultural characteristics. A qualitative investigation can facilitate the understanding of organizations by examining participant knowledge, meaning, and behavior and requires a researcher to inspect ideas and practices that influence the way people conduct themselves professionally in a specific organizational context.

Theoretic Framework

Symbolic interactionism provided the theoretic framework for this study. Symbolic interactionism emphasizes the conscious aspects of human behavior related to interaction and suggests that a person is active, rather than passive, in creating his or her conduct but that the expectations of others involved with the interaction are considered. From a symbolic interactionist perspective, professional socialization is a dynamic, ongoing process marked by one's interaction with others and the environment. Using symbolic interactionism as the theoretic framework allowed us to discover the development of perspectives and meanings related to the participants' socialization processes. We were then able to identify how and why they came to envision themselves as ATCs in the NCAA DI setting, how they perceived their first several years of practice in that context, and how they developed their roles over time.

Participants

A total of 16 interviews were conducted with 11 male (68.75%) and 5 female (31.25%) participants who were either currently or formerly affiliated with NCAA DI programs. Of the 16 participants, 11 were currently full-time collegiate ATCs, 2 were former full-time NCAA DI collegiate ATCs, 1 was a current graduate assistant ATC, and 2 were athletic administrators (1 athletic director and 1 assistant athletic director). The participants collectively represented Districts 3, 4, 5, and 9, and they also represented 4 different NCAA DI athletic conferences. Additionally, the participants (excluding the graduate assistant and administrators) averaged 11.7 years of experience as an ATC, 9.2 years of which were at the NCAA DI level. Eight of these participants were head ATCs, and 5 were assistant ATCs. Northern Illinois University's Institutional Review Board approved the study, and each participant gave informed consent. The participants also gave verbal consent for tape recording before each interview.

Six interviews were arranged with individuals, and several subsequent participants were selected after the original 6 participants suggested the names of other potential participants. This is referred to as a snowball sampling strategy. The total number of participants was not determined at the outset of the study; instead, it was based on the concept of redundancy of information or saturation of data. Lincoln and Guba identified redundancy of information as being the point at which the researcher determines that no new information is forthcoming or that the same information is being discovered again and again from the participants. On reaching this point, data collection was terminated.

Data Collection

Textual data were collected using semistructured interviews that were conducted by one researcher (W.A.P.). Eleven of the interviews were conducted by telephone, whereas 5 were conducted in person, based on feasibility. Additionally, to triangulate the data and enhance the quality and credibility of the analysis, athletic administrators and a graduate assistant ATC were interviewed to compare alternative perspectives and further understand the professional socialization processes that occur within this context. Six of the ATCs also consented to and participated in follow-up electronic interviews (e-mail) that permitted clarification as the data were analyzed and to determine that their perspectives had not changed since the original interview.

The interviews were designed to determine the meanings and central themes in the participants' lives and their relationship to them. Moreover, the interviews allowed not only the interpretation of the present, but also a re-creation of the past experiences of the participants. As such, participants were able to reflect on their past experiences and create a greater understanding of the processes related to their professional development.

To avoid bias in asking questions, a semistructured interview guide was used, and each interview began with the question, “Could you give me a little bit of background about yourself and what brought you to be a certified athletic trainer at the collegiate level?” Examples of other questions or directed statements on the interview guide included the following: (1) “Describe your first few years of being an ATC at the college level.” (2) “What is, or how would you describe, your personal and professional mission?” (3) “Has your mission changed since you first began practicing as an athletic trainer? If so, how?”

Data Analysis

The interview data were transcribed, coded, and analyzed inductively using a modified grounded theory approach. Such an inductive analysis is characterized by the detection of concepts, relationships, and understandings, and the textual data were initially analyzed by creating concepts and categories. The transcripts were read and specific incidents or experiences were given names or labels that represented them. These conceptual statements were then written on index cards, examined, and organized into categories according to their similarities. This was similar to Lincoln and Guba's process of identifying "units of data," such as sentences, paragraphs, or comments, that can provide information about particular concepts. In this study, subcategories were developed based on the anticipatory and organizational socialization experiences and included the following: (1) envisioning the role, (2) formal preparation, (3) organizational entry, (4) role evolution, and (5) gaining stability. Collectively, these subcategories comprised the category "role dynamics: the professional socialization processes of NCAA DI collegiate ATCs.”

Establishing Trustworthiness of the Data Analysis and Interpretation

Trustworthiness of the data analysis and interpretation was established using 3 strategies: (1) data source triangulation, (2) member checks, and (3) peer review. Interviewing alternative participants (athletic administrators and a graduate assistant
ATC) and conducting follow-up electronic interviews completed the data source triangulation. This allowed us to determine that the experiences remained consistent at other times or as individuals interacted\(^{30}\) and to ensure the credibility of the study.\(^{20,27}\)

Member checks were completed by taking the interpretations of the data to 3 of the participants to see if the researcher’s interpretations were reasonable.\(^{20}\) Having an experienced qualitative researcher comment on the findings of the study as they emerged constituted the peer review. The review was accomplished by having this individual examine the recorded transcripts and coding sheets while the various concepts, categories, and themes were explained.

RESULTS

We identified a discernible pattern of career selection influences and organizational-based experiences and perceptions among the participants relative to their challenges and concerns once they entered the collegiate setting. Attempting to understand the experiences of the collegiate ATCs interviewed for this study gave significant insights into the evolution of their professional role and their role stability.

Through the collection and analysis of data, it was determined that the socialization of ATCs occurred in a 5-phase development sequence: (1) envisioning the role, (2) formal preparation, (3) organizational entry, (4) role evolution, and (5) gaining stability (Figure). This model is presented herein and systematically compared with related literature.

Envisioning the Role

Career selection was highly influenced by a personal identity with the culture of sport. Twelve of the current or former full-time collegiate ATCs’ primary attraction to athletic training was a fondness for sport, sport-related health care, or high-level competition, or a combination of these. In fact, more than half of the participants were themselves former high school or collegiate athletes, many of whom were injured during sport participation and subsequently cared for by an athletic trainer. These individuals, therefore, were able to identify with a career that was inextricably linked to the sport culture. When asked what brought them to be an athletic trainer at the collegiate level, it was not uncommon for other participants to remark just as one participant explained,

"Ever since I could remember, I participated in sports and I enjoyed competition. I enjoyed the camaraderie and being part of a team... so I wanted to find [a career] that I could keep in close contact with that kind of atmosphere and be able to help people.

At this stage of the socialization process, the participants appear to have been strongly influenced by the sport culture and a fondness for competition.

Formal Role Preparation

Once the participants in this study envisioned themselves in an athletic training role, they each took the necessary and logical steps to become an ATC. Although a person’s experiences coupled with his or her occupational interests are socializing agents, the more formal anticipatory socialization process begins during an undergraduate professional education. The professional training generally extends from course work to clinical education or field experience or both. The undergraduate experience for the participants in this study, however, did not complete the formal preparation process. That is, a graduate assistantship (GA) seemed necessary to gain an appropriate level of experience to fully prepare them for the NCAA DI collegiate setting.

A GA position appeared to be a rite of passage for becoming an NCAA DI ATC. Except for one individual, each participant in the study had an NCAA DI collegiate athletic GA position. Thus, a GA in the collegiate setting is often a prerequisite to obtaining a collegiate athletic training position, and it is used as training for those aspiring to work in that setting. Unfortunately, however, the participants suggested that the GA is a small developmental step rather than an experience that fully prepares them for the responsibilities of being a full-time NCAA DI ATC.

When asked to compare the GA to the full-time staff position, one collegiate athletic trainer explained:

“When I was a graduate assistant, my sport responsibilities were a little different... the types of athletes that you are dealing with and the quantity of the athletes that you are dealing with is different as well as the type and quantity of the coaches that you are dealing with. Now I deal with a larger quantity of coaches on a daily basis and that makes [the job] tougher. I also deal with a larger quantity of student-athletes.

Not only does the quantity of work differ significantly from the GA, but the level of responsibility does also. For example, when asked about the change in role from a graduate assistant to a full-time staff member, one participant explained that a graduate assistant ultimately still had a head ATC or assistant ATC who made final decisions.

Organizational Entry Phase: A Period of Uncertainty and Adjustment

Making a transition from being a graduate assistant to a full-time NCAA DI ATC offered many challenges to the partici-
The ATCs who were inducted into the NCAA DI organization consistently stated that they experienced a period of uncertainty, although to varying degrees. Additionally, there was some evidence of role strain in that the bulk of participants in the study suggested that they were often overwhelmed, lacking an understanding of exactly how tasks should be completed in the “new system,” and were astonished by the high volume of work. Thus, the induction period of organizational socialization was a period of uncertainty and adjustment for the ATCs. When asked about her initial collegiate experience, one participant exclaimed it to be “overwhelming, I was put over here at [this facility]... by myself with a graduate assistant in the afternoons... but basically [I was] just sort of thrown into the fires.”

The ATCs entering the NCAA DI settings stated that the job differed slightly from what they expected following their GA positions. The primary differences were the intense volume of required work, the added responsibility, and an occasional uncertainty regarding how to act to “fit in.” One participant, when asked about his initial challenges in collegiate athletics, suggested that administrative acceptance is the primary challenge when entering an organization. He stated, “Why I think the main challenge you have is that of acceptance. Are you going to be accepted by that administration, with the principles and so forth that you stand by?”

The ATCs interviewed in this study overwhelmingly suggested that to adjust to their new professional demands they “learned on the run.” Much of their survival in the organizational entry period was the by-product of a great deal of trial and error as they faced situations for which they felt ill prepared, indicating that their formal education was inadequate. One participant stated:

I went in [to my first collegiate position], and I would try to do something that we had done at [the university where I did my graduate work] and were successful with, but it wasn’t successful... [here]. So I’d have to re-evaluate and things like that... I’ll admit I learned a lot on the run.

The participants consistently identified a lack of formal induction processes. More specifically, job responsibilities were described in writing, but no formal training, orientation, or learning processes, apart from administrative tasks (eg, vehicle requests, referral procedures, or travel requests), were implemented. When asked about learning their role during the induction process, participants explained that they “learned by doing” and relied informally on colleagues.

Moreover, many participants “reached back in order to move forward” to successfully learn their role. That is, in order for many to meet the demands of their new positions without a formal induction process, they often went to previous mentors for guidance and help.

Despite the formal preparation necessary to enter the collegiate setting, ATCs were not completely prepared for what they experienced. The length of time this stage lasted, however, varied for each participant. Although the participants generally discussed this stage relative to their first year on the job, it was apparent with 2 participants that this stage was extremely brief.

Role Evolution: A Case of Further Understanding the Professional Role

Information was gained about the participants’ continued development by asking them to explain their professional mission and whether it had changed since entering the collegiate setting. Two less-experienced collegiate ATCs interviewed (each with only 2 years of full-time staff experience) had trouble explaining their mission. The initial response from the others, however, was that their mission was to provide the best quality of health care possible to the athletes. When asked about how their mission has changed, many remarked on how they had come to understand the full nature of their professional role and realized its comprehensive nature. For example, one participant stated that originally her mission was to provide the best possible health care. However, she eventually learned the other aspects necessary for success:

I think that the student-athletes rely on us in several different areas... academically [and] emotionally... because [athletic trainers] are a non-threatening group. You know we are not their peers, we are not competing against them for a position on the team, we are not their coaches to whom they have to prove something or be perfect in their eyes. We are not their teachers. We’re not the administration. We’re not the media. They can sort of let their guard down when we are in their company and... they rely... on you a lot more than for their physical ailments, and I probably didn’t realize I was going to be a friend and a mother to them when I first [started my job].

Another ATC stated that his “mission is to be the best athletic trainer possible. It’s to keep the student-athlete in the center of the focus and provide the best health care.” When asked about whether his mission and focus had changed since being in collegiate athletics, he stated, “Oh yes, dramatically. At one time, all I was worried about was accolades you know, is the team winning and those sorts of things. You know, if the team wins, do I get a ring?” Over time, though, he moved from focusing on acclamation and prestige to the interpersonal relationships with the athletes.

It appeared that ATCs were deeply influenced by the relationships they had with the athletes they served. Undoubtedly, after spending season after season, road trip after road trip, and practice after practice, adding up to an inordinate number of hours, with their patients (something other health professionals rarely do), the collegiate ATCs came to find that even the sense of mission changes over time. They soon learned that their role included far more than health care for athletic-related injuries and technical aspects of the job. Furthermore, it appeared that they became increasingly connected with and committed to their patients.

Three participants suggested that their mission changed over time to include promoting the profession itself, whereas one head ATC indicated that although his mission is to deliver quality health care, it is also to create an environment that allows his staff to grow both professionally and personally.

Once they better understood their role and evolved as professionals, the participants attempted to gain stability in their role. Role stabilization, however, was a direct, progressive step following role evolution for only a few ATCs. For the others,
Gaining Stability

Conversations with ATCs who have been in their respective settings for several years helped to identify the fifth phase, gaining role stability. In an attempt to stabilize one’s professional role, 3 avenues can be taken: (1) stability within, (2) refocusing within, and (3) instability.

Finding “stability within” the organization seemed to occur when the values of the ATC were relatively congruent with the organization’s, and fair levels of collegiality and administrative support existed. In these instances, the perception was that the organization was acting in a moral manner. Moreover, ATCs were able to use their skills and have a degree of autonomy in their role. Despite any disagreements with the administration, these individuals could live with the organizational constraints and felt as though they still contributed to the organization’s success and fulfilled their professional mission. A direct progression to role stability from the role evolution stage was found in 3 instances among all of the interviews. An ATC finding this avenue of role stability was asked why he felt he was successful:

I think part of it is my dedication to the kids and my dedication to the institution. Also, I think I have a fairly high set of morals...to me we have a very ethical program...and I’m pretty proud that we treat everybody equally here. We at least try, and I think the ethical moral standpoint we come from helps everyone out here too.

“Refocusing within” refers to those individuals who believed they did not have adequate organizational support or commitment as it pertained to their role, yet they chose to remain in the organization. They realized that their true reward came from helping the student-athletes and being a trusted health care provider. These individuals learned to “pick their battles” within the organization so they did not become too discouraged:

I’ve gotten—not discouraged—but... I realized that athletic training is a priority, but it’s not one of the main priorities. Winning, the coaches, winning coaches, bringing in money [and] certain programs are more important, and [the administration] will address those needs, and we are support staff, and our needs aren’t really addressed. Everyone’s [needs] are addressed before ours, and I sort of got very discouraged, and instead of getting all upset about it, I just sort of accepted it and tried to pick the battles instead of trying to fight for everything.

This same ATC, when asked what keeps her continuing as a professional in the collegiate setting, stated the following:

I try to focus on [the student-athletes]...I mean I work with coaches, and I work with [the administration], but my primary source of responsibility is towards the student-athletes for their physical and mental well being... And then if I can nurse an injury back or get an athlete back on the field... that makes me feel good... And I always try to focus on them, even if the coaches complain, or if the administration wants us to do more.

“Role instability” refers to the ATCs who were unable to find adequate organizational support or commitment necessary for them to fulfill their professional mission. Subsequently, these individuals removed themselves from the organization and took another position. This occurred with 3 ATCs. For example, one athletic trainer explained how he felt so controlled by some aspects of the organization that he would not be able to adequately attain his professional goals:

I would say that the major reason for leaving the collegiate setting is that I reached a point where I was tired of having my life dictated by other people. And, as much as I could be responsible and lead our staff of athletic trainers and student athletic trainers, I was limited in that our ability to function was always related to what was dictated by everyone else [in the organization]. And the second part of it was that no matter how hard I worked, I never felt like it was enough, or that it was good enough. An example would be that if a basketball player hurt their knee and they were going to see an orthopaedic surgeon tomorrow, you know it was never “That’s great, I’m glad you could get them in,” it was “Why can’t they be seen today? Why are we waiting on this, why aren’t they doing...their surgery now, why is the MRI scheduled for Friday and today’s Monday?”

It must be made clear that role exiting occurred not only with those ATCs experiencing role instability, but with one individual who refocused within and another who experienced a long period of role stability. For example, one participant explained that after being in a period of role stability for 13 years, he was influenced by organizational changes that eventually led to his exiting his role.

I stayed there for 13 years, and it wasn’t until the 13th year that another administrator came in and a coach who [also] administered and started actually using steroids with the team at that time. And then I bailed out. I got out of there. There was no hope for me. They didn’t like me, and I didn’t like them, and I lost everything. They brought in a new group of team doctors. They...[dismissed]...the doctors that had been there since I had [been there] and hired a new bunch. So I had no support there. I lost that. And once I lost that, I knew there was no hope for me. So I bailed. I got out.

DISCUSSION

Investigating the experiences of NCAA DI collegiate ATCs from a process perspective identifies the transitional periods in their anticipatory and organizational socialization. The following section will compare our results with the socialization literature.
Anticipatory Socialization

Consistent with the literature, the experiences throughout the participants’ lives and interactions with significant others and the organization influenced their professional role and career choices. The anticipatory socialization stage is forged by several cultural influences, including the professional discipline, professional influences, individual factors, and societal influences. Anticipatory socialization occurs when people are able to anticipate what it would be like as a member of a particular group or occupation to which they do not yet belong. With respect to selecting athletic training as a career, participants in this study identified with and were influenced by the culture of sport. Lawson stated that “sport socialization is the process by which individuals acquire the knowledge and skills necessary for sport participation as well as the meaning derived from such participation.” Socialization through sport can also nurture one’s choice of career related to sport. Moreover, socialization through sport can affect the psychosocial development and socialization into roles outside sport.

Lum stated that social roles are imagined by virtue of a person’s “reflective thought through the manipulation of symbols.” Such anticipation leads an individual to adopt specific group values and beliefs that facilitate his or her acceptance by the culture of sport. Lawson stated that “sport socialization is the process by which individuals acquire the knowledge and skills necessary for sport participation as well as the meaning derived from such participation.” Socialization through sport can also nurture one’s choice of career related to sport. Moreover, socialization through sport can affect the psychosocial development and socialization into roles outside sport.

Organizational Socialization

Entry into the NCAA DI setting begins the organizational socialization of the ATC. As professionals enter an organization to work, they often commit themselves to a particular way of life complete with its rewards, associations, demands, and possibilities. Organizational socialization has been described as a learning process whereby individuals understand and make sense of their new context, subsequently “learning the ropes” of a specific organizational role. This process simply allows a novice to become a mature practitioner. Initial entry is considered an extension of anticipatory socialization, because it includes those processes that occur before an individual enters an organization and shortly thereafter. Our findings are consistent with other findings that suggest that entering a new position is considered to be an extremely demanding experience. Despite the effort put into undergraduate education and using the GA as a rite of passage, many inductees into the NCAA DI athletic organization still had formidable challenges and adjustments to make to adapt to their roles. Such a transitional period, therefore, is an excellent opportunity to consider the use of socialization tactics and educational interventions, such as a structured mentoring experience, formal training or orientation, and staff development programming, which can offer support from a multitude of perspectives.

Many of the participants reported contacting previous mentors for advice about how to handle challenging situations in their new work environment. Such advice from these mentors helped them to gather themselves and move toward confronting the challenges faced in their work environment. This particular point in their development may be well suited for a more structured mentor relationship with individuals who are in the same or a similar context. Adult mentors can help individuals understand how to better navigate their work environments.

The establishment of mentors and role models is essential to effective lifelong education in the professions. The professional socialization literature consistently recommends mentoring as a useful strategy for dealing with issues of induction and role continuance. In fact, mentoring systems at the organizational level are often used “to introduce people to the inner network of the organization, which may assist them in their career advancement.”

At the organizational level, a formally structured learning orientation may attenuate some of the uncertainty experienced by ATCs entering and evolving through the NCAA DI setting as full-time staff members. One participant suggested that he was oriented about such things as travel procedures and insurance issues but not about other aspects of organizational procedures and norms. A more formalized orientation can help reduce role ambiguity that may lead to role strain. Athletic training supervisors and administrators must recognize the day-to-day learning needs of personnel and initiate individualized goals, objectives, and learning plans to facilitate a smooth organizational entry and professional development over time.

The experiences of ATCs inducted into the NCAA DI setting are surprisingly similar to those of teachers documented by Lortie. Many teachers learned by doing and entered into a “sink or swim” proposition. They were required to begin their role with a full level of responsibility and perform a full complement of teaching tasks. In like fashion, inducted ATCs are expected to begin their roles with the same responsibilities as an ATC who has several years of experience. Consequently, they learned the finer points of their role by solving problems as best they could, often through trial and error.

These learning experiences during the organizational entry period were informal in nature. Thus, undergraduate student athletic trainers may be well served if they are educated about the initial entry into a professional role and how to better use informal learning situations during their initial socializing events. As such, facilitating self-directed learning among undergraduate students can potentially better prepare them for the independent learning required in the workplace. If practitioners are learning through trial and error, then facilitating reflective practice with undergraduate and graduate-level students becomes paramount. Furthermore, because practitioners are ultimately expected to function independently in a work environment, perhaps more attention should be given to progressing student athletic trainers from a more dependent clinical education environment to a more independent field experience environment during the anticipatory socialization period. Other disciplines have used or required internships, preceptorships, residencies, and fellowships to allow students to gain an appropriate level of experience to prepare for a given professional role.

Given the nature of organizational entry, role evolution, and gaining role stability among participants in this study, it appears advisable that potential ATCs in the NCAA DI setting obtain information relative to the type of orientation and direction they will be given once they enter the setting. Examples include whether a formal mentoring or orientation pro-
gram exists to help them adjust to their new demands, the amount and type of feedback they will be given, and the type of organizational support they can expect.

Parkay et al10 suggested that individuals could benefit from opportunities to interact with others who are at higher phases of professional development. Similarly, ATCs just entering an organization could benefit from interacting with other ATCs who have gained role stability. Such interactions could facilitate the professional socialization process and the aspects of professional development that have aided them as professionals. This particular strategy may also be helpful for undergraduate student socialization as well, because understanding what to expect from an organization can facilitate a more effective anticipatory socialization.

The findings of professional socialization in this study parallel those reported by Wanous4 after he synthesized many stage models of organizational socialization. He suggested that when individuals enter an organization, they discover either a confirmation or disconfirmation of their expectations and identify work-related conflicts. Soon individuals clarify their roles and learn how to work within the organizational structure. An individual then establishes commitments and learns the behaviors that are consistent with the organization, subsequently becoming an insider. The exception to the model derived from this study, however, is those who did not gain role stability. In these instances, the ATCs' attitudes, values, and ideals were not consistent with the organizations'. These particular individuals focused on their commitments or removed themselves from the organization and took a position at a different university or a different practice setting (e.g., sports medicine clinic). It is critical, therefore, that potential staff ATCs gain a great deal of information relative to the organization's values, priorities, and expectations to ensure congruity between the individual and the organization to enhance movement toward role stability in that setting. This is particularly important because a work context may either reinforce or contradict the previous socialization procedures that an ATC has experienced.

Limitations

One limitation of our study is that it was not longitudinal. Rather, we relied on the participants' ability to reflect on past experiences and perceptions with respect to their socialization. Becker et al12 used a similar strategy, however, in a landmark study on the socialization of medical students. The professional development of NCAA DI collegiate ATCs is a prime topic for a longitudinal study to clarify the findings presented herein. Such long-term contact with subjects may uncover significant insights not revealed in this study. Another limitation is linked to the generalizability of the study. Although qualitative research that uses small sample sizes may be transferable to similar contexts, it may not be generalizable. Therefore, additional research investigating the professional socialization process in other contexts or settings is necessary to identify potential educational strategies required to facilitate professional growth.

CONCLUSION

We attempted to answer 3 primary questions: (1) What informal and formal processes socialize ATCs into their professional roles at the NCAA DI level? (2) How do ATCs perceive their experiences during their first several years of practice? (3) Do these experiences change over time in a detectable pattern? The conclusions from this study suggest that the professional socialization process of ATCs into their professional roles at the NCAA DI level appears to be primarily informal or unstructured in nature, as indicated by statements such as "learning on the run" and "learning by doing." Moreover, this informal socialization process often involved participants' contacting previous mentors for guidance and advice. The socialization experiences during the first several years of practice appeared to create a great deal of uncertainty and adjustment among the ATCs, but they soon learned the multifaceted nature of their responsibilities as their roles evolved.

Our findings give insight into a discernible pattern of not only socialization experiences and perceptions among the participants' organizational socialization but also their anticipatory socialization. As such, the professional socialization processes of DI collegiate ATCs is explained as a 5-phase developmental sequence: (1) envisioning the role, (2) formal preparation, (3) organizational entry, (4) role evolution, and (5) gaining stability.

The professional development process model presented herein explicates the socialization process of NCAA DI collegiate ATCs. Further examination of individuals who have gained role stability may uncover vital and critical events that allowed them to succeed within their organization.

The profession of athletic training has devoted significant effort to reforming undergraduate athletic training education, but the professional socialization process in athletic training education programs has been a neglected research area. Therefore, it is advisable for future researchers to investigate the development of a professional orientation among student athletic trainers to understand the specific professional values and attitudes to which students are socialized.

ACKNOWLEDGMENTS

We give special thanks to Dr Gene Roth for his insightful comments during this study.

REFERENCES

The Sensorimotor System, Part I: The Physiologic Basis of Functional Joint Stability

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Objective: To define the nomenclature and physiologic mechanisms responsible for functional joint stability.

Data Sources: Information was drawn from an extensive MEDLINE search of the scientific literature conducted in the areas of proprioception, neuromuscular control, and mechanisms of functional joint stability for the years 1970 through 1999. An emphasis was placed on defining pertinent nomenclature based on the original references.

Data Synthesis: Afferent proprioceptive input is conveyed to all levels of the central nervous system. They serve fundamental roles in optimal motor control and sensorimotor control over functional joint stability.

Conclusions/Applications: Sensorimotor control over the dynamic restraints is a complex process that involves components traditionally associated with motor control. Recognizing and understanding the complexities involved will facilitate the continued development and institution of management strategies based on scientific rationales.

Key Words: proprioception, neuromuscular, motor control

The purpose of this 2-part series is to provide an overview of the current understanding surrounding peripheral afferent information acquisition and processing and levels of motor control as they relate to functional joint stability. We recognize that these papers focus heavily upon basic science research that, in many circumstances, lacks immediate clinical application. Our premise is to present the athletic training community with an introduction concerning how the dynamic restraints are activated and controlled by the motor control system of the body. Our goal is that these papers may initiate common understanding regarding the terminology and underlying physiology associated with proprioception and neuromuscular control. Ultimately, by establishing a baseline understanding about the sensorimotor system, clinical techniques can continue to be developed and applied with scientific rationale. Furthermore, through this understanding, clinicians can appreciate future developments and research directions focusing on the restoration of functional joint stability.

The purpose of this first paper is to introduce the sensorimotor motor system, the biological system that controls the contributions of the dynamic restraints for functional joint stability. A secondary purpose is to define the nomenclature pertaining to the mechanisms responsible for both the sensory and motor components of proprioception and neuromuscular control for the maintenance of functional joint stability.

PERTINENT TERMINOLOGY

Before examining the specialized components and physiologic intricacies of the sensorimotor system, we must begin our discussion by defining some broad terms used in the medical and physiologic literature. Homeostasis is defined as the dynamic process by which an organism maintains and controls its internal environment despite perturbations from external forces.1 Because cells, tissues, and organs operating within the body can only function within narrow ranges of environmental conditions, maintaining homeostasis becomes the major driving force underlying many, if not all, physiologic functions of the body. The body is composed of many systems that operate automatically and subconsciously to maintain the body in a homeostatic condition.2 A system is specifically defined as an organized grouping of related structures that perform certain common actions.3 Systems are organized hierarchically, beginning at the cellular level, and contribute to bodily homeostasis in specific domains. In a healthy individual, the system’s homeostasis is usually maintained by 2 different control systems. Stimulation of a corrective response within the corresponding system after sensory detection is often considered feedback controls. In contrast, feedforward controls have been described as anticipatory actions occurring before the sensory detection of a homeostatic disruption.4,5 Initiated feedback actions are largely shaped by previous experience with the detected stimulus. Somatosensory, visual, and vestibular input provides the information necessary for both forms of control during motor activities; however, the methods of information processing differ.5 Feedback control is characterized by a continual processing of afferent information, providing response control on a moment-to-moment basis. In contrast, afferent information during feedforward control is used intermittently until feedback controls are initiated.5,6
Unfortunately, classifying an action as either feedback or feedforward is not as straightforward as their definitions suggest. In some circumstances, a combination of both feedforward and feedback control exists, such as during the maintenance of postural control. Additionally, consider the situation in which a subject watches a tester trigger a device that induces a joint perturbation. Many subjects will naturally "tense up" when they see the tester beginning to push the trigger before the perturbation. Whether the muscle activation before the perturbation reaching the joint is the result of feedforward or feedback control remains controversial. For this reason, the term feedforward control has been recommended to describe actions occurring upon the identification of the beginning, as well as the effects, of an impending event or stimulus. In contrast, feedback control should be used to describe actions occurring in response to the sensory detection of direct effects from the arrival of the event or stimulus to the system.

The actions occurring with both feedback and feedforward controls involve the hierarchic organization of a system, beginning at the cellular level and extending through both the tissue and organ levels. The action patterns used to restore homeostasis are defined as mechanisms. For example, the reflexive response is the mechanism the body uses to maintain or restore joint stability after an imposed joint perturbation. Within a given mechanism are multiple processes that ultimately lead to the achievement of the result. In the case of joint perturbation, the processes include mechanoreceptor stimulation, neural transmission, integration of the signals by the central nervous system (CNS), transmission of an efferent signal, muscle activation, and force production. By definition, for the purposes of this paper, assessing a mechanism refers to the cumulative outcome of the underlying processes. During many clinical and research evaluations, inferences about the integrity of mechanisms are made by measuring specific characteristics of the underlying processes. Onset latency of muscle activation, as measured through electromyography, is frequently assessed in joint perturbation.

One additional physiologic term requiring attention in a broad context before our specialized discussion is stability. Stability is defined as the state of remaining unchanged, even in the presence of forces that would normally change the state or condition. It has been further described as the property of returning to an initial state upon disruption. With respect to joints, based on the above definitions, we define stability as the state of a joint remaining or promptly returning to proper alignment through an equalization of forces.

THE SENSORIMOTOR SYSTEM

The sensorimotor system, a subcomponent of the comprehensive motor control system of the body, is extremely complex. The term sensorimotor system was adopted by the participants of the 1997 Foundation of Sports Medicine Education and Research workshop to describe the sensory, motor, and central integration and processing components involved in maintaining joint homeostasis during bodily movements (functional joint stability) (Figure 1). The components giving rise to functional joint stability must be flexible and adaptable because the required levels vary among both persons and tasks. The process of maintaining functional joint stability is accomplished through a complementary relationship between static and dynamic components. Ligaments, joint capsule, cartilage, friction, and the bony geometry within the articulation comprise the static (passive) components. Dynamic contributions arise from feedforward and feedback neuromotor control over the skeletal muscles crossing the joint. Underlying the effectiveness of the dynamic restraints are the biomechanical and physical characteristics of the joint. These characteristics include range of motion and muscle strength and endurance.

From these descriptions of static and dynamic stability components, it becomes apparent that the terms are not synonymous. Integrity of static stabilizers is measured through clinical joint stress testing (ligamentous laxity testing) and arthrometry, giving rise to the frequently used term clinical stability. Because of the complexity of the control over the dynamic restraints, measuring dynamic stability is more challenging. Currently, as described in a companion paper, we are only able to quantitatively measure certain characteristics of the dynamic stability mechanism.

PROPRIOCEPTION AND NEUROMUSCULAR CONTROL

Proprioception predominates as the most misused term within the sensorimotor system. It has been incorrectly used synonymously and interchangeably with kinesthesia, joint position sense, somatosensation, balance, and reflexive joint stability. In Sherrington’s original description of the "proprioceptive system," proprioception was used to reference the afferent information arising from "proprioceptors" located in the "proprioceptive field." The "proprioceptive field" was specifically defined as that area of the body "screened from the environment" by the surface cells, which contained recep-
Somatosensory Sensations

- **Tactile**
  - Touch
  - Pressure
  - Vibration
  - Tickle

- **Pain**

- **Temperature**

- **Conscious Proprioceptive Senses**
  - Kinesthesia
  - Joint Position Sense
  - Sense of Resistance (force)

**Figure 2. Sensations arising from somatosensory sources.**

In contrast to proprioception, the term somatosensory (or somatosensation) is more global and encompasses all of the mechanoreceptive, thermoreceptive, and pain information arising from the periphery. Conscious appreciation of somatosensory information leads to the sensations of pain, temperature, tactile (ie, touch, pressure, etc), and the conscious modality proprioception sensations. Thus, as Figure 2 illustrates, conscious appreciation of proprioception is a sub-component of somatosensation and, therefore, the terms should not be used interchangeably.

Although Sherrington's definition of the proprioceptive field clearly excludes the receptors sensitive to the external environment ("exteroceptive field"), he did not imply that the receptors in each region function in total exclusion of one another. Rather, Sherrington recognized the interaction between receptors located in both regions of the body, referring to the relationship between the receptors in the exteroceptive and proprioceptive environments as "allied." Specifically, with respect to conscious proprioception appreciation, this aspect of proprioception has undoubtedly led to much of the confusion surrounding the interpretation of conscious proprioceptive acuity in persons suspected of having diminished proprioceptive information arising from articular sources follow-

**PERIPHERAL SENSORY PATHWAYS**

**Sources of Proprioceptive Input**

Based on Sherrington's definition of the proprioceptive field, the mechanoreceptors responsible for proprioceptive information are primarily found in muscle, tendon, ligament, and capsule, with the mechanoreceptors located in the deep skin and fascial layers traditionally associated with sensory reactions being theorized supplementary sources. In general, mechanoreceptors are specialized sensory receptors responsible for quantitatively transducing the mechanical events occurring in their host tissues into neural signals. Although the process gen-
Generally occurs in a similar manner across the various mechanoreceptors, each morphologic type possesses some degree of specificity for the sensory modality to which it responds (light touch versus tissue lengthening), as well as the range of stimuli within a sensory modality. As several detailed reviews have been published on the subject, we offer only a brief review of the characteristics and functions of joint and muscle mechanoreceptors.

Although 4 types of receptors are dispersed throughout ligamentous and capsular tissues, Ruffini receptors are the most frequently described. They are considered to behave as both static and dynamic receptors based on their low-threshold, slow-adapting characteristics. In contrast, the low-threshold, rapidly adapting characteristics of Pacinian corpuscles cause them to be exclusively classified as dynamic receptors. Also present in these tissues are Golgi tendon organ-like endings and free nerve endings.

Mechanoreceptors located within musculotendinous tissue include the Golgi tendon organs (GTOs) spaced along the musculotendinous junction at varying intervals and the muscle spindles located in the muscle tissue. Through each GTO passes a small bundle of muscle tendon fibers destined to attach to muscle fibers. This series arrangement, coupled with the very low threshold and high dynamic sensitivity exhibited by the sensory endings, enables GTOs to provide the CNS with feedback concerning muscle tension. GTO function primarily in signaling active muscle tension (tension developed during contraction) rather than passive tension (tension developed during inactive muscle stretching).

As a whole, muscle spindles are responsible for conveying information regarding muscle length and rate of changes in length. Muscle spindles consist of specialized afferent nerve endings that are wrapped around modified muscle fibers (intrafusal fibers), several of which are enclosed in a connective tissue capsule. There are different types of intrafusal fibers: some are mainly sensitive to changes in muscle length, whereas others are more sensitive to the rate of change in muscle length.

Although the central areas of the intrafusal muscle fibers lack contractile elements, the peripheral areas contain contractile elements, which are innervated independent of extrafusal (skeletal) muscle fibers via the gamma motor neurons (γ-MNs). Activation of the peripheral contractile elements stretches the central regions containing the sensory receptors from both ends. This results in an increase in the firing rates of the sensory ending and an increase in the sensitivity of the muscle spindle to length changes. At the spinal level, various peripheral receptors, such as skin receptors, articular receptors, and chemoreceptors, strongly influence the activity of the γ-MN system and, therefore, the muscle spindle in providing afferent information.

**Sensory Integration at the Spinal Cord Level**

Integration of sensory input received from all parts of the body is largely considered to begin at the level of the spinal cord. Integration describes the summation, gating, and modulation mechanisms that occur as a result of various combinations of excitatory and inhibitory synapses with the afferent neurons. These synapses may originate from several sources, such as other afferent fibers or neurons conveying descending signals from higher CNS structures. Afferent integration is an essential component of coordinated, fluid motor control and occurs along all levels of the CNS. This section offers only a brief overview of afferent integration at the spinal level, as a detailed review has previously been published.

In contrast to the few tactile neurons that travel directly to the cortex without synapsing, many of the axons conveying proprioceptive information bifurcate once they enter the dorsal horn of the spinal cord to synapse with interneurons. The essence of afferent integration at the spinal cord level lies with the interneurons and the neurons connecting with higher CNS levels. Control over these neurons via descending commands from the brain stem and cortex provides these centers with the ability to filter the sensory input that will be conveyed via the ascending tracts. In other words, the supraspinal CNS regions modulate the sensory information from the periphery that enters the ascending tracts.

An additional hypothesis, the final common input hypothesis proposed by Johansson et al., presents an additional and supplemental integrative mechanism. This hypothesis resides on the strong influence that the muscle, skin, and joint afferents and descending pathways have over gamma neuron activation. As mentioned previously, the peripheral regions of intrafusal muscle fibers contain contractile elements innervated by γ-MNs, with the level of activation directly controlling muscle spindle sensitivity. Any of the signals barraging the γ-MN pools alter their level of activation, and, therefore, influence the input arising from the muscle spindles. Thus, the afferent signals from muscle spindles are hypothesized to be a function of muscle length changes superimposed on the integrative peripheral receptor and descending pathway information. In this manner, the γ-MN system may be considered a “premotor neuronal integrative system” that conducts “polymodal feedback” to the CNS (Figure 3).

**Proprioceptive Coding to Higher CNS Centers**

Two theories describe the methods by which specific proprioceptive messages from the various receptors are conveyed to the CNS. The first theory, the labeled line theory, is based...
on the presumption that each unique stimulus triggers a certain receptor connected to a specific nerve fiber that terminates at a specific point or multiple points within the CNS. Critics of this theory suggest that it neglects the fact that most receptors and neurons appear to be sensitive to different types of stimuli and not only to a specific stimulus. The second theory, ensemble coding, suggests that proprioceptive information is transferred to the CNS through an encoding across a neural population of receptors rather than discrete units from the individual receptors. Originally proposed by Erickson, this theory proposes that receptors possess unique, but overlapping, ranges of sensitivity. Application of this theory to the sensorimotor system has been largely a result of the work by Johansson et al. Clinically, this theory may help explain the improved conscious proprioceptive acuity and reduction in subjective instability associated with elastic wraps and neoprene bracing.

**Ascending Spinocerebellar Tracts Conveying Proprioceptive Information**

Most proprioceptive information travels to higher CNS levels through either the dorsal lateral tracts or the spinocerebellar tracts. The 2 dorsal lateral tracts are located in the posterior region of the spinal cord and ultimately convey the signals to the somatosensory cortex. Although the majority of the sensations traveling in this tract are touch, pressure, and vibration, various amounts of the conscious appreciation of position and kinesthetic sensations have also been attributed to this tract. The spinocerebellar tracts are characterized by the fastest transmission velocities in the CNS. As their name suggests, the spinocerebellar tracts terminate in various areas of the cerebellum, where the signals may be processed and integrated with other afferent and descending information. In contrast to the conscious sensory appreciation associated with the dorsal lateral tracts, the spinocerebellar tracts are believed to be responsible for “nonconscious proprioception” (ie, limb position, joint angles, and muscle tension and length) used for reflexive, automatic, and voluntary activities. In addition to relaying peripheral afferent information, parts of these tracts are associated with transmitting an efferent copy of motor neuron drive back to the higher CNS levels.

**Conscious Perception of Proprioception**

Sherrington’s early 1900s view attributing the sense of kinesthesia and joint position sense (“muscular sense”) to muscle receptors was accepted for most of the century, with a brief hiatus existing for a short time period (1950–1970) when several authors considered joint receptors to be the primary source. The change of belief was initiated by the results of several studies considering occulomotor system problems and the overall lack of evidence supporting direct group I afferent projections to the sensorimotor cortex. The premise shifted back to muscle receptors after the demonstration of joint receptors’ response voids through the midranges of motion and reports of movement illusions caused by tendon vibration. Our survey of the available literature on this topic up to present times reveals a plethora of conflicting evidence supporting each tissue’s receptors (joint, muscle, and cutaneous) as the predominant source. Even more uncertain is supposition on the contribution individual morphologic receptors make within each tissue (joint, muscle, and cutaneous) during functional, full-range joint movements. Rather than attempting to review all the original work conducted in this area, which by itself would become a lengthy paper, we will highlight some of the major findings and discuss the implications of the continued controversy with respect to conscious appreciation of joint position sense (JPS) and kinesthesia.

The first step in determining whether a group of tissue receptors could potentially contribute to conscious appreciation of kinesthesia and JPS is through documentation of response sensitivity through the full physiologic range of joint motion. Through the use of animal models, several investigators have concluded that mechanoreceptors located in the joint capsule do not appear to be sufficiently stimulated through the midranges of motion to contribute substantially to proprioception, especially in relation to the seemingly potent input stemming from muscle receptors. Several authors have concluded, based on this evidence, that joint capsule afferents are unlikely to signal JPS and kinesthesia information through the midranges of motion and that their only proprioceptive function is signaling endranges of motion. Grigg, who has evaluated ligamentous receptors as probable candidates based on their low numbers (with respect to joint capsule) and inability to signal specific joint movement and position. It is important to note, however, that the evidence upon which many of these conclusions are based was collected during passive movements. As Pedersen et al stated, researchers have reported increases in joint receptor working ranges (angular range in which a receptor remains active) during active movements. Similar to joint afferents, cutaneous afferents have been speculated to respond only at the extremes of motion. Unfortunately, this finding is not without controversy, as several authors have recently attributed cutaneous mechanoreceptors with a precise ability to convey joint movements through skin strain patterns. In contrast to joint and cutaneous mechanoreceptors, muscle spindles have been almost universally described as able to respond unidirectionally across the entire physiologic range of movement.

As mentioned previously, proprioception for conscious appreciation travels via the dorsal lateral tracts, with the contributions to these tracts from muscle and joint mechanoreceptors remaining largely unknown. Thus, demonstrating the existence of projections to the cortical sensory areas and conscious perceptions after direct receptor stimulation is the second necessity in determining the predominant source of conscious proprioception (Figure 4). Unfortunately, the results of these studies have complicated the conclusions one would draw based solely on the sensitivity evidence. Cortical projections have been reported from joint (both capsular and ligament) afferents, muscle spindles, and GTOs. With respect to conscious appreciation of peripheral receptor stimulation, electric stimulation of both joint and cutaneous (slowly adapting type II) afferent fibers were reported to elicit sensations related to the relevant joint and evoke perceptions of joint movement, respectively. Edin and Johansson demonstrated that mechanical stimulation of cutaneous receptors elicited kinesthetic sensations. While direct stimulation of a single muscle spindle afferent failed to elicit movement perception, stimulation of several muscle spindles through vibration has been reported to evoke conscious movement sensations. The failure of joint and cutaneous afferents anesthesia to disrupt conscious kinesthesia and JPS provides further support for the importance of muscle receptors in conscious proprioception.
In summary, the predominant source or sources contributing to the conscious proprioception remains quite open to debate. We theorize that part of the controversy may reside with the different methods used by researchers. For example, results attained through electric afferent stimulation may not be related to the normal physiologic processes. In addition, we suspect that the underlying processes contributing to the conscious proprioceptive perceptions may differ across anatomical locations. For instance, the results demonstrating the importance of cutaneous receptors to kinesthesia in the finger joints may not be applicable to other areas of the body, especially those containing sparser populations of cutaneous receptors. It is quite probable that the relative importance of each receptor varies according to each unique movement or task, or both. Furthermore, the strong evidence suggesting that the CNS determines proprioceptive input from populations of receptors (ensemble coding) cannot be ignored. This would indicate that the absence of input from joint receptors during midranges of motion may be as important as the active input arising from muscle spindles, especially when coupled with the connections between joint receptors and γ-MN activation. Clearly, this represents an area that requires further investigation and clarification.

LEVELS OF MOTOR CONTROL

The motor components of the sensorimotor system contributing dynamic joint stability are synonymous with areas controlling whole-body motor control. These components consist of a central axis and 2 associate areas. The central axis corresponds to the 3 levels of motor control, spinal cord, brain stem, and cerebral cortex, whereas the 2 associate areas, cerebellum and basal ganglia, are responsible for modulating and regulating the motor commands. Sensory information underlies the planning of all motor output and, as discussed in previous sections, is conveyed to all 3 levels of motor control. Activation of motor neurons may occur in direct response to peripheral sensory input (reflexes) or from descending commands initiated in the brain stem or cerebral cortex, or both. Independent of the initiating source, skeletal muscle activation occurs through signal convergence onto the motor neurons located in the spinal ventral horns. This concept is what Sherrington labeled the final common path. Both types of motor neurons, alpha motor neurons (α MNs) controlling extrajusal muscle fibers (skeletal) and γ MNs controlling intrajusal muscle fibers (muscle spindles), exit the spinal ventral horns.

The central axis areas are organized in both a hierarchic and parallel manner. The hierarchic organization allows the lower motor areas to automatically control the details of common motor activities, while the higher centers can devote resources to controlling the more precise and dexterous motor activities. In addition, as mentioned earlier, higher levels can regulate theafferent information reaching them through inhibitory and facilitatory control over sensory relay nuclei. Through the parallel arrangement, each motor control center can directly issue independent contributory descending motor commands directly on the motor neurons.

Spinal Cord Level

It should be apparent from our earlier discussion that the spinal cord plays an integral role in motor control, despite the gross anatomy suggesting it may only be a medley of conduction pathways. From the spinal cord arise direct motor responses to peripheral sensory information (reflexes) and elementary patterns of motor coordination (rhythmic and central pattern generators). As discussed earlier, very little afferent input and few descending commands synapse directly on motor neurons. Instead, most input terminates upon the interneurons located throughout all areas of cord gray matter. Even in the case of a simple monosynaptic reflex, such as the stretch reflex, bifurcations from the incoming afferent fiber arise. These bifurcations may convey the afferent information to a number of locations, including interneurons, higher motor centers, and other motor neurons (antagonistic). The bifurcations and interneuronal networks provide the basis for the spinal cord's efferent integrative functions.

Reflexes may be elicited from the stimulation of cutaneous, muscle, and joint mechanoreceptors and may involve excitation of α MNs, γ MNs, or both. For many clinicians, the stretch reflex in response to rapid muscle lengthening provides the most familiar example. These reflexes, as well as the other reflexes attributed to the spinal cord neuronal circuitry, are more complex than simple direct input-output connections. Superimposed on even the simplest monosynaptic reflexes are influences from such sources as other afferent input, descending commands, or both.

Brain Stem

Despite being the most primitive part of the brain from a phylogenetic perspective, the brain stem contains major circuits that control postural equilibrium and many of the automatic and stereotyped movements of the body. In addition to being under direct cortical command and providing an indirect relay station from the cortex to the spinal cord, areas of the brain stem directly regulate and modulate motor activities based on the integration of sensory information from visual, vestibular, and somatosensory sources. Two main descending pathways, the medial and lateral pathways, extend from the brain stem to the spinal cord neural networks. The medial pathways influence the motor neu-
rons innervating the axial and proximal muscles, while the lateral pathway controls the distal muscles of the extremities. In addition to controlling postural control, some axons comprising the medial pathways make excitatory and inhibitory (including suppression of spinal reflexes) synapses with the interneurons and motor neurons involved with movement and postural control. Through influences on the γ MNs, parts of both the medial and lateral tracts assist in maintaining and modulating muscle tone.

Cerebral Cortex

In general, the motor cortex is responsible for initiating and controlling more complex and discrete voluntary movements. It is divided into 3 specialized and somatotopically organized areas, each of which project directly and indirectly (via the brain stem) onto interneurons and motor neurons located in the spinal cord. The first area, the primary motor cortex, receives peripheral afferent information via several pathways and is responsible for encoding the muscles to be activated, the force recruited by the muscles produce, and the direction of the movement. The second area, the premotor area, also receives considerable sensory input; however, it is mainly involved with the organization and preparation of motor commands. The supplemental motor area, the third specialized area of the motor cortex, also plays an important role in programming complex sequences of movement that involve groups of muscles.

The major direct descending pathway from the motor cortex to the α MNs and γ MNs is the corticospinal tract. In addition to influencing motor functions directly, the corticospinal tract also affects motor activity indirectly through the descending brainstem pathways.

Associate Areas

Although the 2 associate areas, the cerebellum and basal ganglia, cannot independently initiate motor activity, they are essential for the execution of coordinated motor control. The cerebellum, operating entirely at a subconscious level, plays a major role in both the planning and modification of motor activities through comparison of the intended movement with the outcome movement. This is accomplished through the continuous inflow of information from the motor control areas and the central and peripheral sensory areas. The cerebellum is divided into 3 functional divisions. The first division receives vestibular input, both directly and indirectly from the vestibular labyrinth (semicircular and otolith receptors) and, as might be surmised based on the input, is involved with postural equilibrium. The second cerebellar division is mainly responsible for the planning and initiation of movements, especially those requiring precise and rapid dexterous limb movements. This division receives input from both the sensory and motor cortices. It is the third division, the spinocerebellum, which receives the somatosensory information conveyed through the 4 ascending spinocerebellar tracts. In addition to the somatosensory input, this division of the cerebellum also receives input from the vestibocerebellum and visual and auditory organs. The output from the spinocerebellum serves to adjust ongoing movements through influential connections on the medial and lateral descending tracts in the brain stem and cortex via projections on the vestibular nucleus, reticular formation, red nucleus, and motor cortex. In addition to controlling movements, the spinocerebellum also uses the somatosensory input for feedback regulation of muscle tone through regulation of static γ MNs drive to the muscle spindles. Lastly, the cerebellum also receives an efferent copy of the motor commands arriving at the ventral roots of the spinal cord. The cerebellum has also been implicated in motor learning.

The basal ganglia consist of 5 subcortical nuclei (groups of nerve cells) located deep within the cerebral hemispheres. In contrast to the cerebellum, which has input and output connections with all 3 levels of motor control, the cerebral cortex is the only central axis component having input and output connections (via the thalamus) with the basal ganglia. With respect to motor control, the basal ganglia are believed to be involved with more higher-order, cognitive aspects of motor control. An additional distinction from the cerebellum is that the basal ganglia receive input from the entire cerebral cortex, not just those associated with sensory and motor function. The widespread input and output cortical connections suggest that they are involved with many functions other than motor control.

CONCLUSIONS

The sensorimotor system encompasses all of the sensory, motor, and central integration and processing components involved with maintaining joint homeostasis during bodily movements (functional joint stability). We have attempted to introduce the physiology of joint stability through an in-depth presentation of the sensorimotor system. As evident from the sections concerning ascending proprioception pathways and levels of motor control, the sensorimotor system is much more complex than a simple input-output system that resides primarily in the lower levels of motor control. Rather, activation of the dynamic restraints, and therefore, functional joint stability, arises from components synonymous with the entire motor control system of the body. Thus, functional joint stability is an inherently complex and complicated physiologic process. In the absence of mechanical stability, the fact that many individuals return to preinjury levels suggests that some degree of compensatory mechanisms can be developed to provide the supplemental stability required. These compensatory mechanisms most likely arise from the dynamic restraints of the involved joint, as well as motor adaptations at proximal and distal segments. This would suggest the importance of the supraspinal temporal and spatial organization of the dynamic restraint activation. In part II of this article, we will discuss the importance of proprioception in organizing muscle activation for both motor control and sensorimotor control of functional joint stability.

REFERENCES


The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability

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Objective: To discuss the role of proprioception in motor control and in activation of the dynamic restraints for functional joint stability.

Data Sources: Information was drawn from an extensive MEDLINE search of the scientific literature conducted in the areas of proprioception, motor control, neuromuscular control, and mechanisms of functional joint stability for the years 1970–1999.

Data Synthesis: Proprioception is conveyed to all levels of the central nervous system. It serves fundamental roles for optimal motor control and sensorimotor control over the dynamic restraints.

Conclusions/Applications: Although controversy remains over the precise contributions of specific mechanoreceptors, proprioception as a whole is an essential component to controlling activation of the dynamic restraints and motor control. Enhanced muscle stiffness, of which muscle spindles are a crucial element, is argued to be an important characteristic for dynamic joint stability. Articular mechanoreceptors are attributed instrumental influence over gamma motor neuron activation, and therefore, serve to indirectly influence muscle stiffness. In addition, articular mechanoreceptors appear to influence higher motor center control over the dynamic restraints. Further research conducted in these areas will continue to assist in providing a scientific basis to the selection and development of clinical procedures.

Key Words: neuromuscular, stability, motor control

This is Part II of a 2-part series discussing the current understanding surrounding peripheral afferent information acquisition, processing, and levels of motor control as they relate to functional joint stability. In Part I, the sensorimotor system and the mechanisms responsible for proprioception and neuromuscular control as they relate to functional joint stability were addressed. The purpose of Part II is to build upon and apply the concepts developed in the Part I. Specifically, we will address the contribution of proprioception in controlling the activation of the dynamic restraints and motor control.

The Role of Proprioception in Motor Control

Critical to effective motor control is accurate sensory information concerning both the external and internal environmental conditions of the body.1–4 During goal-directed behavior, such as picking up a box while walking, provisions must be made to adapt the motor program for walking to changes occurring in the external environment (uneven ground) and internal environment (change in center of mass because of the additional load). These provisions are stimulated by sensory triggers occurring in both feedback (mechanoreceptor detection of altered support surface) and feedforward (anticipating center-of-mass change from previous experience) manners. Although some of the afferent information may be redundant across the 3 sensory sources (somatosensory, visual, vestibular), specific unique roles are associated with each source that may not be entirely compensated for by the other sensory sources. For example, proprioceptive information plays an integral role in the ability to modify internal models used with feedforward control5,6 that has been demonstrated to be only partly compensated for by visual information.7

The role of proprioceptive information in motor control can be separated into 2 categories.2 The first category involves the role of proprioception with respect to the external environment. Motor programs often have to be adjusted to accommodate unexpected perturbations or changes in the external environment. Although the source of this information is often largely associated with visual input, there are many circumstances in which proprioceptive input is the quickest or the most accurate, or both.1 In the above example, modification of the motor program for walking was required in response to the uneven support surface. If the person’s vision was fixed on the box to be picked up, he or she might not have visually noted the uneven support surface. In addition to alterations in the plantar cutaneous receptors, muscle and joint mechanoreceptors would have reported the degree of altered ankle joint position and stimulated the motor program modification required. The planning of movements also requires attention to environmental constraints.8 This is especially true with respect to the selection of strategies for the maintenance of postural control.9–11 For example, sensory detection of an unstable handrail from peripheral signals (kinesthesia, changing joint...
positions) would alter the motor program used to avoid falling on a slippery staircase. During the planning stages of a movement, visual images are used to create a model of the environment in which the movement will occur. Proprioception has been described as essential during the movement execution to update the feedforward commands derived from the visual image.5,6

The second category of roles proprioceptive information plays in motor control is in the planning and modification of internally generated motor commands.2 Before and during a motor command, the motor control system must consider the current and changing positions of the joints involved to account for the complex mechanical interactions within the components of the musculoskeletal system.2 Proprioception best provides the needed segmental movement and position information to the motor control system.1,2 In the situation of a single joint moving through a $10^\circ$ arc of motion, the precise muscle force required to perform the task depends upon the joint angle. As one can surmise, the task of determining how much tension in a muscle is required for a movement becomes extremely complex and important with movements involving several joints.2,4,12 Accompanying each angular change in joint position are changes in the mechanical advantages associated with all the muscles that traverse the joint. Many tasks involve a sequence of overlapping joint movements. The motor control system must consider the multiple motions occurring as both a direct function of muscle activation and indirectly from intersegmental dynamics (movement of one joint inducing movement of another). Proprioception provides much of the information required to solve all these movement problems.2,4,7,12,13

Role of Proprioception in Sensorimotor Control of Functional Joint Stability

Motor control for even simple tasks is a plastic process3 that undergoes constant review and modification based upon the integration and analysis of sensory input, efferent motor commands, and resultant movements. Proprioceptive information stemming from joint and muscle receptors, as previously demonstrated, plays an integral role in this process. Underlying the execution of all motor tasks are particular events, often very subtle, that are aimed at preparing, maintaining, and restoring stability of both the entire body (postural stability) and the segments (joint stability). With respect to joint stability, these actions represent neuromuscular control. Proprioceptive information, first recognized and described by Sherrington14 almost 100 years ago, is essential to maintaining both types of stability. Because articular mechanoreceptors are believed to become disrupted in conjunction with joint injury, this section will focus on the role articular mechanoreceptors serve in sensorimotor control over functional joint stability. A discussion of the contribution of articular receptors to postural control has recently been published.15

Since the work of Palmer,10 one of the major tenets concerning the role of joint afferents in functional joint stability has been direct reflexive activation of alpha motor neurons (α MNs).17-19 This belief, however, is not uncontested20-22 and represents one of the biggest ongoing debates within the sensorimotor system. Direct evidence supporting the existence of ligament-muscle reflexes has largely arisen through direct electric and mechanical stimulation of the knee, ankle, and shoulder ligaments or capsule (or both).19,23-28 Similar to the use of electric stimulation on afferent nerve fibers to document cortical projections, the applicability of these findings to normal physiologic function remains speculative and uncertain.27 Specific to the mechanical stimuli, the loading required to elicit α-MN responses has been criticized as exceeding normal physiologic loads.22,28,29 Even assuming that the ligament-muscle reflex exists, one must question its effectiveness in contributing to joint protection because of the latency times22,29,30 and weak response magnitudes,31 especially in comparison with reflexes stimulated from muscle spindles.28 Despite the controversial basic science and empirical support, in vivo human studies involving ankle and knee joint perturbations in conjunction with electromyography have been conducted and have produced varying results.17,32-40 For example, at the ankle, the number of investigations demonstrating increased latencies with mechanically or functionally unstable joints (or both)32-35 is matched by just as many studies failing to elicit differences.36-40 Several factors must be considered with respect to the conclusions that can be drawn from this experimental model. These are reviewed in a subsequent paper describing sensorimotor measurement techniques.41

In contrast with the seemingly controversial activation of α MNs, joint afferents are more unanimously credited with eliciting similar effects on gamma motor neurons (γ MNs).21,22,29,42,43 Interestingly, and in opposition to what many have claimed, Freeman and Wyke44 attributed increases in muscle activity in response to joint mechanoreceptor stimulation to activation of γ MNs, not α MNs. Since their study, many investigations have demonstrated reflexive action of joint afferents on γ MNs through electric stimulation44 and tissue traction using force levels below those associated with tissue damage and nociception.21,22,42,45,46 Increased γ-MN activation, which may occur from input arising from cutaneous or muscle sources as well as descending supraspinal commands, serves to heighten muscle spindle sensitivity. What does increased muscle spindle sensitivity have in connection with sensorimotor control of functional joint stability? The answer to this question will become evident in the following discussion of stiffness.

Muscle stiffness is defined as the ratio of change in force per change in length.29,47,48 In contrast to muscle stiffness, which refers specifically to the stiffness properties exhibited by tenomuscular tissues, joint stiffness involves the contributions of all of the structures located within and over the joint (muscles, tendons, skin, subcutaneous tissue, fascia, ligaments, joint capsule, and cartilage).49-51 Several studies have been conducted in attempts to quantify the contributions of each structure to joint stiffness. These studies generally indicate that the muscle and joint ligamentous and capsular structures traversing the joint contribute equally in passive modes.50,51

The constituents of muscle stiffness can be categorized into intrinsic and extrinsic (reflex) components.52 Many of the elements comprising muscle tissue and connecting noncontractile tissues (tendon, fascia) contain high amounts of collagen and, therefore, exhibit the properties of elasticity and viscosity when stretched. In addition, the intrinsic component encompasses the number of actin-myosin cross-bridges (level of muscle activation) existing at an instant.29,53 as well as the factors of both single muscle fibers (ie, sarcomere length-tension and force-velocity relationships) and whole muscles (ie, arrangement of muscle fibers within a muscle).54 The levels of activation existing within a muscle at a given instant are a
function of both preceding reflexes and descending influences on the α-MN pool.29

The extrinsic contribution of muscle stiffness arises from the increased reflexive neural activation of the muscle. This is largely determined by the excitability of the motoneuron pool,29 which in itself is largely dependent upon the sensitivity of primary muscle spindle afferents eliciting autogenic and heterogenic reflexes, as well as descending neural commands. Superimposed on these constituents are a number of interacting factors involving the whole muscle-joint complex, such as joint kinematics (ie, angle, velocity), attachment sites (ie, exact location of muscle insertions), and tissue transitions (ie, muscle, tendon, bone).54

From a theoretic perspective, increased muscle stiffness and, therefore, enhanced joint stiffness, appears to be a beneficial characteristic for augmented functional joint stability. First, stiffer muscles should potentially resist sudden joint displacements more effectively.29,47,55,56 Although not all destabilizing forces may be entirely countered, many could potentially be lessened in magnitude, thereby reducing the incidence of joint subluxation and injury. This may be essential in maintaining functional stability when mechanical stability is deficient and may assist in explaining the moderate correlation between hamstring muscle stiffness and functional ability in anterior cruciate ligament (ACL)-deficient individuals found by McNair et al.47 Directly, voluntary muscle contraction of a muscle group has been demonstrated to increase joint stiffness.36,57 Cocontraction of antagonistic muscles is believed to further enhance joint stiffness by increasing the compression between the articular surfaces.29,56,57

Second, intrinsically stiffer muscles enhance the potential capacities of the extrinsic component. Stiffer muscles as a result of increased activation are also believed to transmit loads to muscle spindles more readily, thereby reducing some of the lag time associated with initiation of reflexive activity.58,59 Some of the physical events contributing to electromechanical delay, such as the time interval between muscle activation and onset of segmental acceleration,60 are reduced in muscles with higher activation levels. Thus, not only is the initial resistance to joint displacement superior through heightened intrinsic stiffness, but the ability to recruit an improved reflexive response is also enhanced.

Higher motor control centers have been credited with compensating for static stabilizer deficiency losses through altered movement and muscle activation patterns.61–63 Similar to the spinal reflexes discussed, both direct and indirect evidence suggests that joint and ligamentous mechanoreceptors are important for supraspinal sensorimotor control over dynamic joint stability. In humans, the difficulty surrounding this aspect of the sensorimotor system arises from the inability to easily induce isolated experimental manipulations to one or more target structures without eliciting numerous confounding factors. Thus, researchers most often attempt to retrospectively measure patients with different conditions and speculate concerning whether elicited changes or adaptations result from damage to static stabilizers, neural elements, or both. Direct evidence supporting the role of articular receptors in sensorimotor control of dynamic joint stability can only be obtained from animal studies after experimentally induced deafferentation. An exorbitant amount of retrospective human research has documented alterations in movement and muscle activation patterns in mechanically and functionally unstable joints, so we will only review several of the common themes supporting the role of articular receptors to higher motor control centers.

With knee injuries, for example, persons sustaining an ACL rupture develop an adaptive motor pattern that involves increased hamstrings activation before joint loading64–67 and maintaining the knee in a more flexed position during the acceptance of the load.61,68,69 Both of these alterations are believed to prevent anterior tibial translation in the absence of the ACL. The increase in hamstrings activity occurs before joint loading in a feedforward control manner. This suggests that the motor program for the activity was changed and indirectly supports the idea of motor control change above a reflexive level.

The alterations in muscle activation sequences appear to occur not only at the involved joint but also at distal and proximal joints, further supporting the idea of higher motor changes. With respect to alterations in proximal joint positioning and activation, evidence has been found in subjects sustaining ACL rupture61 and ankle injury.38,70 Increased activation of musculature acting on the ankle and lower leg (anterior tibialis and soleus) has been demonstrated in ACL-deficient subjects.65 After ankle injury, several investigators71–73 have reported use of postural control strategies that rely more heavily on proximal joint (hip) muscle activation. Collectively, all of these investigations support the premise of higher center motor control changes after orthopaedic injury. Again, the stimulus for these changes remains debatable: afferent changes from the articular receptors, loss of mechanical stability, or both.

Freeman and Wyke24 pioneered direct evidence supporting the importance of articular receptors in sensorimotor control over joint stability by surgically resecting the posterior or medial articular nerves of cats. Since both of these nerves convey afferent information predominantly from the knee joint, the surgical procedure caused the deafferentation of the joint without disrupting mechanical stability. After the surgery, in addition to spinal-level motor alterations, the animals displayed changes in supraspinal motor programs controlling voluntary movements. Further, postural control adjustments that were initiated from visual and vestibular sources were also altered. The authors hypothesized that the alterations developed secondary to the loss of local input concerning stresses on the knee joint capsule. When accompanied by mechanical stability disruptions, the adaptations in movement programs developed after injury may help prevent damage to secondary restraints and arthropathy.28 O’Connor et al,75 using dogs, reported that although joint deafferentation alone was not enough to induce joint degeneration, when combined with ACL transection, severe degenerative changes became more quickly evident than after ligament transection alone.

Thus, it appears that proprioception is fundamental for sensorimotor control over joint stability, with articular receptors providing unique, subtle roles. With respect to stiffness, muscle spindles with higher γ-MN drive enhance both the feedback and feedback controls of the dynamic restraint mechanism through direct regulation of muscle activation levels. Since γ-MN activation is largely influenced by peripheral afferent input, the adequacy and accuracy of the input become important considerations. Given the sensitivity of joint and ligament receptors through ranges of joint motion and their potential influences on γ-MN activity, it becomes quite likely that this indirect mechanism may outweigh the importance of the controversial direct α-MN reflexes. At higher motor levels, joint receptors may play essential roles in the development of
motor program adaptations to compensate for losses in mechanical stability. Figure 4 in Part I summarizes the role of articular receptors in sensorimotor control of functional stability. Further research is needed in all of these areas to fully elucidate the precise mechanisms by which joint receptors contribute.

CONCLUSIONS

Proprioception is conveyed to all levels of the central nervous system, where it provides a unique sensory component to optimize motor control. Additionally, proprioceptive information is necessary for neuromuscular control of the dynamic restraints. Joint receptors, which are often damaged to some degree during articular injury, appear to be an important component to proprioception. While their role in eliciting direct muscular reflexes remains controversial, their role in influencing the γ MNs and supraspinal motor programs appears to be more substantial. Further research concerning the role of articular mechanoreceptors in promoting γ-MN activation and supraspinal motor control is needed. Supraspinal control over the dynamic restraints may be the area that has the most relevance to the development of preventive and rehabilitative strategies. Intervening at supraspinal levels may provide the key to promoting increased dynamic stability from a preparatory perspective, rather than the debatable reactive perspective.

REFERENCES

Sensorimotor System Measurement Techniques

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Objective: To provide an overview of currently available sensorimotor assessment techniques.

Data Sources: We drew information from an extensive review of the scientific literature conducted in the areas of proprioception, neuromuscular control, and motor control measurement. Literature searches were conducted using MEDLINE for the years 1965 to 1999 with the key words proprioception, somatosensory evoked potentials, nerve conduction testing, electromyography, muscle dynamometry, isometric, isokinetic, kinematic, posture, equilibrium, balance, stiffness, neuromuscular, sensorimotor, and measurement. Additional sources were collected using the reference lists of identified articles.

Data Synthesis: Sensorimotor measurement techniques are discussed with reference to the underlying physiologic mechanisms, influential factors and locations of the variable within the system, clinical research questions, limitations of the measurement technique, and directions for future research.

Conclusions/Recommendations: The complex interactions and relationships among the individual components of the sensorimotor system make measuring and analyzing specific characteristics and functions difficult. Additionally, the specific assessment techniques used to measure a variable can influence attained results. Optimizing the application of sensorimotor research to clinical settings can, therefore, be best accomplished through the use of common nomenclature to describe underlying physiologic mechanisms and specific measurement techniques.

Key Words: proprioception, neuromuscular, assessment

The rapid growth of the athletic training profession has been accompanied by an equally rapid increase in focus on basic and clinical research. Many elements of the profession, such as the boost in research submissions to the Journal of Athletic Training and increase in the size of the Free Communications Program of our National Athletic Trainers’ Association Annual Meeting and Clinical Symposia, provide the supporting evidence for this statement. It is essential, however, that as more research is conducted within the profession, such research be completed in a manner that allows for common understanding between researchers and clinicians. Therefore, the purpose of our article is to provide an overview of the currently available sensorimotor measurement techniques in an attempt to initiate a basis for the needed understanding. For each measurement technique discussed, the major underlying physiologic mechanisms, influential factors, and location of the variable within the sensorimotor system will be identified. Additionally, in the context of the current article, we will give a few representative examples of investigations using each technique that have led to advancements in our understanding of the system in either normal or pathologic states.

Maintaining functional joint stability through complementary relationships between static and dynamic restraints is the role of the sensorimotor system.1-3 The sensorimotor system encompasses all of the sensory, motor, and central integration and processing components involved in maintaining functional joint stability.1 In our previous articles,2,3 we reviewed the anatomy and physiology of the entire sensorimotor system. As can be surmised through those reviews, the complex interactions and relationships among the individual components of the sensorimotor system make measuring and analyzing specific characteristics and functions extremely difficult. Adding further complexity are the numerous compensatory mechanisms interspersed throughout the system. For example, the normal ability to close one’s eyes during stance without loss of postural equilibrium resides with the ability of the somatosensory and vestibular senses to provide sufficient afferent information despite the absence of visual input. Similarly, vestibular sense–deficient persons are able to maintain equilibrium as long as visual or somatosensory (or both) inputs are available.4 If we were to assess postural stability in these patients, we might not detect a vestibular sense deficiency unless visual or somatosensory (or both) contributions were eliminated or reduced. Many similar compensatory mechanisms exist throughout the various areas of the sensorimotor system. In research involving surgical manipulation of animal models (eg, decerebrate animals), isolation of specific sensorimotor components and mechanisms can be performed. In contrast, investigations involving human subjects usually require the
use of groups with known or specific deficiencies or the induction of temporary alterations (eg, nerve blocks), or both. Although many different measurement techniques and instruments are currently available for in vivo human research, only a few can purely evaluate the target variable of interest in isolation.

Most assessment techniques currently available evaluate the integrity and function of sensorimotor components by measuring variables along the afferent or efferent pathways or the final outcome of skeletal muscle activation or a combination of these. Currently, no direct assessment methods are available to isolate the higher central integrating and processing centers. From a physiologic perspective, we stress the importance of being as specific as possible in referring to both the variable and suspected mechanisms. It is essential that both factors be considered during any interpretation of results. We use assessment of reflex latency in response to an imposed joint perturbation with electromyography (EMG) as an example. The variable being measured is onset of muscle activity, a variable located on the efferent pathway. In this example, it is necessary to recognize the presence of both the underlying mechanism and influencing factors. The major underlying mechanism leading to elicitation of the variable involves the afferent acquisition and transmission to central integration or processing centers (or both), where the propagation of an efferent neural signal to the muscle can be initiated. The pathway through the central nervous system can range from a simple monosynaptic relay to the efferent neurons' more complex polysynaptic reflex pathways that include transmission through the brain stem to voluntary activation initiated by the motor cortex. Many factors influence this mechanism, such as the integrity of the mechanoreceptors and the level and type (facilitatory or inhibitory) of descending supraspinal control over the neural pathways. All of these factors must be considered in the final interpretation of the variable.

Additional factors that confound valid and reliable variable measurement are the specific techniques used in data collection, processing, and analysis. Each of these can have profound effects on the final outcome of a measurement and thereby influence the reported results. Reverting back to our joint perturbation example, such factors include details of subject instruction, anticipation and expectations, number of trials, data sampling frequencies, and filtering and smoothing techniques. Although controversy will always surround many of the measurement techniques, there is no substitute for clearly describing the exact procedures used. Attention to each of these will facilitate the common understanding of both clinicians and researchers.

PERIPHERAL AFFERENT ACQUISITION AND TRANSMISSION MEASUREMENTS

Proprioception

Several different testing techniques have been developed to measure the conscious submodalities of proprioception. Because there are 3 submodalities (joint position sense [JPS], kinesthesia, and sense of tension), clarification is required to distinguish the target variable of the assessment. The JPS test measures the accuracy of position replication and can be conducted actively or passively in both open and closed kinetic chain positions. Both direct measurements of replicated joint angles6-8 (goniometers, potentiometers, video) and indirect measures9 (visual analog scales) have been used. Kinesthesia testing is conducted by measuring the threshold to detection of passive motion (TTDPM), or more specific testing can be conducted by using the criterion of threshold to detection of passive motion direction (TTDMD).10-12 The TTDMD assesses one's ability to not only detect motion but also detect in which direction the motion is occurring. Slow speeds, ranging from 0.5 to 2°/s, are used to target the slow-adapting mechanoreceptors, such as Ruffini endings or Golgi-type organs.13 The sense of tension is measured by comparing the ability of subjects to replicate torque magnitudes produced by a group of muscles under varying conditions.

Common to all currently available proprioception testing methods are dependencies on conscious appreciation (perception) of mechanoreceptor signals. As detailed in our previous article,13 proprioceptive information travels to the higher brain centers through the dorsal lateral tracts (conscious appreciation) and the spinocerebellar pathways (stimulation and regulation of motor activities). The precise quantities being conveyed to both ascending tracts from each type of mechanoreceptor, as well as the temporal relationship between arrival at the cerebellum and the somatosensory cortex, remain unknown. Additionally, whether the quantity necessary for conscious perception is identical to the requirements for motor control is unknown.

The sources of conscious proprioceptive information potentially include joint, muscle, and cutaneous mechanoreceptors.14-23 Existing evidence supports the receptors in each tissue as the primary source, so this topic remains very controversial.3 In addition, visual and auditory signals can provide additional cues to JPS, TTDPM, and TTDMD. For example, seeing the position or movement of the limb (vision) or hearing the instrumentation begin to move the joint (auditory) prevents conclusions from being accurately drawn regarding conscious proprioceptive acuity. In addition, if an assessment is attempting to focus on the integrity of capsular mechanoreceptors, appropriate precautions are needed to reduce supplemental proprioceptive information arising from cutaneous mechanoreceptors. In other words, the effects of a deafferented joint on proprioceptive acuity might go undetected without specific attention to reducing or eliminating supplemental sources of information. A good example would be stimulation of cutaneous mechanoreceptors caused by stabilization straps.

Unfortunately, discrimination between muscle and joint afferents cannot be accomplished without more sophisticated experimental manipulation. Methods used to reduce inputs from cutaneous, muscle, and joint mechanoreceptors include anesthesia and ischemia.24,25 Vibration is a technique that has been specifically used to induce stimulation of the muscle spindle afferents, thereby changing muscle tone and, ultimately, the information provided by the muscle spindles.26,27 With respect to conscious proprioception perception, vibration could be incorporated into assessments to potentially determine muscle spindle contributions.

A wide variety of equipment and instrumentation, including commercial isokinetic dynamometers, electromagnetic tracking devices, and custom-made jigs, has been developed to measure conscious appreciation of proprioception. In our laboratory, we use a motor-driven proprioception testing device that can passively move the limb for both kinesthetic and passive JPS assessment (Figure 1). Subjects are fitted with a blindfold, headphones, and pneumatic cuff to eliminate con-
Figure 1. The proprioception testing device is a motor-driven jig used to test both position sense and kinesthesia. Subjects are fitted with a blindfold, headset containing white noise, and pneumatic sleeve to negate visual, audio, and tactile cues.

Figure 2. The electromagnetic motion tracking device is used to assess position sense and replicate movement patterns and for 3-dimensional kinematic analysis of movement.

foundering cues to motion detection and JPS, including vision, audible sensing of the motor-driven apparatus, and vibration induced by motor on the limb. A unique feature of the device is its ability to conduct assessments at very slow speeds (<0.5°/s), unlike most isokinetic devices with minimum speeds of 2°/s.

In addition to the proprioception testing device, we have also used an electromagnetic tracking system to measure the ability to actively reproduce given joint positions or paths of motion (Figure 2). The big advantage of such a device is that subjects have free, unrestricted movement, unlike in the proprioception testing device, where they are limited to 1 degree of freedom (eg, knee flexion-extension or humeral rotation). This is especially important at the shoulder joint, where natural movement patterns involve multiplanar movements.

Numerous studies using the previously mentioned approaches have been conducted to compare conscious proprioceptive acuity (JPS and kinesthesia) between normal and pathologic groups at the ankle, knee, and shoulder joints. Although some of these investigators have found deficits, others have not. Possible explanations for the different results include the failure to control any of the previously mentioned confounding factors, inherent instrumentation differences (eg, position of the patient with respect to gravity), varying methodologic approaches (eg, angular positions, speed of passive movements), and different subject characteristics (eg, pathologic group compared with control group versus bilateral comparison).

In addition to comparisons between pathologic and healthy joints, research considering conscious appreciation of proprioception has been conducted in several related areas. The ability of surgical intervention to restore conscious proprioceptive acuity along with mechanical stability has been examined. Additionally, the suggestion that a decrease in proprioception may predispose one to joint injury prompted investigators to prospectively consider proprioceptive acuity before an athletic season and after varying intensities and modes of exercise. Lastly, investigators have examined the relationships between conscious proprioceptive acuity and functional activity tests, functional rating scores, and hamstrings: quadriceps peak torque ratios to determine the degree to which conscious proprioceptive acuity relates to more functional measures. Future research directions include validating conscious proprioceptive acuity through simultaneous measurement of afferent pathway action potentials (ie, microneurography) and correlating decreases in conscious proprioception with deficits in sensorimotor control over dynamic joint stability.

Somatosensory Evoked Potentials

Evoked potentials are methods of testing the integrity of afferent pathways to the cerebral cortex. These techniques, which are traditionally and predominantly used in neurology to confirm and localize sensory abnormalities, involve measuring neurophysiologic and electroencephalographic responses to stimulation of sensory sources (somatosensory, visual, and vestibular). The cortical evoked responses are complex waveforms that represent the sensory impulse traveling to the sensory cortex. Specific to the somatosensory afferent pathways, the technique is referred to as somatosensory evoked potentials (SEPs). The SEPs can be elicited either through transcutaneous electrical stimulation of peripheral nerves and sensory organs or more physiologic stimuli such as joint movement. Once a stimulus is given peripherally, measurements can be made along the afferent pathways. For example, after an electric stimulus is delivered to the wrist (median nerve), the nerve action potentials can be detected as they propagate centrally at the level of the brachial plexus (Erb point), midcervical spinal cord (fifth cervical vertebrae), upper midbrain-thalamus, and somatosensory cortex.

The techniques are performed by introducing an electric potential with known characteristics (eg, peak characteristics, amplitude, and wavelength) to the afferent pathway. How these characteristics change along the pathway is then assessed. Common variables assessed include the amplitude changes, wavelength changes, and latencies between introduction of the potential and measurement of the potential along the pathway. The luxury of this technique is that it allows for the establishment of objective evidence of abnormality or deficiency by identifying if and where lesions occur along the
afferent pathway. Unfortunately, neurophysiologists have a difficult time correlating sensory deficits with results from SEP testing because it is difficult to evaluate the submodality of the sensory system by simple stimulation of peripheral afferent nerves.

Several recent investigations using SEPs have made some important contributions to our understanding of the sensory-motor system. By selectively inducing ischemia at the base of the finger and shoulder, Mima et al confirmed the importance of muscle afferents for the dynamic aspect of proprioception. Pitman et al demonstrated a direct link between the anterior cruciate ligament (ACL) and the sensory cortex, with the greatest potentials being recorded on stimulation of the ligament’s midsubstance. Additionally, significant correlations between kinesthetic deficits (ie, deficits in detecting joint motion) and SEP abnormalities from the afferent pathways from the ACL have been demonstrated in ACL-deficient individuals. The patterns of alterations in SEPs led the authors to speculate that the central nervous system had undergone modification and reorganization processes after the peripheral inputs were lost. Lastly, Barrack et al recently used SEPs to suggest the occurrence of reinnervation in central-third patellar tendon grafts. At the shoulder, Tibone et al demonstrated that no differences exist in evoked potentials between people who are unstable at the shoulder and a healthy population. As such, the decreased proprioception that was demonstrated at the shoulder probably results from the increased tissue laxity decreasing mechanoreceptor stimulation rather than tissue deafferentation. Further research is needed using SEPs to advance our understanding of peripheral afferent receptors projecting on the cortex and the alterations and modifications demonstrated by higher central nervous system areas in their absence.

EFFERENT TRANSMISSION MEASUREMENTS

Nerve Conduction Testing

Nerve conduction testing (NCT) is an objective method of assessing the functional status of the peripheral alpha motor neuron system. The basis for NCT resides with the proximal and distal reaction propagation that occurs along an entire nerve after electric stimulation. Motor neurons that are readily measured include the median, ulnar, common peroneal, and posterior tibial.

In addition, NCT is performed using both an electric current generator and EMG recording. An electric current with known characteristics (eg, amplitude and wavelength) is applied to the efferent, the neural pathway, usually on the innervating nerve. Then EMG recordings are taken distal to the applied current, usually on the desired muscle. For example, ulnar nerve motor nerve conduction testing is performed by stimulating the ulnar nerve at the wrist while recording changes in the induced current at the fifth finger and hypothenar eminence. Two limitations exist with NCT. First, the technique is often performed with needle-type electrodes. This can be very uncomfortable for the patient. Second, the timing of the test is critical. It may take as long as 3 weeks after injury for deficits to manifest in an NCT, even in the presence of positive clinical findings. This can be extremely problematic in the sports medicine setting, where there is often pressure for quick return-to-play decisions. As with many conditions, a lack of objective signs and subjective symptoms does not always mean the patient is injury free.

Also, NCT can assess several variables. Commonly, nerve conduction velocity is the assessment that is erroneously mentioned by physicians when, in fact, they are assessing other variables. The change in amplitude is far more important for diagnosis of neuronal lesions than are the velocity changes. Conduction velocity is measured by calculating the velocity between the stimulation of one point and the recording of the introduced current. The limitation of conduction velocity assessment is that alterations in velocity may only manifest in lesions that cause focal slowing. Unlike conduction velocity, amplitude changes indicate not only myelination changes but also loss of intact axons, no matter what type of lesion exists. Amplitude assessment indicates the number of intact axons that exist along the nerve innervating a muscle (ie, a decrease in intact axons results in a decrease in amplitude between the introduced and recorded current characteristics). Often, these results are compared with the uninvolved, contralateral limb for a measure of control.

With respect to an orthopaedic application, numerous reports have been published demonstrating impaired motor nerve conduction velocity after injury. Kleinrensink et al reported alterations in the superficial and deep peroneal nerves after inversion ankle injury, suggesting a possible contributing factor to functional ankle instability. Di Benedetto and Markey used nerve conduction velocity testing to assess motor deficits in football players with diagnosed brachial plexopathies. Nerve conduction was determined for the muscles supplied by the long thoracic, suprascapular, musculocutaneous, axillary, lateral pectoral, and thoracodorsal nerves. Conduction slowing was present in 16 of the 18 injured football players tested. With NCT, the authors were able to conclude that the abnormalities most likely resulted from compression of the most superficially located fibers of the brachial plexus at the Erb point. The results suggested that the most significant causative factor was ill-fitting shoulder pads against the neck during tackling. Further researchers should consider alterations in NCT as an objective assessment tool and possible factor in functional joint instability.

Muscle Activation Patterns

Electromyography is a tool that provides for the detection of electric activity accompanying skeletal muscle activation. The information gathered through EMG can be used to determine the initiation, cessation, and magnitude of muscle activity. Generally, 3 fundamental types of variables arise from EMG: onset, amplitude, and frequency. Although initially EMG may appear to be a straightforward process, closer inspection quickly reveals a complicated and tedious assessment technique. Confounding factors that arise from physiologic, anatomic, and technical elements surround both signal acquisition and processing. These elements can directly influence the apparent results attained. Effective EMG use and interpretation requires one to understand as much as possible the sources of each of these elements and their influences on EMG signals. Several comprehensive discussions and monographs detailing the current understandings and developments have been written. Further, because the acquisition and processing methods used will influence EMG signals, clinicians and researchers should make extensive efforts to meet the recommended publication standards advocated by the Journal of Electromyography and Kinesiology.

Electromyography measures the myoelectric event associated
with muscle contraction. On receiving an action potential from the motor neuron, a muscle action potential propagates bidirectionally along the muscle fibers. Electromyography uses electrodes to detect and record the depolarization wave front and subsequent repolarization that occurs as part of the muscle action potential.

The 2 electrode types commonly used in neuromuscular and biomechanical research are surface and fine wire. Generally, surface electrodes are used for superficial muscles and tend to record a greater muscle area than fine-wire electrodes; however, because of their large collection area, the risk of collecting muscle activity from unwanted muscles (eg, cross-talk) is high. To decrease this risk, standardized electrode positions are helpful in isolating the desired muscles. Unfortunately, only one relatively recent article has addressed electrode placement. However, Bas mushrooms and Blumenstein provided a general description of surface-electrode placement for clinical biofeedback assessment. Generally, a site halfway between the innervation zone and the distal myotendinous junction is recommended. In conjunction with a bipolar configuration, electrodes should be placed parallel to the direction of the muscle fibers, with a 1-cm interelectrode distance. The parallel orientation is critical to ensuring phasic delays between the 2 electrodes. Silver-silver chloride electrodes are considered the optimal materials for surface electrode construction because of their electrochemical stability. An additional consideration associated with surface EMG is adequate skin preparation. Komi and Buskirk established the reliability of surface-electrode EMG as an intraclass correlation coefficient of 0.88 to 0.91 within sessions and 0.64 to 0.73 between testing sessions for amplitude characteristics of the signal.

To assess muscles that cannot be recorded with surface electrodes because of their location, fine-wire electrodes are advocated. Fine-wire electrodes consist of some type of conducting wire that is inserted intramuscularly through a cannula (Figure 3A). For example, because of the deep anatomical orientation of the rotator cuff muscles, fine-wire EMG is necessary to measure their muscle firing characteristics (Figure 3B). The fine-wire electrodes can be constructed with either a single-wire or dual-wire design. The dual fine-wire configuration described by Bas mushrooms and Deluc is the gold standard in biomechanical-neuromuscular research. The reliability of fine-wire electrode use is somewhat less than that for surface-electrode EMG. Komi and Buskirk reported that reliability coefficients for amplitude characteristics of the signal within sessions were approximately 0.62, whereas the between-day coefficients were approximately 0.55. Compromised reliability may result from fine-wire electrode movement or fracture within the muscle. Jonsson and Bagge reported that fine-wire electrodes may migrate as much as 14.6 mm and fracture with movement. Both Bas mushrooms and Deluc and Jonsson and Bagge recommended performing several contractions of the desired muscle before data collection to fix the electrode within the muscle tissue. In terms of fracture prevention, Jonsson and Bagge suggested that 0.05-mm fine wire is less likely to fracture than 0.025-mm wire. Fortunately, the risk of pain and infection associated with wire fractures is minimal, and they can often be left untreated. Like surface EMG, fine-wire EMG requires correct placement to avoid cross-talk. Fortunately, a plethora of literature describes fine-wire electrode placement. reported that EMG data collected with both fine-wire and surface electrodes were statistically similar. Other important EMG hardware considerations include the use of on-site preamplifiers (active electrodes) to reduce artifact and noise, high-quality differential amplifiers with high common-mode rejection ratios, appropriate antialiasing filters, and adequate sampling frequency during analog-to-digital conversion. Based on the frequency spectrum of EMG presented by Winter, surface EMG data need to be sampled at 1000 Hz, whereas fine-wire data should be sampled at higher rates (>2000 Hz).

In addition to varied hardware components and characteristics, a wide variety of data processing approaches have been used in the literature, each aimed at extracting pertinent information. Because the resulting muscle forces and joint torques are of much lower frequencies than raw EMG signals, the most common processing approach involves amplitude demodulation (linear envelope detection). In this process, the raw biphasic EMG signal is first full-wave rectified and then subsequently undergoes some form of smoothing function (Figure 4). Frequently used to smooth the signal are low-pass filters such as Butterworth, Chebyshev, or Paynter. The lower the cutoff frequency of the filter, the smoother the signal. The tradeoff to smoother signals is increased phase distortions. Thus, many researchers use zero-phase lag filters during the creation of the linear envelope. Once the linear envelope is
created, the signals can be time and amplitude normalized (Figure 4) and variables of interest can be calculated.

Because EMG is specific to the sensorimotor system, it provides a means to examine several aspects of the dynamic restraint mechanism. First, EMG has been used to measure the reflexive responses to ankle (Figure 5A) and knee joint perturbations. Three characteristics of reflexive responses are often considered: onset latency, sequence of activation, and peak activation (Figure 5B). Onset latency refers to the time between stimulus and the initiation of muscle electrical activity as detected through EMG. Sequence of activation refers to the order in which each muscle is activated. Peak activation refers to the maximum amplitude the EMG signal reaches during the reflexive response. For example, in Figure 5, the sequence of activation is peroneus brevis, peroneus longus, and anterior tibialis. Although reflexes in response to joint perturbation have been traditionally considered to arise from direct connections between ligamentous and capsular mechanoreceptors and alpha motor neurons, more recent research supports the premise of muscle spindles as the initiating sensory organs. As our previous articles detailed, ligamentous and capsular mechanoreceptors are essential for modulating muscle-spindle sensitivity via the gamma efferent system. In other words, stimulation of gamma motor neurons heightens muscle-spindle sensitivity, which in turn increases the level of muscle activation existing in the muscle at a given instant. Whether surface EMG is sensitive enough to detect differences in levels of muscle activation both before and after a perturbation stimulus as a result of gamma-system modulation over muscle-spindle response sensitivity remains unknown. An additional influential consideration in reflex testing that is not under experimental control in vivo is the descending brain stem and cortical commands modulating alpha and gamma motor neuron pool excitability. For example, anticipation and expectations based on prior experience, both of which arise at the cortical level, have been demonstrated to alter postural reflex latencies and sequences of activation.

During more functional tasks involving both the lower and upper extremities, such as walking (Figure 6A), landing, and throwing, EMG enables quantification of muscle activation sequences, amplitude, and duration. Often a task is subdivided into phases according to joint loading to determine preparatory and reactive muscle activity (Figure 6B).
activity is often operationally defined as the activity occurring before foot contact, whereas reactive activity encompasses the area of muscle activity occurring after foot contact. Several investigators have considered differences in muscle activation sequences and amplitudes and sex differences between normal subjects and groups with various conditions. In addition to comparing normal and pathologic groups, several investigators have considered the effects of braces and orthoses on EMG activity during functional tasks.

Muscle activation patterns have also been examined during voluntary commands of specific motor patterns. With respect to rehabilitation exercise, identifying the specific muscle activation patterns characteristic of a particular exercise helps to provide a scientific rationale for its use. For example, most recently, Henry qualified the degrees of coactivation accompanying 6 selected shoulder rehabilitation exercises. Similarly, by combining EMG with isokinetic assessments, information can be attained about coactivation patterns accompanying voluntary muscle activation and the ratio between EMG activity and force production.

Muscle Performance Characteristics

Measuring muscle performance characteristics has been an integral component of sensorimotor system assessment for many years. Several different assessment approaches involving different types of muscle contractions are available, with isokinetics being the most popular. Isokinetics involves keeping the angular speed of a moving limb constant throughout the range of motion, independent of magnitude and velocity of muscle contractions. Although isokinetic contractions have been criticized as a nonfunctional mode of muscle contraction, they continue to be used extensively because of the ease of quantifying torque, work, and power in a clinical setting. A thorough review of isokinetic testing, assessment interpretation, and application has been published.

It is important to recognize isokinetic measures as representative of the resultant body segment torque produced by voluntary skeletal muscle activation. Isokinetic torque does not immediately or directly reflect muscle force production but rather the final outcome of a descending neural command on the muscles across a limb segment. In other words, torque is a function of many factors, such as level of muscle activation, muscle dynamics (length and velocity), joint geometry (moment arm length and joint congruency), limb weight (inertia), and movement velocity. As a joint is moved through a range of motion by muscle activation, several of these factors change, giving rise to varying torque production capabilities despite similar activation levels. Additionally, different combinations of compressive and rotary forces result from similar activation levels as a joint moves through the full range of motion. This has been hypothesized to afford muscles the ability to provide dynamic stability at end ranges while remaining a prime mover through the midranges of motion.

Sufficient voluntary activation of muscle (timing and magnitude) does not guarantee that the same muscle will perform as an adequate dynamic stabilizer for a mechanically unstable joint. Several studies have demonstrated the absence of a relationship between isokinetic peak torque and functional abilities in ACL-deficient subjects and healthy individuals. Further research is needed to consider the relationships between voluntary muscle activation and force production capabilities and the function of the dynamic restraint mechanisms during functional activity.

Kinetic and Kinematic Measurements

Function and maintenance of the body's structures requires balancing forces that originate from both the environment and within the body. Sources of environmental forces include gravity, friction, and contact with other objects, whereas internal forces most often originate from muscle activation and restraint provided by ligaments. It is the science of biomechanics that studies the effects of forces acting on or being produced...
by the body during human movement through measurement
techniques such as kinetic and kinematic analyses.61

Kinetics is the study of forces that cause movement and
resulting energetics.61 Although forces can be measured di-
rectly through surgically implanted transducers, they are more
commonly measured indirectly using force platforms. Force
platforms can assess force in 3 orthogonal vectors (2 horizon-
tal, 1 vertical) and the moments around each vector. From
these force data, variables such as peak force, time to peak
force, and impulse can be calculated to describe the forces
associated with acceleration of the body’s center of mass (Fig-
ure 7).

In comparison, kinematics is the study of motion indepen-
dent of the causative forces and includes measurement of lin-
ear and angular displacements, velocities, and accelerations.61
Kinematic measurements are accomplished by tracking the
placement of specific body segments during motion. This
can be accomplished with devices such as high-speed cam-
eras,108,109 electromagnetic tracking systems,110,111 electrogo-
niometers,112,113 and accelerometers.114,115

Using reflective markers that reflect either natural lighting
or infrared light, depending on the system, high-speed video
cameras can capture movement of these markers both digitally
and on a videocassette tape during functional activities such
as hitting a golf ball (Figure 8A). From the tracking of these
markers, segment models can be created for the assessment of
the desired segment (Figure 8B). One limitation of video-

Figure 7. A, Assessment of ground reaction forces during a land-
ing task. B, Typical vertical ground reaction forces during landing.

Figure 8. A, Kinematic analysis of the golf swing using a high-
speed video camera system. B, Three-dimensional representation
of the golf swing for kinematic analysis.
sition of the desired limb can be calculated through derivative calculations. Combining synchronized kinetic and kinematic data with anthropometric data will allow calculations and predictions concerning joint-reaction forces and muscle moments to be made through the process of link-segment modeling.

Kinetic and kinematic measurements have been widely used to identify functional adaptations in patients with mechanically unstable joints. For example, video motion analysis of patients with an ACL rupture revealed increased knee flexion during hopping and walking, suggesting that these individuals exhibit a "quadriceps-avoidance gait." By providing measures for the outcomes of muscle activation during functional tasks and movement sequences, these assessment tools will continue to increase our understanding of successful and unsuccessful motor adaptations secondary to joint instability.

**Postural Control Measures**

Postural control has been one of the most misconstrued concepts within the sensorimotor system. Deficits in postural control after orthopaedic injury have been largely attributed to disruptions in the integrity of the afferent information that arises from ligamentous and capsular mechanoreceptors, despite the importance of articular information for postural control being largely unknown. Although the exact significance of proprioceptive information for postural control remains unknown, the somatosensory system as a whole has been demonstrated to play a major role. Postural control combines sensory input from 3 sources (somatosensory, visual, and vestibular) within the central nervous system to develop postural control strategies executed by the joints throughout the kinetic chain. Thus, postural control can become disrupted after articular injury not only from diminished afferent articular information but also by virtue of central strategy selection changes (eg, central inhibitions) or deficiencies in the motor systems (eg, strength, mechanical stability) or both.

During postural control assessments, because each of the sensory sources (somatosensory, visual, and vestibular) can compensate for reductions in the contributions from the remaining sources, specific techniques must be used for inferences to be drawn concerning the integrity of each source. Using unstable, compliant, or moving support surfaces is believed to alter somatosensory input that arises from foot contact with the support surface. Other methods of diminishing or altering mechanoreceptor inputs include local anesthetic injection, inducing ischemia or hypothermia and vibration. Altering visual inputs is usually done by eliminating visual information (eg, eye closure) or providing inaccurate visual information through sway referencing or conflict domes. Vestibular inputs have been altered through head tilting and galvanic stimulation.

Because postural control is specific to the task, another important consideration in conducting postural control assessments is the type of task used. Generally, the task involved with an assessment can be considered to either remain in equilibrium or to maintain equilibrium while another activity is performed. Assessing the ability to remain in equilibrium is frequently done during periods of quiet stance or after support surface perturbations or bodily delivered perturbations. The size and shape of the base of support are commonly manipulated. Single-leg assessments provide a means for bilateral comparisons, an often important application in orthopaedic settings. In addition, single-leg stance requires the body's center of gravity to be reorganized over a narrow and short base of support, thereby increasing the importance of segmental control in the frontal plane. In contrast to the assessment task of maintaining equilibrium, conscious attention is not normally required or centered on maintaining postural control during activities of daily living. Typically, a conscious motor command is initiated (eg, running) with the specific details of the movement (eg, sequence of muscle activation) programmed by various areas of the central nervous system, whereas the conscious can shift focus to another thought. Thus, it naturally follows that postural control assessments should include circumstances that attempt to duplicate similar scenarios. An example of this type of task is the single-leg hop stabilization test.

In addition to a variety of assessment tasks, many different measurement techniques have been used to quantify postural stability and the types of strategies selected for maintaining equilibrium (Figure 9). Generally, postural control measurement techniques can be considered as either clinical or instrumented. Clinical measures are obtained without sophisticated equipment. Examples include error scoring systems and measurement of the length a person can reach or the time one can maintain equilibrium in a given stance (or both). Instrumented measures are frequently obtained from support surface sensors, with force platforms being the most dominant tool used. Force plates provide the opportunity to monitor center of pressure and variability in horizontal and vertical reaction forces associated with corrective muscular actions. In addition to measuring changes in postural control through the support surface, kinematic methods can be used to determine the types of movements that occur at each limb segment. Lastly, by incorporating EMG measures, levels of coactivation and characteristics of muscle responses to postural perturbations...
Studies of disruptions in postural control after orthopaedic injury as measured through force plates during static stance have yielded controversial results. Although some investigators have found decreases in postural stability after joint injury, others have failed to elicit significant differences. Since force plates depend on center-of-pressure changes and forces exerted against the platform, they may fail to reveal alterations that occur at proximal limb segments. Several researchers have reported alterations in postural control strategies during quiet stance and after perturbation. These results may support the idea that a pathologic joint condition disrupts postural control not only from a sensory perspective but also via the central integration process or deficiencies in the motor system (or both). An additional use of postural control measures in athletic training research is the area of mild head injury. Several reports have documented changes in postural stability in athletes who sustain mild head injury using both clinical and instrumented measures. Further research is needed to consider postural control through force plate, kinematic, and EMG measures during more dynamic and functional activities.

Muscle and Joint Stiffness

Muscle stiffness, defined as the ratio of change in force per change in length, is beginning to receive attention from several perspectives within orthopaedic research. Interestingly enough, the closely related characteristic of joint stiffness has been a subject of interest for many years in the rheumatology field. In contrast to muscle stiffness, which refers specifically to the stiffness properties exhibited by tenomuscular tissues, joint stiffness involves the contributions of all of the structures located within and over the joint (muscles, tendons, skin, subcutaneous tissue, fascia, ligaments, joint capsule, and cartilage). In our previous articles, we reviewed the theoretic importance of stiffness to functional joint stability and the role of joint mechanoreceptors in stiffness regulation.

Several testing models have been used to measure stiffness during various levels of muscle activation. The first method measures the resistance to passive movement of the joint and, therefore, reflects the stiffness characteristics of all structures that span the joint (joint stiffness) (Figure 10A). Data regarding angular position and resistance are related using a polynomial equation, with the slope of the line representing stiffness due to elasticity (Figure 10B). Recently, this model was applied in an orthopaedic investigation determining the effects of sex and joint angle on the contribution of the gastrocnemius muscle to ankle joint stiffness.

Sinkjaer et al have used a complex version of this testing design with a high-speed, servo-controlled motor to produce angular perturbations. The motor-driven device applies a high-velocity, low-amplitude dorsiflexion movement to the ankle. The perturbation device uses potentiometers to measure the resistance of the ankle for the dorsiflexion movement and ankle joint position and EMG to measure reflexive muscle activity. Through their series of studies, Sinkjaer et al have been able to quantify not only the contributions of intrinsic stiffness (stiffness before sensorimotor activation of the stretch reflex) but also the role the stretch reflex plays in providing joint stiffness (extrinsic stiffness). Extrinsic stiffness data may suggest that although joint stiffness is increased when compared with intrinsic stiffness alone, the reflex may not react quickly enough to support the joint, indicating that intrinsic stiffness may be a more vital component of stability. Intrinsic stiffness provides the first line of defense for joint stability when force is applied to the joint. Similarly, Kirsch, Kearney, and Hunter have used similar methods to determine the influence of activation levels and angular position on joint mechanics and stiffness.

Another stiffness testing approach focuses more on the stiffness of the musculotendinous complex crossing a particular joint by using a single-degree-of-mass spring system with a damping component. With this method, 2 different approaches have been used. Oatis assessed stiffness by measuring the damping of joint motion during muscle relaxation. For example, the subject was seated with the lower leg hanging off the table. Each trial consisted of the tester holding the relaxed leg of the subject, then dropping the limb, allowing for free pendulum motion. From knee-flexion data obtained with an electrogoniometer, as well as anthropometric assessment of limb characteristics, knee stiffness was calculated. Unlike Oatis, who calculated stiffness in the absence of muscle...
contraction, McNair et al.149 and Wilson et al.165 measured the damping to induced oscillations under varying degrees of muscle contraction. McNair et al.149 positioned subjects prone with the knee and hip flexed at 30° of flexion. By having subjects contract at 30%, 45%, and 60% of a hamstring maximum voluntary contraction, gentle downward force was applied to the posterior aspect of the limb. McNair et al.149 calculated stiffness by measuring the oscillation characteristics of the limb using an accelerometer. As one would expect, stiffness increased as a function of muscle contraction because of increased cross-bridge activation.149 McNair et al.149 found a moderate correlation between hamstring muscle stiffness and functional ability in ACL-deficient individuals. These results suggest that the hamstrings may resist anterior translation of the tibia in the absence of the ACL.

Lastly, stiffness has been measured during functional tasks such as running,166,167 hopping,168,169 and landing.170 Stiffness during these activities has been calculated by determining either the relationship between the vertical ground reaction force and center-of-mass displacement167 or the natural frequency of the equivalent mass-spring system.170 The advantage to these methods is being able to assess stiffness during functional movements. Future researchers should consider using these methods to advance the findings of McNair et al with respect to ACL-deficient participants and to possibly explain the increased incidence of noncontact ACL injuries in females.

CONCLUSIONS

Collectively, the techniques we have discussed in this article provide a means to evaluate the integrity and function of sensorimotor components by measuring variables along the afferent or efferent (or both) pathways and the final outcome of skeletal muscle activation. In most of the studies, these techniques have been used in isolation to compare normal and abnormal groups. However, conducting comprehensive comparisons of variables located on both the afferent and efferent pathways in patients with different combinations of mechanical and functional stability status may better solidify our understanding of the sensorimotor system. These types of investigations have the potential advantages of identifying the coexistence of sensorimotor deficits after injury and the successful compensatory patterns developed in patients maintaining functional joint stability in the absence of mechanical stability.

Once deficits and effective compensatory patterns are identified, investigators can begin to examine the efficacy of management strategies, both conservative and surgical, in restoring functional joint stability. The measurement techniques discussed in this article also can be applied to prospective and preventive considerations of joint injury. Current major research trends include identifying sex differences and the influence of fatigue as predisposing factors to joint injury. Optimizing the application of sensorimotor research to clinical settings requires the use of common nomenclature and techniques understood by both clinicians and researchers. Our purpose was to initiate a bridge of understanding by providing an overview of the currently available sensorimotor measurement techniques and procedures.

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National Athletic Trainers’ Association Position Statement: Emergency Planning in Athletics

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Objectives: To educate athletic trainers and others about the need for emergency planning, to provide guidelines in the development of emergency plans, and to advocate documentation of emergency planning.

Background: Most injuries sustained during athletics or other physical activity are relatively minor. However, potentially limb-threatening or life-threatening emergencies in athletics and physical activity are unpredictable and occur without warning. Proper management of these injuries is critical and should be carried out by trained health services personnel to minimize risk to the injured participant. The organization or institution and its personnel can be placed at risk by the lack of an emergency plan, which may be the foundation of a legal claim.

Recommendations: The National Athletic Trainers’ Association recommends that each organization or institution that sponsors athletic activities or events develop and implement a written emergency plan. Emergency plans should be developed by organizational or institutional personnel in consultation with the local emergency medical services. Components of the emergency plan include identification of the personnel involved, specification of the equipment needed to respond to the emergency, and establishment of a communication system to summon emergency care. Additional components of the emergency plan are identification of the mode of emergency transport, specification of the venue or activity location, and incorporation of emergency service personnel into the development and implementation process. Emergency plans should be reviewed and rehearsed annually, with written documentation of any modifications. The plan should identify responsibility for documentation of actions taken during the emergency, evaluation of the emergency response, institutional personnel training, and equipment maintenance. Further, training of the involved personnel should include automatic external defibrillation, cardiopulmonary resuscitation, first aid, and prevention of disease transmission.

Key Words: policies and procedures, athletics, planning, catastrophic

Although most injuries that occur in athletics are relatively minor, limb-threatening or life-threatening injuries are unpredictable and can occur without warning. Because of the relatively low incidence rate of catastrophic injuries, athletic program personnel may develop a false sense of security over time in the absence of such injuries. However, these injuries can occur during any physical activity and at any level of participation. Of additional concern is the heightened public awareness associated with the nature and management of such injuries. Medicolegal interests can lead to questions about the qualifications of the personnel involved, the preparedness of the organization for handling these situations, and the actions taken by program personnel.

Proper emergency management of limb- or life-threatening injuries is critical and should be handled by trained medical and allied health personnel. Preparation for response to emergencies includes education and training, maintenance of emergency equipment and supplies, appropriate use of personnel, and the formation and implementation of an emergency plan. The emergency plan should be thought of as a blueprint for handling emergencies. A sound emergency plan is easily understood and establishes accountability for the management of emergencies. Furthermore, failure to have an emergency plan can be considered negligence.

POSITION STATEMENT

Based on an extensive survey of the literature and expert review, the following is the position of the National Athletic Trainers’ Association (NATA):

1. Each institution or organization that sponsors athletic activities must have a written emergency plan. The emergency plan should be comprehensive and practical, yet flexible enough to adapt to any emergency situation.
2. Emergency plans must be written documents and should be distributed to certified athletic trainers, team and at-
tending physicians, athletic training students, institutional and organizational safety personnel, institutional and organizational administrators, and coaches. The emergency plan should be developed in consultation with local emergency medical services personnel.

3. An emergency plan for athletics identifies the personnel involved in carrying out the emergency plan and outlines the qualifications of those executing the plan. Sports medicine professionals, officials, and coaches should be trained in automatic external defibrillation, cardiopulmonary resuscitation, first aid, and prevention of disease transmission.

4. The emergency plan should specify the equipment needed to carry out the tasks required in the event of an emergency. In addition, the emergency plan should outline the location of the emergency equipment. Further, the equipment available should be appropriate to the level of training of the personnel involved.

5. Establishment of a clear mechanism for communication to appropriate emergency care service providers and identification of the mode of transportation for the injured participant are critical elements of an emergency plan.

6. The emergency plan should be specific to the activity venue. That is, each activity site should have a defined emergency plan that is derived from the overall institutional or organizational policies on emergency planning.

7. Emergency plans should incorporate the emergency care facilities to which the injured individual will be taken. Emergency receiving facilities should be notified in advance of scheduled events and contests. Personnel from the emergency receiving facilities should be included in the development of the emergency plan for the institution or organization.

8. The emergency plan specifies the necessary documentation supporting the implementation and evaluation of the emergency plan. This documentation should identify responsibility for documenting actions taken during the emergency, evaluation of the emergency response, and institutional personnel training.

9. The emergency plan should be reviewed and rehearsed annually, although more frequent review and rehearsals may be necessary. The results of these reviews and rehearsals should be documented and should indicate whether the emergency plan was modified, with further documentation reflecting how the plan was changed.

10. All personnel involved with the organization and sponsorship of athletic activities share a professional responsibility to provide for the emergency care of an injured person, including the development and implementation of an emergency plan.

11. All personnel involved with the organization and sponsorship of athletic activities share a legal duty to develop, implement, and evaluate an emergency plan for all sponsored athletic activities.

12. The emergency plan should be reviewed by the administration and legal counsel of the sponsoring organization or institution.

BACKGROUND FOR THIS POSITION STAND

Need for Emergency Plans

Emergencies, accidents, and natural disasters are rarely predictable; however, when they do occur, rapid, controlled response will likely make the difference between an effective and an ineffective emergency response. Response can be hindered by the chaotic actions and increased emotions of those who make attempts to help persons who are injured or in danger. One method of control for these unpredictable events is an emergency plan that, if well designed and rehearsed, can provide responders with an organized approach to their reaction. The development of the emergency plan takes care and time to ensure that all necessary contingencies have been included. Lessons learned from major emergencies are also important to consider when developing or revising an emergency plan.

Emergency plans are applicable to agencies of the government, such as law enforcement, fire and rescue, and federal emergency management teams. Furthermore, the use of emergency plans is directly applicable to sport and fitness activities due to the inherent possibility of “an untoward event” that requires access to emergency medical services. Of course, when developing an emergency plan for athletics, there is one notable difference from those used by local, state, and federal emergency management personnel. With few exceptions, typically only one athlete, fan, or sideline participant is at risk at one time due to bleeding, internal injury, cardiac arrest, shock, or traumatic head or spine injury. However, emergency planning in athletics should account for an untoward event involving a game official, fan, or sideline participant as well as the participating athlete. Although triage in athletic emergency situations may be rare, this does not minimize the risks involved and the need for carefully prepared emergency care plans. The need for emergency plans in athletics can be divided into 2 major categories: professional and legal.

Professional Need. The first category for consideration in determining the need for emergency plans in athletics is organizational and professional responsibility. Certain governing bodies associated with athletic competition have stated that institutions and organizations must provide for access to emergency medical services if an emergency should occur during any aspect of athletic activity, including in-season and off-season activities. The National Collegiate Athletic Association (NCAA) has recommended that all member institutions develop an emergency plan for their athletic programs. The National Federation of State High School Associations has recommended the same at the secondary school level. The NCAA states, “Each scheduled practice or contest of an institution-sponsored intercollegiate athletics event, as well as out-of-season practices and skills sessions, should include an emergency plan.” The 1999–2000 NCAA Sports Medicine Handbook further outlines the key components of the emergency plan.

Although the 1999–2000 NCAA Sports Medicine Handbook is a useful guide, a recent survey of NCAA member institutions revealed that at least 10% of the institutions do not maintain any form of an emergency plan. In addition, more than one third of the institutions do not maintain emergency plans for the off-season strength and conditioning activities of the sports.

Personnel coverage at NCAA institutions was also found to be an issue. Nearly all schools provided personnel qualified to administer emergency care for high-risk contact sports, but fewer than two thirds of institutions provided adequate personnel to sports such as cross-country and track. In a memorandum dated March 25, 1999, and sent to key personnel at
by several national organizations concerned with the delivery of health care services to fitness and sport participants, including the NATA Education Council, NATA Board of Certification, Inc, American College of Sports Medicine, International Health Racquet and Sports Club Association, American College of Cardiology, and Young Men's Christian Association. The NATA-approved athletic training educational competencies for athletic trainers include several references to emergency action plans. The knowledge of the key components of an emergency plan, the ability to recognize and appraise emergency plans, and the ability to develop emergency plans are all considered required tasks of the athletic trainer. These responsibilities justify the need for the athletic trainer to be involved in the development and application of emergency plans as a partial fulfillment of his or her professional obligations.

In addition to the equipment and personnel involved in emergency response, the emergency plan must include consideration for the sport activity and rules of competition, the weather conditions, and the level of competition. The variation in these factors makes venue-specific planning necessary because of the numerous contingencies that may occur. For example, many youth sport activities include both new participants of various sizes who may not know the rules of the activity and those who have participated for years. Also, outdoor sport activities include the possibility of lightning strikes, excessive heat and humidity, and excessive cold, among other environmental concerns that may not be factors during indoor activities. Organizations in areas of the country in which snow may accumulate must consider provisions for ensuring that accessibility by emergency vehicles is not hampered. In addition, the availability of safety equipment that is necessary for participation may be an issue for those in underserved areas. The burden of considering all the possible contingencies in light of the various situations must rest on the professionals, who are best trained to recognize the need for emergency plans and who can develop and implement the venue-specific plans.

Legal Need. Also of significance is the legal basis for the development and application of an emergency plan. It is well known that organizational medical personnel, including certified athletic trainers, have a legal duty as reasonable and prudent professionals to ensure high-quality care of the participants. Of further legal precedence is the accepted standard of care by which allied health professionals are measured. This standard of care provides necessary accountability for the actions of both the practitioners and the governing body that oversees those practitioners. The emergency plan has been categorized as a written document that defines the standard of care required during an emergency situation. Herbert emphasized that well-formulated, adequately written, and periodically rehearsed emergency response protocols are absolutely required by sports medicine programs. Herbert further stated that the absence of an emergency plan frequently is the basis for claim and suit based on negligence.

One key indicator for the need for an emergency action plan is the concept of foreseeability. The organization administrators and the members of the sports medicine team must question whether a particular emergency situation has a reasonable possibility of occurring during the sport activity in question. For example, if it is reasonably possible that a catastrophic event such as a head injury, spine injury, or other severe trauma may occur during practice, conditioning, or competition in a sport, a previously prepared emergency plan must be in place. The medical and allied health care personnel must constantly be on guard for potential injuries, and although the occurrence of limb-threatening or life-threatening emergencies is not common, the potential exists. Therefore, prepared emergency responders must have planned in advance for the action to be taken in the event of such an emergency.

Several legal claims and suits have indicated or alluded to the need for emergency plans. In Gathers v Loyola Marymount University, the state court settlement included a statement that care was delayed for the injured athlete, and the plaintiffs further alleged that the defendants acted negligently and carelessly in not providing appropriate emergency response. These observations strongly support the need to have clear emergency plans in place, rehearsed, and carried out. In several additional cases, courts have stated that proper care was delayed, and it can be reasoned that these delays could have been avoided with the application of a well-prepared emergency plan.

Perhaps the most significant case bearing on the need for emergency planning is Kleinknecht v Gettysburg College, which came before the appellate court in 1993. In a portion of the decision, the court stated that the college owed a duty to the athletes who are recruited to be athletes at the institution. Further, as a part of that duty, the college must provide “prompt and adequate emergency services while engaged in the school-sponsored intercollegiate athletic activity for which the athlete had been recruited.” The same court further ruled that reasonable measures must be ensured and in place to provide prompt treatment of emergency situations. One can conclude from these rulings that planning is critical to ensure prompt and proper emergency medical care, further validating the need for an emergency plan.

Based on the review of the legal and professional literature, there is no doubt regarding the need for organizations at all levels that sponsor athletic activities to maintain an up-to-date, thorough, and regularly rehearsed emergency plan. Furthermore, members of the sports medicine team have both legal and professional obligations to perform this duty to protect the interests of both the participating athletes and the organization or institution. At best, failure to do so will inevitably result in inefficient athlete care, whereas at worst, gross negligence and potential life-threatening ramifications for the injured athlete or organizational personnel are likely.

Components of Emergency Plans

Organizations that sponsor athletic activities have a duty to develop an emergency plan that can be implemented immediately and to provide appropriate standards of health care to all sports participants. Athletic injuries may occur at any time and during any activity. The sports medicine team must be prepared through the formulation of an emergency plan, proper coverage of events, maintenance of appropriate emergency equipment and supplies, use of appropriate emergency medical personnel, and continuing education in the area of emergency medicine. Some potential emergencies may be averted through careful preparticipation physical...
Sample Venue-Specific Emergency Protocol

University Sports Medicine Football Emergency Protocol

1. Call 911 or other emergency number consistent with organizational policies
2. Instruct emergency medical services (EMS) personnel to “report to _______ and meet _______ at _______ as we have an injured student-athlete in need of emergency medical treatment.”

University Football Practice Complex: _______ Street entrance (gate across street from _______ ) cross street: _______ Street

University Stadium: Gate _______ entrance off _______ Road

3. Provide necessary information to EMS personnel:
   - name, address, telephone number of caller
   - number of victims; condition of victims
   - first-aid treatment initiated
   - specific directions as needed to locate scene
   - other information as requested by dispatcher

4. Provide appropriate emergency care until arrival of EMS personnel: on arrival of EMS personnel, provide pertinent information (method of injury, vital signs, treatment rendered, medical history) and assist with emergency care as needed

Note:
- sports medicine staff member should accompany student-athlete to hospital
- notify other sports medicine staff immediately
- parents should be contacted by sports medicine staff
- inform coach(es) and administration
- obtain medical history and insurance information
- appropriate injury reports should be completed

Emergency Telephone Numbers

- Hospital _______ - _______
- Emergency Department _______ - _______
- University Health Center _______ - _______
- Campus Police _______ - _______

Emergency Signals

- Physician: arm extended overhead with clenched first
- Paramedics: point to location in end zone by home locker room and wave onto field
- Spine board: arms held horizontally
- Stretcher: supinated hands in front of body or waist level
- Splints: hand to lower leg or thigh

screenings, adequate medical coverage, safe practice and training techniques, and other safety measures. However, accidents and injuries are inherent with sports participation, and proper preparation on the part of the sports medicine team will enable each emergency situation to be managed appropriately.

The goal of the sports medicine team is the delivery of the highest possible quality health care to the athlete. Management of the emergency situation that occurs during athletic activities may involve certified athletic trainers and students, emergency medical personnel, physicians, and coaches working together. Just as with an athletic team, the sports medicine team must work together as an efficient unit to accomplish its goals. In an emergency situation, the team concept becomes even more critical, because time is crucial and seconds may mean the difference among life, death, and permanent disability. The sharing of information, training, and skills among the various emergency medical care providers helps reach the goal.

Implementation. Once the importance of the emergency plan is realized and the plan has been developed, the plan must be implemented. Implementation of the emergency plan requires 3 basic steps.

First, the plan must be committed to writing (Table) to provide a clear response mechanism and to allow for continuity among emergency team members. This can be accomplished by using a flow sheet or an organizational chart. It is also important to have a separate plan or to modify the plan for different athletic venues and for practices and games. Emergency team members, such as the team physician, who are present at games may not necessarily be present at practices. Moreover, the location and type of equipment and communication devices may differ among sports, venues, and activity levels.

The second step is education. It is important to educate all the members of the emergency team regarding the emergency plan. All personnel should be familiar with the emergency medical services system that will provide coverage to their venues and include their input in the emergency plan. Each team member, as well as institution or organization administrators, should have a written copy of the emergency plan that provides documentation of his or her roles and responsibilities in emergency situations. A copy of the emergency plan specific to each venue should be posted prominently by the available telephone.

Third, the emergency plan and procedures have to be rehearsed. This provides team members a chance to maintain their emergency skills at a high level of competency. It also provides an opportunity for athletic trainers and emergency medical personnel to communicate regarding specific policies and procedures in their particular region of practice. This rehearsal can be accomplished through an annual in-service meeting, preferably before the highest-risk sports season (e.g., football, ice hockey, lacrosse). Reviews should be undertaken as needed throughout the sports season, because emergency medical procedures and personnel may change.
Personnel. In an athletic environment, the first person who responds to an emergency situation may vary widely; it may be a coach or a game official, a certified athletic trainer, an emergency medical technician, or a physician. This variation in the first responder makes it imperative that an emergency plan be in place and rehearsed. With a plan in place and rehearsed, these differently trained individuals will be able to work together as an effective team when responding to emergency situations.

The plan should also outline who is responsible for summoning help and clearing the uninjured from the area.

In addition, all personnel associated with practices, competitions, skills instruction, and strength and conditioning activities should have training in automatic external defibrillation and current certification in cardiopulmonary resuscitation, first aid, and the prevention of disease transmission.

Equipment. All necessary supplemental equipment should be at the site and quickly accessible. Equipment should be in good operating condition, and personnel must be trained in advance to use it properly. Improvements in technology and emergency training require personnel to become familiar with the use of automatic external defibrillators, oxygen, and advanced airways.

It is imperative that health professionals and organizational administrators recognize that recent guidelines published by the American Heart Association call for the availability and use of automatic external defibrillators and that defibrillation is considered a component of basic life support. In addition, these guidelines emphasize use of the bag-valve mask in emergency resuscitation and the use of emergency oxygen and advanced airways in emergency care. Personnel should consider receiving appropriate training for these devices and should limit use to devices for which they have been trained.

To ensure that emergency equipment is in working order, all equipment should be checked on a regular basis. Also, the use of equipment should be regularly rehearsed by emergency personnel, and the emergency equipment that is available should be appropriate for the level of training of the emergency medical providers and the venue.

Communication. Access to a working telephone or other telecommunications device, whether fixed or mobile, should be ensured. The communications system should be checked before each practice or competition to ensure proper working order. A back-up communication plan should be in effect in case the primary communication system fails. A listing of appropriate emergency numbers should be either posted by the communication system or readily available, as well as the street address of the venue and specific directions (cross streets, landmarks, and so on) (Table).

Transportation. The emergency plan should encompass transportation of the sick and injured. Emphasis should be placed on having an ambulance on site at high-risk events. Emergency medical services response time should also be factored in when determining on-site ambulance coverage. Consideration should be given to the level of transportation service that is available (eg, basic life support, advanced life support) and the equipment and training level of the personnel who staff the ambulance.

In the event that an ambulance is on site, a location should be designated with rapid access to the site and a cleared route for entering and exiting the venue. In the emergency evaluation, the primary survey assists the emergency care provider in identifying emergencies that require critical intervention and in determining transport decisions. In an emergency situation, the athlete should be transported by ambulance to the most appropriate receiving facility, where the necessary staff and equipment can deliver appropriate care.

In addition, a plan must be available to ensure that the activity areas are supervised if the emergency care provider leaves the site to transport the athlete.

Venue Location. The emergency plan should be venue specific, based on the site of the practice or competition and the activity involved (Table). The plan for each venue should encompass accessibility to emergency personnel, communication system, equipment, and transportation.

At home sites, the host medical providers should orient the visiting medical personnel regarding the site, emergency personnel, equipment available, and procedures associated with the emergency plan.

At away or neutral sites, the coach or athletic trainer should identify, before the event, the availability of communication with emergency medical services and should verify service and reception, particularly in rural areas. In addition, the name and location of the nearest emergency care facility and the availability of an ambulance at the event site should be ascertained.

Emergency Care Facilities. The emergency plan should incorporate access to an emergency medical facility. In selection of the appropriate facility, consideration should be given to the location with respect to the athletic venue. Consideration should also include the level of service available at the emergency facility.

The designated emergency facility and emergency medical services should be notified in advance of athletic events. Furthermore, it is recommended that the emergency plan be reviewed with both medical facility administrators and in-service medical staff regarding pertinent issues involved in athlete care, such as proper removal of athletic equipment in the facility when appropriate.

Documentation. A written emergency plan should be reviewed and approved by sports medicine team members and institutions involved. If multiple facilities or sites are to be used, each will require a separate plan. Additional documentation should encompass the following:

1. Delineation of the person and/or group responsible for documenting the events of the emergency situation
2. Follow-up documentation on evaluation of response to emergency situation
3. Documentation of regular rehearsal of the emergency plan
4. Documentation of personnel training
5. Documentation of emergency equipment maintenance

It is prudent to invest organizational and institutional ownership in the emergency plan by involving administrators and sport coaches as well as sports medicine personnel in the planning and documentation process. The emergency plan should be reviewed at least annually with all involved personnel. Any revisions or modifications should be reviewed and approved by the personnel involved at all levels of the sponsoring organization or institution and of the responding emergency medical services.

SUMMARY

The purpose of this statement is to present the position of the NATA on emergency planning in athletics. Specifically,
professional and legal requirements mandate that organizations or institutions sponsoring athletic activities have a written emergency plan. A well-thought-out emergency plan consists of a number of factors, including, but not necessarily limited to, personnel, equipment, communication, transportation, and documentation. Finally, all sports medicine professionals, coaches, and organizational administrators share professional and legal duties to develop, implement, and evaluate emergency plans for sponsored athletic activities.

**ACKNOWLEDGMENTS**

This position statement was reviewed for the National Athletic Trainers’ Association by the Pronouncements Committee and by John Cottone, EdD, ATC; Francis X. Feld, MEd, MS, CRNA, ATC, NREMT-P; and Richard Ray, EdD, ATC.

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ERRATUM


On page 404, the group labels in Figure 4 were incorrect. Figure 4 should have appeared as follows:

![Figure 4. Overall stress.](image-url)
REQUEST FOR PROPOSALS
Bone & Joint Decade

The NATA Research and Education Foundation announces that funding is available for Bone and Joint Decade Grant Awards. Priority consideration is given to proposals that include a certified athletic trainer as an integral member of the research team. Multiple awards are available.

BACKGROUND

Musculoskeletal disorders are the most common causes of severe long-term pain and physical disability. It is estimated that nearly 30 million people sustain a musculoskeletal injury in the United States each year with a societal cost of some $254 billion. Bone and joint disease is the primary cause of visits to physicians. The National Athletic Trainers’ Association Research and Education Foundation is working in concert with the United Nations, the World Health Organization, and numerous other health care organizations and national governments to support the 2000-2010 Bone and Joint Decade. The Bone and Joint Decade initiative is a global campaign to improve the quality of life for people who have musculoskeletal disorders, and to advance understanding and treatment of musculoskeletal disorders through prevention, education and research. The goals of the Bone and Joint Decade will be achieved by:

1. Raising awareness of the growing burden of musculoskeletal disorders on society.
2. Empowering patients to participate in their own care.
4. Advancing understanding of musculoskeletal disorders through research to improve prevention and treatment.

The Bone and Joint Decade focuses on four clinic areas: joint diseases, spinal disorders, osteoporosis, and trauma to the extremities. Since physical activity is associated with the cause and treatment of each clinic area, athletic trainers invariably confront problems related to the prevention, evaluation and management of these conditions.

OBJECTIVES

The NATA Research and Education Foundation encourages submission of high-quality research proposals that will clarify the effectiveness of preventative, diagnostic and treatment methods for musculoskeletal injuries and diseases relative to participation in physical activity. Areas of interest may include but are not limited to: efficacy of treatments to reduce long-term consequences of injury, with particular relevance to the development of joint disease; efficacy of prevention strategies of serious musculoskeletal injuries to the extremities and spine; efficacy of methods to identify participant injury risk; efficacy of methods to identify participant risk for and treatment of exercise-induced osteoporosis.

PROCEDURE

Pre-Proposal Submission: The NATA Foundation now requires that investigators interested in submitting a grant application
to the NATA Foundation first submit a “Pre-proposal”. The purpose of the Pre-proposal is to optimize the time invested by both the NATA Foundation Research Committee and the investigators in grant proposals submitted to the NATA Foundation. The Pre-proposal will allow the NATA Foundation Research Committee to evaluate whether or not the proposed research project is of interest to the NATA Foundation. The NATA Foundation Research Committee will evaluate the Pre-proposal both for subject matter (topic and hypotheses) and for research design/methodology. Based upon this evaluation, the committee will then either invite the submission of a full proposal or indicate that the proposed project is not of interest to the NATA Foundation. An invitation to submit a full proposal does not imply a commitment to funding. It does indicate that the topic is of potential interest to the NATA Foundation and that the general research design seems reasonable based on the information given in the Pre-proposal. A full proposal must be submitted within two (2) years after the date of the letter indicating acceptance of the Pre-proposal and providing an invitation to submit a full proposal. Otherwise, to assure timeliness and pertinence of the subject matter, a new Pre-proposal must be submitted. A commitment to funding may occur only after a detailed review of the full proposal by the NATA Foundation Research Committee.

**REQUIREMENTS OF GRANT RECIPIENTS**

Recipients of Bone and Joint Decade grant awards will be requested to present their findings at the 2007 NATA Annual Meeting and Clinical Symposia in Anaheim, California. The findings, however, may be presented at an earlier NATA Annual Meeting, if delay would be detrimental. In this case, the principal investigator could present prior to 2007, and also present a topic related to the funding support at the June 2007 Annual Meeting. Travel costs for either or both meetings would be legitimate budget expenses in the original request for funding.

**MAIL COMPLETED PRE-PROPOSAL TO:**

Michael R. Sitler, EdD, ATC
Chair, NATA Foundation Research Committee
Department of Kinesiology, 114 Pearson Hall
Temple University, Philadelphia, PA 19122

**INSTRUCTIONS FOR SUBMISSION:**

A Pre-proposal may be submitted at any time. The Pre-proposal must be submitted in both hard copy (2 page limit, single-spaced) and 3.5” diskette. The applicant will receive results of the review within 6 weeks after the pre-proposal is received. Submission deadlines for full proposals are March 1 and September 1. The applicant must be explicit and concise in providing the following information:

1. Name, Credentials, Address, Phone, Fax, E-mail, Sponsoring Institution, Title of Proposal

2. Statement of the Problem. This section should contain a brief statement of the problem and should state explicitly how the project relates to athletic training and/or the health care of the physically active.

3. Specific Aims and Hypotheses. This section should present the specific questions to be addressed and the specific hypotheses that will be tested in the project. It is often helpful to present numbered specific aims accompanied by the associated hypotheses.

4. Experimental Design and General Methods. This section should contain a general outline of the research design of the proposed study, and should indicate what methods will be used to collect key data. There is no need to provide detailed descriptions of the methods.
Thank You to Our 2001 Manuscript Reviewers

We extend our condolences to the family of Mary B. Johnson, PhD, ATC, who passed away December 28, 2001. Dr. Johnson served *JAT* for many years as a distinguished Guest Reviewer and member of the Editorial Board.

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Authors' Guide

(Revised January 2001)

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2. All manuscripts must be accompanied by a letter signed by each author and must contain the following statements: This manuscript 1) contains original unpublished material that has been submitted solely to the Journal of Athletic Training, 2) is not under simultaneous review by any other publication, and 3) will not be submitted elsewhere or withdrawn until a decision has been made concerning its suitability for publication by the Journal of Athletic Training. In consideration of the NATA’s taking action in reviewing and editing my submission, I, the undersigned author hereby transfer, assign, or otherwise convey all copyright ownership to the NATA, in the event that such work is published by the NATA.

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of this study showed." use "Our results showed."

19. The body or main part of the manuscript varies according to the type of article (examples follow); however, the body should include a discussion section in which the importance of the material presented is discussed and related to other pertinent literature. When appropriate, a discussion subsection may be added if the clinical relevance of the findings is recommended. Liberal use of headings and subheadings, charts, graphs, and figures is recommended.

a. The body of an Original Research article consists of a methods section, a presentation of the results, and a discussion of the results. The methods section should contain sufficient detail concerning the methods, procedures, and apparatus employed so that others can reproduce the results. The results should be summarized using descriptive and inferential statistics and a few well-planned and carefully constructed illustrations.

b. The body of a Literature Review article should be organized into subsections in which related thoughts of others are presented, summarized, and referenced. Each subsection should have a heading and brief summary, possibly one sentence. Sections must be arranged so that they progressively focus on the problem or question posed in the introduction.

c. The body of a Case Report should include the following components: personal data (age, sex, race, marital status, and occupation when relevant—not name), chief complaint, history of present complaint (including symptoms), results of physical examination (example: "Physical findings relevant to the rehabilitation program were . . . '), medical history (surgery, laboratory results, examination, etc.), diagnosis, treatment and clinical course (rehabilitation until and after return to competition), criteria for return to competition, and deviation from expectations (what makes this case unique).

d. The body of a Clinical Techniques article should include both the how and why of the technique: a step-by-step explanation of how to perform the technique, supplemented by photographs or illustrations, and an explanation of why the technique should be used. The discussion concerning the why of the technique should review similar techniques, point out how the new technique differs, and explain the advantages and disadvantages of the technique in comparison with other techniques.

20. Percentages should be accompanied by the numbers used to calculate them. When reporting nonsignificant results, a power analysis should be provided.

21. Communications articles, including official Position Statements and Policy Statements from the NATA Pronouncements Committee; technical notes on such topics as research design and statistics; and articles on other professional issues of interest to the readership are solicited by the Journal. An author who has a suggestion for such a paper is advised to contact the Editorial Office for instructions.

22. The manuscript should not have a separate summary section—the abstract serves as a summary. It is appropriate, however, to tie the article together with a summary paragraph or list of conclusions at the end of the discussion section.

23. References should be numbered consecutively, using superscripted arabic numerals, in the order in which they are cited in the text. References should be used liberally. It is unethical to present others’ ideas as your own. Also, use references so that readers who desire further information on the topic can benefit from your scholarship.

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32. Media Reviews will appear in the NATA News.
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