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Impact Factor: 2.478

Craig R. Denegar, PhD, ATC, PT, FNATA;
Christopher D. Ingersoll, PhD, ATC, FNATA, FACSM

In June 2010, the Thomson Reuters Journal Citation Reports for scientific journals during the previous 2 years were released. The *Journal of Athletic Training* (*JAT*) scored 2.478! What does a 2.478 mean, and why is it important? The score means that, on average, each article published in *JAT* in 2007 and 2008 was cited in other scientific journals approximately 2.5 times in 2009.

But what does 2.478 really mean? This score reflects the advancement of research in athletic training, the evolution of *JAT* into a highly regarded scientific journal, and, ultimately, the growth of athletic training as a leading health care profession. We were first exposed to *Athletic Training: The Journal of the National Athletic Trainers' Association* early in our careers. Our predecessors worked hard to develop a journal that was informative and relevant to the members of the association. Today, only 9 sports science journals of the 73 in this category worldwide have higher impact factors, and *JAT* looks very different than it did even 20 years ago. In those 20 years, *JAT* has been included in many indexes, including MEDLINE, and has become the official journal of the Taiwan Athletic Trainers' Society and the Japan Athletic Trainers' Organization. These changes reflect the globalization of our profession.

Until 2008, *JAT* was published quarterly. Today, we review and publish more articles than at any time in our history. Despite being more selective than ever before in accepting articles for publication, we fill 6 issues annually, approximately 80 articles per year. However, the impact factor does not rise with the publication of more articles but rather with the publication of higher-quality articles. We can be proud of this growth in both quantity and quality, which is a testament to our scholarly community. More athletic trainers are engaged in the research essential to advancing athletic training than ever before. The quality of their work is reflected in the success of *JAT*. The progress of the journal is also due to the work of the largest editorial team in the history of *JAT,* a team that includes editors, an editorial board, and hundreds of reviewers. To all, we say thank you!

Although it is important to recognize the work of everyone who has contributed to making *JAT* a leading journal, we also need to take a moment and consider what *JAT* contributes to our athletic training community. A profession's journal is its window to the world. Broadcast and print media coverage of reports published in *JAT* educates the public and other health care professionals, recognizes the unique expertise of the athletic trainer, and demonstrates the profession's ongoing commitment to research. Thanks in large part to advances in information technology, patients and providers from all medical disciplines and in all parts of the globe can find the information they seek in *JAT*. Increasingly, authors from around the world seek to publish their research findings in *JAT*. We have no stronger vehicle than *JAT* to promote athletic training and to help others understand the role of the athletic trainer in protecting the health of our patients and encouraging healthy living through exercise.

Not every athletic trainer will publish in *JAT,* but what is published in *JAT* affects every athletic trainer. It may be just a number—2.478—but it's a number that every member of the NATA should be proud of and celebrate.

Note: Craig R. Denegar, PhD, ATC, PT, FNATA, is the JAT *Senior Associate Editor. Christopher D. Ingersoll, PhD, ATC, FNATA, FACSM, is the* JAT *Editor-in-Chief.*

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original research

Increased QT Interval Variability in 3 Recently Concussed Athletes: An Exploratory Observation

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Context: The QT interval variability index (QTVI) is a noninvasive measure of beat-to-beat fluctuations of the QT interval as seen from a single electrocardiographic lead. It represents the relationship between the respective variabilities of the QT and R-R intervals. Recently, the QTVI was demonstrated to be an index of vagal cardiac autonomic modulation in resting conditions.

Objective: To determine whether QTVI varied in athletes at 48 hours, 1 week, and 2 weeks after a concussive head injury.

Design: Case series.

Setting: Testing facility.

Patients or Other Participants: Three athletes with recent concussions and 3 uninjured athletes with similar demographic factors.

Main Outcome Measure(s): Continuous 3-lead electrocardiograms were obtained in a seated, resting position over 2 successive weeks. Separate, unpaired *t* tests were performed to determine whether group-visit differences were present in the QTVI at 48 hours, 1 week, or 2 weeks.

Results: No demographic differences were present between groups. At 48 hours, the QTVI was greater in the concussion group than in the matched controls. At weeks 1 and 2, the QTVI in the concussion group was lower than at 48 hours and not different from that of the control group.

Conclusions: Vagal cardiac autonomic modulation, as quantified by the QTVI, appeared to be negatively affected in concussed athletes within 48 hours of injury, resolved within 1 week, and remained at control group levels 2 weeks later. Serial assessments of QTVI may be of clinical utility in identifying suspected cases of acute concussion and may provide helpful information for determining when an athlete can return to play safely.

Key Words: autonomic nervous system, heart, cardiovascular system, return to play

Key Points

- The QT interval variability index was higher at rest in concussed participants than in the control group.
- This resting change suggests that vagal cardioautonomic modulation was impaired in recently concussed participants.
- The QT interval variability index change resolved within 1 week of injury.

By definition, a sport concussion is a complex pathophysiologic process affecting the brain that is induced by traumatic biomechanical forces.[1] The nature of the brain injury results in a number of short-term and, in some cases, long-term symptoms. The primary assessment and management of concussion has included comprehensive evaluations designed to identify symptoms from the cognitive, vestibular, and somatic realms; these evaluations are often used in the subsequent determination of playing status.[2] To date, the respective assessment techniques have routinely demonstrated efficacy across multiple groups of athletes.

An underexplored area that may have utility in the identification of acute concussion injury is assessment of cardiovascular autonomic function. Linear and nonlinear computations of heart rate variability (HRV), a measure of the autonomically mediated periodicity in a mean heart rate,[3] have demonstrated transient, abnormal autonomic responses to exercise or low-intensity provocations in recently concussed athletes that were not present at rest.[4,5] Although these findings are limited in their scope and have not been tested on a large scale, the basis for concussion to affect cardiac autonomic modulation during provoked conditions is established. A shortcoming to the assessment of cardiac autonomic modulation in concussion is that the measures of HRV, including low-frequency (LF) and high-frequency (HF) components and the LF/HF ratio, which represent cardiac/baroreceptor, parasympathetic, and sympathovagal balance,[3] respectively, have not differentiated the injured from the uninjured at rest.

Recently, the QT interval variability index (QTVI) was found to be a sensitive index of cardiac autonomic modulation; specifically, at rest it was found to represent vagal activity.[6,7] The QTVI is a proportion that quantifies the respective variances of the QT and R-R intervals normalized to their means.[8] Thus, the measure compares the autonomic mediated depolarization of the ventricular myocardium and sinoatrial node, which are predominantly under sympathetic and vagal control in resting conditions.[9] Deranged cardiac autonomic modulation and resting balance in acute concussion may be shown on the QTVI. The purpose of this exploratory study was to determine whether the QTVI varied in recently concussed athletes at rest when compared with control participants within 48 hours of injury presentation and at 1 week and 2 weeks later.

METHODS

Participants

Three athletes with concussion and 3 in-season, demographically matched (ie, sex, age, height, mass) and sport position–matched (ie, assumption of similar fitness) control participants volunteered for this pilot study. Requirements were that the athlete either have a confirmed diagnosis of concussion by the clinical staff and not be taking any medications with known actions on the cardiovascular system, including fast-acting inhalers (concussion group), or be in season with no acute medical illness and be willing to participate (control group). A player suspected of sustaining a head injury was identified by the sports medicine staff (ie, certified athletic trainers and team physician, on the field or in the clinic) and removed from athletic activity for further clinical evaluation and confirmation using accepted practices of concussion assessment. These included review of somatic symptoms and a computerized neurocognitive test battery (Concussion Resolution Index; HeadMinder, Inc, New York, NY) for comparison with the preseason assessment. The study procedures were approved by the university institutional review board, and all volunteers provided written informed consent before the study began.

Procedures

The initial study observation was completed 48 hours after either concussion or clinical presentation of concussion and repeated at 1 week and 2 weeks after the initial visit. At each visit, 3 electrodes were placed in standardized fashion (ie, modified limb leads were placed distal to the midclavicle bilaterally and precordial lead V5) for 5 minutes of continuous heart rate monitoring. Data from lead II were monitored and collected during test conditions and used for offline analysis. After instrumentation and before data collection, participants remained seated in the upright position at quiet rest for approximately 20 minutes to acclimate to the testing facility. To offset contamination by circadian variability, data collection occurred between 3:00 and 6:30 PM for all study visits. Efforts were made to begin subsequent visits within 30 minutes of the time of the initial visit.

Measures

The electrocardiographic signal was captured at 500 Hz with a 12-bit analog-to-digital converter using a customized LabVIEW program (National Instruments Corporation, Austin, TX). The digital signal was filtered with a zero-lag, fourth-order Butterworth low-pass filter with default cutoff frequencies of 6 Hz (high-pass filter) and 100 Hz (low-pass filter). The QT interval was calculated as the elapsed time from the onset of the Q wave to the termination of the T wave (QTe). The QTe interval was corrected for heart rate using the Bazett correction formula. The QTVI was calculated from 60 seconds of artifact-free data using WinCPRS software (Absolute Aliens Oy, Turku, Finland) as follows:

$$\mathrm{QTVI} = \log_{10}[(\mathrm{QTe}_v)/(\mathrm{QTe}_m)^2]/[(\mathrm{R\text{-}R}_v)/(\mathrm{R\text{-}R}_m)^2],$$

where QTe_v is the QT interval variance, QTe_m is the mean QT interval, $\mathrm{R\text{-}R}_v$ is the R-R interval variance, and $\mathrm{R\text{-}R}_m$ is the mean R-R interval.[7]

Statistical Analysis

Data are reported as group mean ± SD. All data were analyzed using Statview (version 5.0; SAS Institute Inc, Cary, NC). The a priori level of significance was set at $P \le .05$. Independent variables group (control, concussion) and visit (48 hours, 1 week, 2 weeks) were combined to create a concatenate variable with 6 categorical levels (control at 48 hours, control at 1 week, control at 2 weeks, concussion at 48 hours, concussion at 1 week, concussion at 2 weeks). Separate, unpaired *t* tests were performed to identify demographic (age, height, mass; with regard to sex, both groups consisted of 2 males and 1 female) and group-visit differences in heart rate, corrected heart rate, and QTVI.

RESULTS

Because of differences in symptom presentation and subsequent clinical action, the 3 concussed athletes were evaluated on days 2, 3, and 5, respectively, after each one's suspected date of injury. No group differences were present between demographic variables, heart rate, or QT interval corrected for heart rate at any visit (Table 1). Based on clinical assessment, 2 of the concussed athletes were removed from athletic participation for 10 and 14 days, respectively. The other athlete was excluded from participation for the remainder of the season due to residual neurocognitive symptoms. The present injury was the first concussion for each of the 3 athletes. Control athletes reported no history of concussion and were free of all injuries during the study. Self-reported general and somatic symptoms for each visit are reported (Table 2). At 48 hours, a higher QTVI was observed in the concussion group than in the control group (–0.4 ± 0.4 versus –1.7 ± 0.4, $P = 0.016$). In the concussion group at 1 week (–1.8 ± 0.3 versus –0.4 ± 0.4, $P < .01$) and 2 weeks (–1.7 ± 0.3 versus –0.4 ± 0.4, $P = .013$), QTVI was less than at 48 hours. The QTVI in the concussion group at 1 week (–1.8 ± 0.3 versus –1.7 ± 0.3, $P = .67$) and 2 weeks (–1.7 ± 0.3 versus –1.6 ± 0.1, $P = .43$) was not different from that of the control group (Figure).

Table 1. Participant Characteristics (Mean ± SD)[a]

Characteristic	Concussion Group	Control Group
Age, y	19 ± 2	19 ± 2
Height, cm	178 ± 10	180 ± 13
Mass, kg	80 ± 17	81 ± 14
Sex	2 males, 1 female	2 males, 1 female
Heart rate, beats/min		
48 h	58 ± 8	62 ± 6
1 wk	61 ± 4	61 ± 7
2 wk	66 ± 6	58 ± 6
QT interval corrected for heart rate, ms		
48 h	377 ± 21	369 ± 34
1 wk	403 ± 32	398 ± 38
2 wk	353 ± 35	396 ± 34

[a] No differences were noted between groups in any of the characteristics ($P > .05$)

Table 2. Self-Reported Symptoms (No. of Reports/No. in Group)

Time	Concussion Group	Control Group
48 h	Photosensitivity (2/3) Headaches (2/3) Nausea (2/3) Dizziness (3/3) Neck/back pain (1/3) Vertigo (1/3)	None
1 wk	Photosensitivity (1/3) Headaches (2/3) Dizziness (1/3) Neck/back pain (1/3) Vertigo (1/3)	None
2 wk	None	None

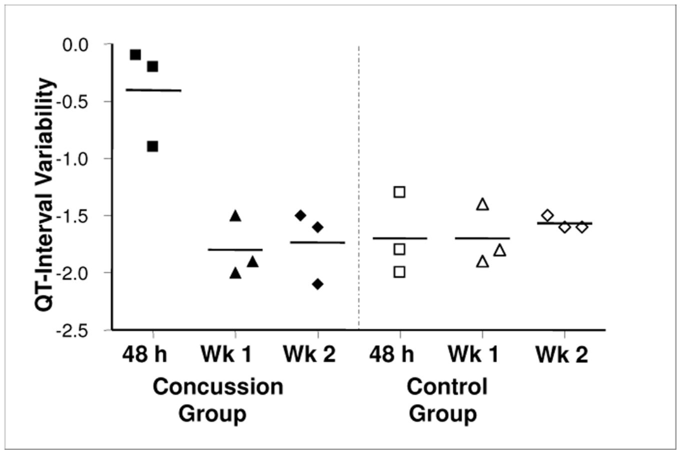

Figure. QT interval variability at rest in 3 athletes with concussion and 3 uninjured control participants at 48 hours, 1 week, and 2 weeks after injury. Shapes at each time point represent individual participants; horizontal lines indicate group means.

DISCUSSION

The findings from this exploratory study demonstrate a higher QTVI within 48 hours of injury presentation in recently concussed athletes than in uninjured, matched control participants. The QTVI returned to the control group level within 1 week and remained at this level for the 2-week postinjury follow-up, suggesting that the impairment had resolved. The magnitude of change in the concussion group at 48 hours was profound: 75% greater than the nearest control group or concussion group week 1 or 2 observation. Individually, the smallest QTVI noted at 48 hours was still 36% greater than any other individual observation. To the best of our knowledge, this is the first demonstration of a resting, noninvasive measure of cardiovascular or autonomic function to differentiate a person with acute concussion from one without an injury. These findings suggest that cardiac autonomic modulation is temporarily negatively affected by a concussion, which in turn affects the balance between autonomic mediated depolarization of the ventricular myocardium and the sinoatrial node.[8]

The QTVI has been used primarily in models of cardiac disease.[10–12] Healthy volunteers have negative QTVIs; increases toward a positive value serve as a predictor of fatal ventricular arrhythmias and sudden cardiac death.[13] At this time, we do not contend that people with acute or subacute concussion are at risk for aberrant cardiac outcomes, although these results suggest a transient period of cardiac electrical instability. Recently, the QTVI was demonstrated to reflect autonomic state (eg, rest, provoked conditions).[6] Those authors determined that the QTVI at rest reflects vagal modulation of heart rate. Conversely, during provocation, the QTVI was directly related to sympathetic modulation. We speculate that our finding of increased QTVI at rest within 48 hours of a concussion is a consequence of vagal dysfunction.

Impaired cardiac autonomic modulation after concussion is probably a functional consequence of short-term changes in cerebral cellular metabolism. According to the Walker et al[14] convulsive theory, a concussive insult to the brain results in hyperexcitability due to widespread neuronal membrane depolarization, which has since been characterized by a significant outflow of neurometabolites and excitatory neurotransmitters.[15,16] Experimental evidence from brain injury models has demonstrated lateralized cortical autonomic outflow,[17,18] such that direct electrical stimulation (producing an efferent output) of the left insular cortex results in cardiac parasympathetic effects (eg, bradycardia and preserved HRV) and regulation of baroreflex sensitivity, whereas stimulation of the right insular cortex results in generalized sympathetic cardiovascular responses (eg, faster heart rate, loss of HRV, peripheral vasoconstriction).[19,20] Similarly, left insular cortex lesions (eg, those associated with stroke) increase basal cardiac sympathetic tone and decrease HRV[21] and are associated with an increased risk of adverse cardiac outcomes,[22] all of which may be explained by ablation of parasympathetic outflow.

Previous reports[4,23] of autonomic control in concussed athletes suggest the presence of exaggerated sympathetic control of heart rate during exercise based on group differences in the LF band or the LF/HF ratio. From an applied autonomics perspective, the LF band of HRV has been related to both sympathetic and parasympathetic control of HR.[24,25] Recently, the LF band of HRV was shown to reflect the baroreflex and not sympathetic cardiac control in the supine position.[26] Empirical evidence and inconsistencies in these outcomes contribute to lingering questions about their accuracy and reliability during exercise.[27–32] We must appreciate the fact that elevated heart rates during exercise are due more to metabolic demand than to sympathetic control, let alone autonomic influence. Thus, evidence of exaggerated sympathetic control of heart rate from HRV variables in concussed athletes, although probable, remains debatable and may be more easily described with low-intensity provocations such as an isometric handgrip test, during which heart rate responses are lower than in an exercise assessment.[5]

From a clinical perspective, the immediate application of our findings is limited, because standard electrocardiographic technology is not equipped to perform the QTVI algorithm. This observation is preliminary and must be replicated on a larger scale before a definitive conclusion about or association between QTVI and concussion can be made. It is possible that the resolution of QTVI occurred at some point between our 48-hour and 1-week observations, but given our design, we were not able to capture the exact time. Investigations with a larger and more diverse sampling are warranted to verify this finding and to facilitate a further understanding of the causes and implications of concussive head trauma on cardiac autonomic modulation. Future efforts to assess cardiac autonomic modulation after concussion should use a resting and low-intensity provocation in a serial manner over the first 10 to 14 days and, if possible, include preseason, preinjury data for comparison. Applying this technique during provoked conditions will require high-resolution digital electrocardiography to minimize signal artifact. This will reduce the need for noise-reduction filters, which can affect the temporal nature of the data. Our concussed athletes did not report any cardiovascular or abnormal symptoms to the research staff during this study; however, the presence of other cognitive and somatic symptoms precluded their involvement in sport-related activities.

CONCLUSIONS

Concussive head trauma appears to induce a short-term period of cardiac electrical instability, with the QTVI increased by 48 hours after injury presentation. With future verification, these findings may have clinical use in identifying suspected cases of acute concussion. Measuring cardiac autonomic modulation has potential use as a complement to the concussive screening battery. Furthermore, serial application of this testing model may be beneficial in the decision-making process for safe return to play.

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Persistent Motor System Abnormalities in Formerly Concussed Athletes

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Context: The known detrimental effects of sport concussions on motor system function include balance problems, slowed motor execution, and abnormal motor cortex excitability.

Objective: To assess whether these concussion-related alterations of motor system function are still evident in collegiate football players who sustained concussions but returned to competition more than 9 months before testing.

Design: Case-control study.

Setting: University laboratory.

Patients or Other Participants: A group of 21 active, university-level football players who had experienced concussions was compared with 15 university football players who had not sustained concussions.

Intervention(s): A force platform was used to assess center-of-pressure (COP) displacement and COP oscillation regularity (approximate entropy) as measures of postural stability in the upright position. A rapid alternating-movement task was also used to assess motor execution speed. Transcranial magnetic stimulation over the motor cortex was used to measure long-interval intracortical inhibition and the cortical silent period, presumably reflecting γ-aminobutyric acid subtype B receptor–mediated intracortical inhibition.

Main Outcome Measure(s): COP displacement and oscillation regularity, motor execution speed, long-interval intracortical inhibition, cortical silent period.

Results: Relative to controls, previously concussed athletes showed persistently lower COP oscillation randomness, normal performance on a rapid alternating-movement task, and more M1 intracortical inhibition that was related to the number of previous concussions.

Conclusions: Sport concussions were associated with pervasive changes in postural control and more M1 intracortical inhibition, providing neurophysiologic and behavioral evidence of lasting, subclinical changes in motor system integrity in concussed athletes.

Key Words: traumatic brain injuries, transcranial magnetic stimulation, clinical neurophysiology, motor control, primary motor cortex

Key Points

- Collegiate football players who had sustained a concussion more than 9 months earlier displayed persistent alterations in postural control and more primary motor cortex intracortical inhibition.
- Neurophysiologic and behavioral evidence is presented for lasting, subclinical changes in motor system integrity in athletes with a history of concussion.

The incidence of sport concussions has substantially increased over the last 15 years, and these injuries are now considered a major public health concern, with an estimated 50000 to 300000 new cases occurring every year in the United States.[1] Although recovery from cognitive impairments after sport concussion has drawn most of the attention from the scientific community in the last few decades, the investigation of motor system abnormalities has recently come to the forefront of the sport concussion literature. Indeed, postural-stability assessment in various stances and on various surfaces was integrated into clinical practice to assist clinicians in determining when concussed athletes who experienced balance problems could safely return to play.[2] Postural stability typically returns to baseline levels within a few days after concussion on conventional measures of center-of-pressure (COP) displacement,[3–5] but approximate entropy (ApEn) calculation as a nonlinear dynamic measure of postural control has greater sensitivity to subtle physiologic alterations associated with sport concussion.[4] More specifically, this measure was introduced to detect changes in COP oscillation randomness when participants attempt to stand as steadily as possible on a force platform. In contrast to conventional measures of COP displacement, which can reflect only overall magnitude of COP displacement over a defined time window, the ApEn calculation considers the sequential order of successive data points during a trial.[6] Therefore, this temporal analysis probably provides a measure of the participant's ability to produce context-adapted, rapid online postural adjustments. Compared with that of non-concussed athletes, COP oscillation randomness was reduced from postconcussion day 1 to day 4, especially when participants stood still on a fixed surface, in both eyes-open and eyes-closed conditions.[5] Authors[5] have advocated nonlinear ApEn measures of postural stability as a valuable measurement alternative to reduce uncertainty in return-to-play decisions,[5] and assessing long-term recovery of COP oscillation abnormalities beyond the acute postconcussion phase could provide further support for clinical utility. This approach may be especially relevant considering that balance control in a dual-task condition involving gait and a simple mental task was still affected in concussed athletes relative to a control group 28 days after injury.[7]

In parallel, transcranial magnetic stimulation (TMS) has shed light on persistent motor cortex excitability alterations after sport concussion. Previously demonstrated in patients tested within 2 weeks of sustaining mild to moderate head injuries,[8] increased intracortical inhibition of the primary motor cortex (M1), as reflected by the duration of the TMS-induced cortical silent period (CSP), was found in previously concussed athletes who had been asymptomatic, on average, for 2 years before testing.[9] In addition, this prospective study showed that athletes with multiple concussions who sustained another concussion displayed further increases in M1 intracortical inhibition.[9] Another group[10] demonstrated the chronicity of this pervasive CSP duration lengthening in otherwise healthy, former university-level contact-sport athletes who had sustained their last sport concussions more than 3 decades earlier. Although the biological substrates of CSP duration modulation are uncertain, research has pointed to changes in intracortical inhibitory systems of the motor cortex mediated by γ-aminobutyric acid subtype B ($GABA_B$) receptor activity.[11–15] The main inhibitory neurotransmitter in the human central nervous system (CNS), GABA is involved in numerous CNS functions.[16] Slice preparation studies indicate that GABA receptors (particularly $GABA_B$ receptors) play an important role in regulating neuronal excitability and long-term potentiation.[17,18] Perhaps most pertinent in the context of this study, the administration of $GABA_B$ receptor-agonist baclofen was recently found to suppress long-term potentiation-like plasticity in human M1.[19] In animal studies, this increase in GABA neurotransmission prevented long-term potential–dependent motor learning.[20,21] Although no direct evidence exists for the involvement of GABA receptors in postconcussive brain alterations, abnormal GABA transmission has been reported in rat models of brain injury.[22,23]

In addition to CSP lengthening,[9,10] previously concussed former athletes also displayed lower motor execution velocity than nonconcussed former athletes on a rapid alternating movements (RAM) task. This task was selected because RAM velocity is known to decline with age[24] and to be altered in patients with moderate to severe head injuries who performed normally on neuropsychological tests[25] at least 1 year after injury. Most notably, RAM velocity was strongly correlated with M1 intracortical inhibition anomalies among previously concussed former athletes.[10]

Therefore, our purpose was to report on the persistent effects of concussions on motor system functions—namely COP oscillation regularity,[5] motor execution on an RAM task,[10] and M1 intracortical inhibition[9,10]—that have not been assessed in young, previously concussed athletes who have long since received medical clearance to return to competition. In addition, we sought to further validate the persistent and cumulative dysfunctions of M1 intracortical inhibition with the introduction of the more widely accepted and less empirically debated long-interval intracortical inhibition (LICI) TMS paradigm.[12]

METHODS

Participants

All 36 participants were active male players (age = 22.3 ± 3.45 years; range, 19 to 26 years) from 2 Canadian university football teams, recruited with the help of the team physician, who provided information about the number of previous sport concussions. Participants were included if they met all of the following criteria: no history of alcohol or substance abuse; no medical condition necessitating daily medication; and no previous history of psychiatric illness, learning disability, neurologic history, or traumatic brain injury unrelated to contact sports. The study was approved by the local ethics committee, and all participants provided written informed consent before testing. Volunteers received financial compensation of CaD $50 for their participation.

The study consisted of 2 groups. The concussed group was composed of 21 university-level football players who had sustained their last sport concussion more than 9 months before testing.

Lingering concussion-related effects on TMS measures in university football players have been demonstrated in this time frame since injury.[9] The number of concussions per athlete ranged from 1 to 5 (mean = 2.65 ± 1.45), and the time since the last concussion ranged from 9 to 34 months (mean = 19.03 ± 13.77 months). Information on concussions sustained while the athletes were at the university was obtained from the medical records, whereas information on concussions sustained before the athletes entered college was mostly self-reported. At the time of testing, concussed athletes were asymptomatic, reporting very few (if any) symptoms on the Postconcussion Symptom Scale (mean = 2.15 ± 2.08 symptoms).[26] The control group consisted of 15 university football players who reported no history of sport concussion or neurologic insult. Unequal group sample sizes reflected limited access to high-demand football players within regional university settings. The 2 groups were equivalent in terms of age ($F_{1,34} = 0.58$, $P > .05$), postconcussion symptoms ($F_{1,34} = 0.02$, $P > .05$), and level of education ($F_{1,34} = 0.21$, $P > .05$). All 36 participants completed both experimental sessions.

Procedures

The experiment consisted of two 1-hour testing sessions that took place 1 to 5 weeks apart during the football off-season. During the first session, a concussion history questionnaire, a general health questionnaire, the Postconcussion Symptom Scale, and the TMS protocol were administered. (For more information on the questionnaires, see our previously published article.[27]) The second session consisted of the RAM task and postural-control assessment.

Postural-Control Paradigm. Participants were instructed to stand as steady as possible in an upright position on a force platform (model OR6-5; Advance Mechanical Technology, Inc, Watertown, MA) with their eyes open and feet side by side, parallel, at pelvis width. Two trials separated by a 60-second resting period were recorded, and each trial lasted 30 seconds. Analyses were computed for the first trial except in the cases of 2 participants who had flawed first-trial recordings because they did not accurately follow the task instructions. We used second-trial recordings in these participants because negligible practice effects were demonstrated in between-trials analyses for participants with 2 valid trials ($F_{1,33} = 0.025$, $P > .05$). Furthermore, within-subject COP displacement during quiet standing with feet side by side is fairly stable across trials.[28] *Postural stability* referred to the root mean square amplitude of COP displacement in both the mediolateral (ML) and anteroposterior (AP) directions. The ApEn values were computed using test trials for the ML and AP components of the COP coordinates.[5]

The RAM Task. Each participant was seated on a straight-back chair and told to keep his elbows close to his trunk and flexed at an angle of 90º. He was instructed to rotate 2 handheld spheres as quickly as possible, with maximal movement amplitude (complete pronation-supination at the wrist). To track the participant's hand position and orientation in 3-dimensional space, we placed 4 infrared light-emitting diodes at strategic positions on the spheres. The coordinates of the diodes were recorded at a frequency of 200 Hz using a 3-dimensional motion-analysis system (Optotrak Certus, Northern Digital Inc, Waterloo, Ontario, Canada), and hand orientation was later analyzed using customized analysis software (MATLAB, The MathWorks, Inc, Natick, MA). For each of the 3 conditions (both hands, left hand only, right hand only), 2 periods of 15 seconds each were recorded, separated by a 2-minute pause. Further analyses were conducted on the first-trial data except in 3 cases in which a number of missing diodes prevented appropriate analyses.

Velocity and performance were the main performance measures computed using the algorithms developed by Okada and Okada[29] and adapted by others.[30–32] *Velocity* is a composite measure of range/duration (ie, average angular displacement for a pronation-supination cycle/time per cycle). *Sharpness* reflects the delays associated with changes of direction; more delays reflect less sharp pronation-supination turns. (See references 29–32 for detailed descriptions of these performance measures). Finally, *bimanual coordination* refers to movement synchrony between hands (ie, smaller values reflect better synchrony).

We derived bimanual coordination scores in the following way. Angular variations of the 2 hands were normalized as a function of each hand's maximal rotation amplitude. We subtracted angular variations computed for the dominant hand from those of the nondominant hand, such that a resulting horizontal line would indicate perfectly synchronized hands. We then computed deviations (in absolute degrees) from the perfect horizontal plane for each sampling point (200 Hz) and averaged them to obtain a bimanual coordination score for each trial.

The TMS Recordings and Data Analysis. The TMS was performed using a figure-8 coil positioned optimally to elicit motor evoked potentials in the right first dorsal interosseous muscle. The CSP duration was calculated at 3 TMS intensities. Five single-pulse stimulations for each of 3 TMS intensities (110%, 120%, and 130% of the resting motor threshold [rMT] intensity) were applied to the left M1 while participants maintained a voluntary isometric muscle contraction of the right first dorsal interosseous muscle at approximately 10% of maximum strength. The CSP duration was calculated with the graphical method described by Garvey et al.[33] An interstimulus interval of 100 milliseconds was used to assess LICI.[12] The intensity of the conditioning stimulus was set at 120% of the rMT, and the test stimulus intensity was adjusted to induce motor evoked potentials of approximately 1 mV peak-to-peak amplitude. Fifteen motor evoked potentials each were collected for the test stimulus alone and for the conditioning stimulus test condition. The LICI was presented as the following ratio: test stimulus/conditioning stimulus.

Statistical Analyses

All values are expressed as mean ± SD. Demographic information, TMS data, postural-stability scores, and ApEn values were subjected to standard descriptive statistics and analyses of variance. Simple contrast analyses were computed to assess between-groups differences for CSP across TMS intensities. Two-tailed Pearson correlations were calculated between the LICI and CSP values of previously concussed athletes and between the number of previous concussions and the LICI, CSP, and postural-stability values. Tukey corrections for multiple comparisons were subsequently applied. Power statistics were also computed for between-groups differences across experimental measures.

RESULTS

Postural Control

The ApEn values were lower (ie, more regular) in asymptomatic, previously concussed athletes than in control athletes in the AP direction ($F_{1,35}$ = 8.90, P < .05, Cohen d = 1.03) but not in the ML direction ($F_{1,35}$ = 1.48, P > .05, Cohen d = .40) (Figure 1A). In contrast, between-groups analysis of variance (ANOVA) was not significant for RMS amplitude of COP displacement in either the AP ($F_{1,35}$ = 1.210, P > .05, Cohen d = .26)

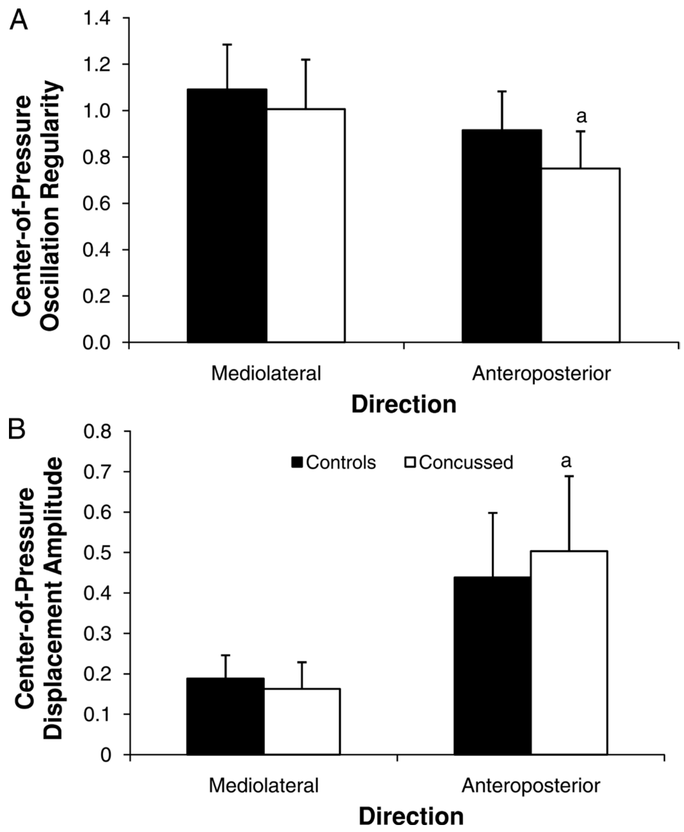

Figure 1. A, Approximate entropy values expressed as the center-of-pressure (COP) oscillation regularity in the mediolateral and anteroposterior directions (range, 0–2). Greater approximate entropy values reflect more COP oscillation randomness. B, Root mean square amplitude of COP displacement for the anteroposterior and mediolateral directions. Smaller COP displacement amplitude reflects better postural stability. [a]*P* < .05.

or ML ($F_{1,35}$=1.24, P>.05, Cohen d=.28) direction (Figure 1B).

The RAM Task Results

In a 2 (groups)×2 (hand dominance)×2 (number of hands) 3-way ANOVA for velocity, the 3-way interaction was not significant ($F_{2,34}$=2.888, P>.05). In sharp contrast to findings in former athletes with a history of concussion at least 30 years earlier,[10] these young, previously concussed athletes performed pronation-supination cycles with greater velocity than the control group ($F_{1,35}$=6.87, P<.05, Cohen d=0.97). Further analyses revealed that this was true for 2 hand conditions (dominant hand: $F_{1,35}$=8.02, P<.05; both hands: $F_{1,35}$=5.87, P<.05), whereas only a trend toward significance was found for the velocity measure computed for the nondominant hand ($F_{1,35}$=2.89, P<.1). As expected, the main effect of hand condition was significant ($F_{2,35}$=7.07, P<.05). However, bimanual coordination was equivalent across groups ($F_{1,35}$=2.28, P<.15, Cohen d=0.57). In the bimanual task condition, computing an overall performance score on the RAM task with equal weight on velocity and bimanual coordination (velocity score×[1/bimanual coordination score]) revealed that the groups were equivalent ($F_{1,35}$=1.01, P>.05).

In the 2 (groups)×2 (hand dominance)×2 (number of hands) 3-way ANOVA for sharpness, the group×hand condition interaction was not significant ($F_{2,34}$=1.78, P>.05, Cohen d=0.51). Groups did not differ according to sharpness ($F_{1,35}$=3.11, P>.05). Finally, the main effect of hand condition was not significant ($F_{2,35}$=1.00, P>.05).

The TMS Results

Relative to controls, a 1-factor between-groups ANOVA revealed that previously concussed athletes exhibited lower LICI ratios ($F_{1,35}$=5.96, P<.03, Cohen d=.82) (Figure 2A). In a 2 (groups)×3 (stimulation intensity) 2-way ANOVA for CSP, the group×intensity interaction was not significant ($F_{2,30}$=1.17, P>.05). More importantly, the main effect of group revealed that previously concussed athletes exhibited CSP prolongation relative to control athletes ($F_{1,35}$=15.61, P<.001, Cohen d=1.14) (Figure 2B). As expected, the main effect of

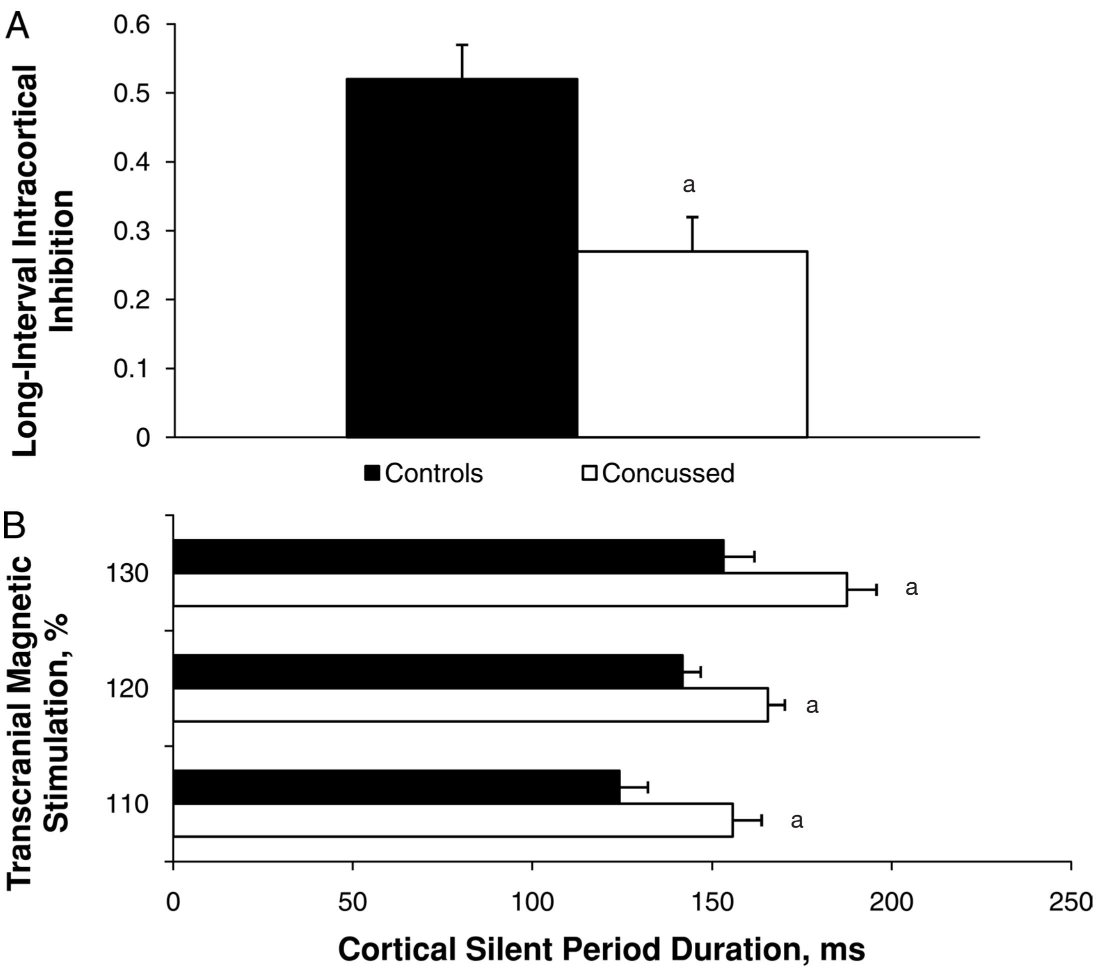

Figure 2. A, Long-interval intracortical inhibition, expressed as the ratio of the conditioning stimulus−test stimulus/test stimulus. Intensity of the conditioning stimulus was set at 120% of the resting motor threshold, and test stimulus intensity was adjusted to induce motor evoked potentials of approximately 1 mV peak-to-peak amplitude. B, Cortical silent period duration when transcranial magnetic stimulation at 3 intensities (110%, 120%, and 130%), expressed as a percentage of the resting motor threshold, was applied to the vertex while participants in each group performed a voluntary isometric muscle contraction of the right hand first dorsal interosseous muscle at approximately 10% of maximum strength. [a]P<.05.

intensity yielded a difference in CSP duration across all groups ($F_{2,35}=80.11$, $P<.001$).

Furthermore, LICI in concussed athletes correlated with the duration of the CSP elicited when pulses were delivered at intensities of 120% and 130% of the rMT (120%: $r=0.479$, $P<.05$; 130%: $r=0.501$, $P<.05$), whereas the Pearson correlation computed with CSP at 110% did not reach statistical significance ($r=0.214$, $P>.05$).

Two-tailed Pearson correlations between the number of previous concussions and the LICI ratio values were correlated ($r=0.47$, $P<.05$). Similarly, CSP duration correlated with the number of previous concussions for both 120% ($r=0.52$, $P<.05$) and 130% of rMT conditions ($r=0.49$, $P<.05$). The correlation between COP oscillation regularity and the number of previous concussions did not reach significance ($r=0.261$, $P<.15$). Finally, velocity scores on the RAM task were not correlated with the number of previous concussions ($r=-0.114$, $P>.05$). The Table summarizes data from the 3 main outcome measures.

DISCUSSION

Relative to athletes who had no history of concussion, the current study revealed 3 main findings about previously concussed athletes who had returned to competition 9 months before testing: (1) They exhibited a persistent decrease in COP oscillation randomness only in the AP direction while displaying equivalent RMS amplitude displacements on COP measures, (2) they performed normally on a RAM task, and (3) they demonstrated an increase in intracortical inhibition in M1, the extent of which increased as a function of the number of previous concussions.

Consistent with previous data,[5] previously concussed athletes who resumed competition more than 9 months before testing still exhibited greater COP oscillation regularity according to the ApEn measure of postural control, despite equivalent postural-stability scores on conventional, linear measures. Although the functional significance of greater COP oscillation regularity with regard to postural stability is still largely unknown, previous authors[5,34] suggested that it represents an adaptive compensatory mechanism to allow concussed athletes to achieve postural stability. More specifically, we know that ankle muscles dominate the regulation of postural stability in the AP direction[28] and that contracting these muscles increases control over postural sway and, consequently, decreases COP oscillation randomness. One possible explanation for increased COP oscillation regularity could therefore be that concussed athletes deliberately increase cocontraction of the lower extremity musculature to compensate for postural-stability losses.[5] Another possibility is that concussive injuries result in stiffened lower extremity musculature. However, acquired lower musculature stiffness after concussion is at odds with concussed athletes' increased M1 intracortical inhibition, considering that muscle stiffness has been associated with reduced M1 inhibition.[35,36]

In parallel, the present increase in COP oscillation regularity specific to the AP direction contrasts with a previous report[5] on concussion-related effects that showed increases in both the AP and ML directions on postconcussion day 1 and decreased ApEn values in the ML time series at day 4. Although underlying concussion-related pathophysiologic substrates that might mediate this increased COP oscillation regularity are unknown, a recent group[6] applied ApEn calculations to assess the effects of a secondary cognitive task on postural stability in healthy young adults. They showed higher ApEn values in the COP AP time series that were not apparent on conventional linear measures of postural control. This added measurement sensitivity was proposed[6] to originate from the fact that ApEn takes into account the sequential order of successive data points, in contrast with traditional linear measurements, which can reflect only the overall magnitude of COP displacement. Moreover, the authors[6] suggested that higher ApEn values specific to the AP direction during the dual-task condition reflected this documented higher ApEn measurement sensitivity. This suggestion is consistent with a previous report[28] showing that control of AP displacement by the ankle muscles is the chief mechanism of upright postural control when the feet are side by side and that a force platform records more AP displacement in this condition than ML displacement.

In sharp contrast to formerly concussed athletes who experienced concussions 30 years earlier[10] and demonstrated motor execution slowness on the RAM task, young concussed athletes attained significantly better scores than controls. However, when equal weight was attributed to velocity and bimanual coordination precision, performance was equivalent

Table. Statistical Analysis of the 3 Main Motor System Measures Reflecting Group (History of Concussion, No History of Concussion) Main Effects

Motor System Measure	Dependent Variables		Statistical Analysis	*P* Value
Postural control	Approximate entropy	Anteroposterior	$F=8.90$	<.05
		Mediolateral	$F=1.48$	>.05
	Linear postural-control measure	Root mean square amplitude	$F=1.24$	>.05
Rapid alternating movements (pronation-supination cycles)	Velocity		$F=6.87$	<.05
	Bimanual coordination		$F=2.28$	>.05
	Sharpness		$F=3.11$	>.05
	Overall performance index		$F=1.01$	>.05
Intracortical inhibition of primary motor cortex	Cortical silent period		$F=15.61$	<.05
	Long-interval intracortical inhibition		$F=5.96$	<.05
Correlation with number of previous sport concussions	Cortical silent period	120% of resting motor threshold	$r=0.52$	<.05
	Long-interval intracortical inhibition	130% of resting motor threshold	$r=0.047$	<.05
			$r=0.49$	<.05

across the groups. Relative to controls, previously concussed athletes therefore appeared to favor speed over movement accuracy. This qualitatively distinct performance across groups may be mediated by various factors extraneous to concussions, including performance motivation. Athletes in the acute postconcussion phase are highly motivated to downplay the effects of the injury to accelerate return to play.[37,38] Although we are only speculating, the speed-accuracy tradeoff we found might reflect greater performance motivation among previously concussed participants, especially because the task instructions placed more emphasis on speed than on movement precision. Unlike the older, previously concussed athletes who displayed CSP prolongation that strongly correlated with motor execution slowness,[10] the young athletes displayed prolonged CSP duration without motor execution slowness. This inconsistent pattern across age groups, coupled with unknown concussion-related pathophysiologic features affecting both CSP and motor execution speed, warrants caution when interpreting findings. The normal aging process has repeatedly been associated with motor execution slowness,[39–41] so a history of sport concussions might render the aging, concussed brain particularly vulnerable to further movement slowness, at least partly through lifelong intracortical inhibition abnormalities. Given that many professional athletes retire in their late thirties, longitudinal studies could be helpful in characterizing the presence of motor execution slowness and possibly associated functional impairments in formerly concussed athletes. Similarly, knowing that aging is associated with increased amounts of postural sway,[42] which may ultimately lead to falls, longitudinal follow-up could inform us about the long-term repercussions of concussion-related increases in COP oscillation regularity in comparison with former athletes lacking a history of concussion.

Among active university football players, those presenting with a history of sport concussion showed more LICI and longer CSP duration relative to their nonconcussed counterparts. In accordance with numerous studies[43–45] suggesting that CSP and LICI reflect similar M1 intracortical inhibitory mechanisms, LICI correlated with CSP duration. Furthermore, altered M1 intracortical inhibition was strongly associated with the number of previous concussions: athletes who sustained more concussions typically exhibited more M1 intracortical inhibition. In conjunction with the demonstrated direct increase in LICI with intake of the $GABA_B$ agonist baclofen,[12] our results provide compelling evidence that sport concussions induce long-lasting alterations of intracortical inhibition at least partially mediated by $GABA_B$ receptor activity.[11,13–15,46] Although Pearson correlations between M1 intracortical inhibition indices and the number of previous sport concussions are considered strong,[47] we should remain cautious when interpreting such associations because derived coefficients of determination (r^2) indicate that only 25% of M1 intracortical inhibition variance can be explained by the number of previous sport concussions. Consequently, other intervening factors may contribute to the known long-term and cumulative effects of sport concussions. The absence of correlations between COP oscillation regularity and CSP or LICI in concussed athletes also points to the complexity of the pathophysiology of concussion. This finding is consistent with recommendations in the consensus statement of the Third International Conference on Concussion in Sport[48] suggesting that multidisciplinary assessments benefit the management of patients with concussion.

Having to rely on concussion history self-reports as opposed to medical records for sport concussions that occurred years before testing is not optimal. Prospective studies conducted with young athletes followed longitudinally are therefore needed to validate the persistent, cumulative effects of concussions observed in the present study. Another major limitation to the present study is the lack of imaging results. In fact, one possible explanation for our findings could be their potential association with structural damage related to sport concussions; in addition to exhibiting more severe postconcussion alterations, athletes with multiple concussions are more likely to have sustained structural damage. Adding structural imaging in future studies would be instrumental to systematically addressing this issue.

In summary, we showed that sport concussions induced pervasive changes in postural control and more M1 intracortical inhibition, providing neurophysiologic and behavioral evidence of lasting, subclinical changes of motor system integrity in previously concussed athletes. Normal performance of young, previously concussed athletes on a RAM task also suggests that rather than being induced by sport concussions alone, motor execution slowness symptoms evidenced 30 years after concussion[10] seem to be at least partially mediated by the combined adverse effects of aging with a history of sport concussions.

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original research

Intrarater Reliability of the Adductor Squeeze Test in Gaelic Games Athletes

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Context: Groin pain is commonly experienced by athletes involved in field-based sports and is particularly prevalent in Gaelic Games athletes. The adductor squeeze test is commonly used in the assessment of groin pain and injuries. To date, no evidence in the literature provides the reliability of the adductor squeeze test using a sphygmomanometer in assessing the adductor muscle integrity of Gaelic Games athletes. Given the high proportion of groin pain encountered in Gaelic Games athletes, establishing the reliability of the adductor squeeze test will allow clinicians to monitor injury responses and to assess return-to-play criteria.

Objective: To evaluate the intrarater reliability of a commercially available sphygmomanometer for measuring adductor squeeze values in Gaelic Games athletes and to determine if different squeeze values are associated with the 3 commonly used test positions.

Design: Descriptive laboratory study.

Setting: University clinical skills laboratory.

Patients or Other Participants: Eighteen male Gaelic Games athletes without any previous or current history of groin or pelvic pain.

Intervention(s): Each participant performed the adductor squeeze test in 3 positions of hip joint flexion (0°, 45°, and 90°) on 2 test days separated by at least 1 week.

Main Outcome Measure(s): Adductor squeeze test values (mm Hg) quantified by a commercially available sphygmomanometer.

Results: Intrarater reliability intraclass correlation values ranged from 0.89 to 0.92 (intraclass correlation coefficients were 0°, 0.89; 45°, 0.92; and 90°, 0.90). The highest squeeze values were recorded in the 45° of hip flexion test position, and these values differed from those demonstrated in the 0° and 90° hip flexion test positions ($P < .05$).

Conclusions: A commercially available sphygmomanometer is a reliable device for measuring adductor squeeze test values.

Key Words: groin injuries, measurements, rehabilitation, strength

Key Points

- For all 3 test positions, the intrarater reliability of a commercially available sphygmomanometer in assessing adductor squeeze values in Gaelic Games athletes was excellent, with the highest reliability and greatest squeeze values noted in the 45° of hip flexion test position.
- We hypothesize that the 45° of hip flexion test position is likely to place maximal stress on the adductor musculature and the medial and anterior pelvic rings.
- A commercially available sphygmomanometer for the measurement of adductor squeeze values could aid clinicians in monitoring athletes' responses to treatment strategies used during rehabilitation for groin pain.

Chronic groin pain is a common problem among athletes, and approximately 5% of all soccer injuries are estimated[1] to affect the groin. The multifactorial nature of, and the various anatomical structures that contribute to, groin pain have made the condition difficult to prevent and manage. The development of groin pain in athletes has previously been shown[2,3] to be related to the strength of the adductor muscles. Furthermore, athletes who endure a large number of side-to-side movements, repetitive twisting and kicking, and rapid changes of direction appear to be most at risk of developing groin pain.[4–6] An adductor muscle–strengthening program comprises an effective strategy for reducing the incidence of groin pain in athletes.[2]

Gaelic Games are the traditional sports played in Ireland, the most popular being Gaelic football and hurling. Both are collision-contact sports with speed, strength, and agility demands similar to those of Australian rules football, rugby union and rugby league, field hockey, and lacrosse. These games are played at high speed, which, when combined with significant physical contact, acceleration, deceleration, and turning, has been proposed[7] to increase the likelihood of injury during the season. Newell et al[8] demonstrated that 65% of Gaelic football intercounty players were unable to fully participate in training/games for 1 to 3 weeks in a typical season as a result of injury.

O'Donoghue and King[9] investigated the high-intensity work-to-rest ratios in Gaelic Games by coding 55 players during senior intervarsity matches. High-intensity activities were classified as running, sprinting, shuffling, and game-related activity (eg, kicking, passing, aerial challenging). On average, high-intensity work bouts lasted 5.7 seconds each and cumulatively accounted for 14% of actual game time. In a prospective study, Wilson et al[7] showed that 71.1% of injuries in Gaelic Games football players involved the lower limb, with groin injury being one of the most commonly encountered conditions.

Anatomical structures such as the adductor musculature and pubic symphysis are associated with groin pain; thus, researchers have described various pain-provocation tests for assessment. The pubic symphysis gap test was described by Rodriguez et al[10]: the patient is placed in 90° of hip and knee flexion and asked to squeeze the knees against the examiner's clenched fist. The squeeze test, described by Verrall et al,[11] requires the patient to squeeze the fist of the examiner, which is placed between the patient's knees with the hip joint in 45° of flexion and the feet resting on a plinth. A test in which the hip and knee joints are in neutral position has been described by Hölmich et al[12] and essentially consists of an isometric adduction against the examiner's fist, with the athlete lying supine. However, these tests are fundamentally similar, regardless of hip position or the object placed between the patient's knees, in that the individual squeezes both adductors of each leg; pain in the groin region constitutes a positive test. Thus, all 3 test positions (0°, 45°, and 90°) are commonly used in the clinical assessment of groin pain, and the patient is asked to maximally contract both sets of adductor muscles simultaneously or to essentially "squeeze the fist." The test is considered positive if the individual complains of pain in the adductor muscles or the bony structures of the anterior and medial pelvic ring. For the purpose of this article, we will use the generic term *adductor squeeze test* while specifying the associated hip-joint–flexion position.

Although the aforementioned studies describe isometric adductor activation in various hip flexion positions, the functional contribution of the adductor musculature in activities such as linear running indicates a more expansive role than simple frontal-plane motion. Dostal et al[13] noted that the adductor muscle group assists in sagittal-plane hip motion. The adductor magnus, regardless of hip position, assists the hamstrings and gluteus maximus in hip extension. Furthermore, hip flexion of more than 60° places the adductor longus in an orientation that is posterior to its axis of rotation, thereby assisting in hip extension, whereas hip flexion of less than 60° places the adductor longus in a position that is anterior to its axis of rotation, thereby producing a flexion moment arm.[14] This multifunctional role of the adductor muscle group provides the clinical rationale for adductor squeeze tests in varied positions and may also offer a basis for designing more functional tests to stress the adductor musculature.

Authors[15,16] of 2 recently published studies have quantified adductor strength during the adductor squeeze test with a handheld dynamometer and sphygmomanometer. Participants in these investigations were drawn from the Australian rules football and soccer populations. To date, no references in the literature have addressed reliability of the adductor squeeze test using a sphygmomanometer to assess adductor muscle integrity of Gaelic games athletes. Because of the high proportion of groin pain encountered in Gaelic games athletes, it is necessary to establish the reliability of the adductor squeeze test to allow clinicians to both monitor injury responses and assess return-to-play criteria.

Thus, the aims of our study were to determine (1) the intrarater reliability of the adductor squeeze test using a commercially available sphygmomanometer and (2) if any differences exist in the squeeze values (pressure values recorded on the sphygmomanometer dial) observed in the 3 test positions.

METHODS

Participants

Eighteen male Gaelic Games players (age = 21.11 ± 2.53 years, height = 1.78 ± 0.06 m, mass = 78.24 ± 11.76 kg) volunteered for the study. Participant recruitment was undertaken by placing notices on the University Sports Centre notice board. Inclusion criteria were as follows: (1) male, (2) currently playing Gaelic Games football or hurling, (3) no previous or current history of groin pain in either limb, (4) no previous or current history of pelvic pain, and (5) no other lower limb injury in the previous 6 months. Two of the investigators assessed the inclusion criteria for each participant via direct interview. The study was granted ethical approval by the University Human Research Ethics Committee, and before testing, each participant read an information leaflet and signed an informed consent.

Procedures

All testing was undertaken in a university clinical skills laboratory. Each participant visited the laboratory on 2 occasions, with visits separated by at least 1 week. Upon arriving at the laboratory for the first testing session, each participant was informed of the testing procedures and allowed 3 submaximal practice trials in each test position for familiarization with the protocol. All testing was supervised by a physiotherapist with 7 years of postqualification experience.

During testing, participants were positioned supine with their arms crossed and their heads flat on a plinth (Figures 1 through 3). Participants wore shorts during the testing session and were barefoot while lying on the plinth. For each session, participants were required to perform 3 maximum trials each of the adductor squeeze test in 0°, 45°, and 90° of hip flexion. The position of hip-joint flexion was measured and verified by 2 investigators using a goniometer. Furthermore, the hip joints were kept in neutral rotation in each of the test positions. The order of test position was randomized using a concealed-envelope procedure. The squeeze test was quantified using a sphygmomanometer (Disytest; Welch Allyn, Skaneateles, NY) that was preinflated to 10 mm Hg. The cuff of the sphygmomanometer was placed between the participant's knees, and he was instructed to squeeze the cuff as hard as he could. Specific emphasis was placed on correct positioning of the sphygmomanometer, such that the middle third of the cuff was located at the most prominent point of the medial femoral condyles. Before each squeeze test, the sphygmomanometer was allowed to settle for a period of 30 seconds (according to the manufacturer's recommendations); room temperature was monitored and kept constant across testing sessions. The highest pressure (squeeze) value displayed on the sphygmomanometer dial was recorded during each maximal adductor squeeze test. As noted in Figures 1 through 3, the participants were unable to see the sphygmomanometer dial during the testing session. They were allowed 2 minutes of rest between performances of the maximal squeeze test at each position.

Figure 1. The adductor squeeze test at 0° of hip flexion using a commercially available sphygmomanometer.

Figure 2. The adductor squeeze test at 45° of hip flexion using a commercially available sphygmomanometer.

Statistical Analysis

The sample size for the study was based on the methods described by Walter et al.[17] For the values $\varrho_0 = 0.5$, $\varrho_1 = 0.8$, $\alpha = .05$, and $\beta = .2$, a sample size of 15 was necessary. The average of 3 trials for each test position was used for statistical analysis. Intraclass correlation coefficients (ICCs) and 95% confidence intervals (CIs) were calculated to determine intrarater reliability. We chose the ICC (3,1) model, which corresponds to a 2-way mixed model, with single-measure reliability and absolute agreement calculated via SPSS (version 15.0; SPSS Inc, Chicago, IL). Reliability was judged based on established criteria: >0.75, excellent reliability; 0.60 to 0.74, good reliability; 0.40 to 0.59, fair reliability; and <0.40, poor reliability.[18]

Figure 3. The adductor squeeze test at 90° of hip flexion using a commercially available sphygmomanometer.

Furthermore, we calculated the standard error of measurement (SEM; according to the equations published by Weir[19]), the SEM percentage, and the minimal detectable change. Repeated-measures analysis of variance was used to test for differences in the values obtained during each of the test positions (0°, 45°, and 90°). When a main effect was observed, a Bonferroni adjusted pairwise comparison was undertaken. Values for η^2_p are included as indicators of effect sizes using analysis of variance.

RESULTS

Intrarater reliability (ICC values) ranged from 0.89 (95% CI = 0.74, 0.96) at 0° of hip flexion to 0.92 (95% CI = 0.82, 0.97) at 45° of hip flexion, thus indicating excellent reliability in all test positions (Table 1). The smallest amount of measurement error was seen at the 45° of hip flexion test position (SEM = 1.60%), compared with the 0° (SEM = 3.27%) and 90° (SEM = 2.21%) positions.

Mean squeeze values for each of the 3 test positions on days 1 and 2 of testing are shown in Table 2. A statistically significant effect was found for the 45° of hip flexion test position. Higher values were obtained in this test position compared with the 0° ($P < .01$) and 90° ($P < .01$) positions on day 1 and with the 0° ($P < .05$) and 90° ($P < .01$) positions on day 2. The η^2_p values were 0.78 on day 1 and 0.82 on day 2, indicating strong effect sizes.

DISCUSSION

Groin pain is a frequently encountered clinical entity in Gaelic Games athletes.[7] To our knowledge, no authors to date have investigated the intrarater reliability of the adductor squeeze test in asymptomatic Gaelic Games athletes using a

Table 1. Intraclass Correlation Coefficient Estimates for the Adductor Squeeze Test Using a Sphygmomanometer

Hip flexion Test Position, °	Intraclass Correlation Coefficient (3,1)	95% Confidence Interval	Standard Error of Measurement, mm Hg	Standard Error of Measurement, %	Minimal Detectable Change
0	0.89	0.74, 0.96	6.75	3.27	18.71
45	0.92	0.82, 0.97	3.83	1.60	10.62
90	0.90	0.66, 0.97	4.23	2.21	11.73

Table 2. Adductor Squeeze Values for 3 Test Positions on Days 1 and 2

	Adductor Squeeze Value, mm Hg (Mean ± SD)			
	0°	45°	90°	η^2_p
Day 1	202.50 ± 57.28	236.76 ± 47.29[a,b]	186.11 ± 44.01	0.78
Day 2	210.18 ± 61.73	241.48 ± 48.91[a,b]	196.94 ± 39.84	0.82

[a] Different from 0°.
[b] Different from 90°.

commercially available sphygmomanometer. Thus, we are the first to investigate this issue and to analyze the differences in squeeze values across the 3 test positions.

The ICC values calculated for each of the test positions demonstrated excellent reliability, with values of 0.89, 0.92, and 0.90 for the 0°, 45°, and 90° of hip flexion test positions, respectively. These results concur with those of Fulcher et al[15] and Malliaras et al.[16] Malliaras et al[16] used a commercially available sphygmomanometer to examine squeeze test values in elite junior Australian rules football and soccer players. They obtained ICC values for the 0°, 30°, and 45° hip flexion test positions of 0.81, 0.91, and 0.94, respectively. We also tested 0° and 45° of hip flexion and found ICC values of 0.89 and 0.92, respectively. Furthermore, the squeeze values we observed are somewhat comparable to those of Malliaras et al,[16] who reported 210.8 ± 39.3 mm Hg in the 0° of hip flexion test position and 209.6 ± 42.3 mm Hg in the 45° of hip flexion test position. Fulcher et al[15] quantified adductor strength in male semiprofessional soccer players in the test positions of 0°, 45°, and 90° of hip flexion using a handheld dynamometer. Their ICC values were 0.85, 0.77, and 0.87, respectively, which are consistent with the ICC values we obtained.

In addition to computing ICC values, we also undertook statistical analysis to determine if maximum squeeze values differed among the 3 test positions. On both days, the mean squeeze value was higher at 45° of hip flexion than at 0° and 90° of hip flexion (Table 2). Additionally, η^2_p values for day 1 and day 2 were 0.78 and 0.82, respectively, indicating strong effect sizes. Given that the 45° of hip flexion test position was associated with the greatest squeeze value, the greatest stress on the adductor musculature and pubic bone during the adductor squeeze test is likely to occur in this testing position. For this reason, we believe that when assessing both groin pain and adductor squeeze values, 45° of hip flexion is the optimal testing position. To confirm our hypothesis, further testing is required to determine electromyographic activity of the adductor longus muscle at the different positions of hip-joint flexion.

The present study does have a number of points worth noting. All participants were free from groin pain, according to the aforementioned inclusion criteria, and, therefore, there were no confounding issues stemming from a previous history of groin pain. This factor is in contrast to the studies of Fulcher et al[15] and Malliaras et al.[16] Fulcher et al[15] found that 30% of participants reported a degree of groin discomfort during the testing. Furthermore, 70% of participants reported a previous history of groin pain.

Test-retest methods are criticized by many researchers as a method of gauging reliability. Among the difficulties associated with these methods is the fact that short intervals between administrations of the instrument can yield reliability estimates that are too high. In our study, the interval between test and retest was a minimum of 7 days (mean = 9 days). In previous studies,[15,16] retesting was carried out during the same session. We believe that our testing protocol better simulates the process of assessing and monitoring athletes in a clinical environment. Furthermore, in our study, for the retest session, the examiner was blinded to the initial test session results, which reduced the risk of reporting bias.

Early detection and intervention are the keys to optimal management and prevention of chronic injury. The current lack of reliable clinical indicators (ie, clinical and functional screening tests) to assess the likelihood of developing chronic groin pain makes it difficult to establish effective prophylactic strategies.[20] For the adductor squeeze test, 45° of hip flexion was the best testing position. No participants had groin pain; hence, a true picture of normative data in a healthy population is provided. We found excellent intrarater reliability for measuring adductor squeeze values using a sphygmomanometer in healthy male Gaelic Games athletes. We propose that a commercially available sphygmomanometer is a cost-effective method of assessing adductor squeeze values in clinical practice. It allows for the objective measurement of adductor squeeze values, which could be readily used by clinicians to monitor potential injury risk, advance rehabilitation, and determine suitability for return to sport participation.

Future studies are now warranted to determine the predictive power of the adductor squeeze test in identifying athletes at risk of developing groin pain. This question could be answered by a prospective study, with regular testing of squeeze values across the course of an athletic season. Also, the interrater reliability of the adductor squeeze test needs to be established in Gaelic Games athletes. In addition, investigators should concentrate on the acquisition of squeeze values in athletes with acute and chronic groin pain.

CONCLUSIONS

A commercially available sphygmomanometer is a reliable tool for assessing adductor squeeze values in Gaelic Games athletes. Furthermore, our results indicate that 45° of hip flexion may represent the optimal test position for the adductor squeeze test.

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A Preliminary Multifactorial Approach Describing the Relationships Among Lower Extremity Alignment, Hip Muscle Activation, and Lower Extremity Joint Excursion

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Context: Multiple factors have been suggested to increase the risk of faulty dynamic alignments that predict noncontact anterior cruciate ligament injury. Few researchers have examined this relationship using an integrated, multifactorial approach.

Objective: To describe the relationship among static lower extremity alignment (LEA), hip muscle activation, and hip and knee motion during a single-leg squat.

Design: Descriptive laboratory study.

Setting: Research laboratory.

Patients or Other Participants: Thirty men (age = 23.9 ± 3.6 years, height = 178.5 ± 9.9 cm, mass = 82.0 ± 14.1 kg) and 30 women (age = 22.2 ± 2.6 years, height = 162.4 ± 6.3 cm, mass = 60.3 ± 8.1 kg).

Main Outcome Measure(s): Pelvic angle, femoral anteversion, quadriceps angle, tibiofemoral angle, and genu recurvatum were measured to the nearest degree; navicular drop was measured to the nearest millimeter. The average root mean square amplitude of the gluteus medius and maximus muscles was assessed during the single-leg squat and normalized to the peak root mean square value during maximal contractions for each muscle. Kinematic data of hip and knee were also assessed during the single-leg squat. Structural equation modeling was used to describe the relationships among static LEA, hip muscle activation, and joint kinematics, while also accounting for an individual's sex and hip strength.

Results: Smaller pelvic angle and greater femoral anteversion, tibiofemoral angle, and navicular drop predicted greater hip internal-rotation excursion and knee external-rotation excursion. Decreased gluteus maximus activation predicted greater hip internal-rotation excursion but decreased knee valgus excursion. No LEA characteristic predicted gluteus medius or gluteus maximus muscle activation during the single-leg squat.

Conclusions: Static LEA, characterized by a more internally rotated hip and valgus knee alignment and less gluteus maximus activation, was related to commonly observed components of functional valgus collapse during the single-leg squat. This exploratory analysis suggests that LEA does not influence hip muscle activation in controlling joint motion during a single-leg squat.

Key Words: knee injuries, anterior cruciate ligament, risk factors, posture, malalignment

Key Points

- Static lower extremity alignment characteristics and hip muscle activation were directly related to commonly observed components of functional valgus collapse during the single-leg squat.
- However, relationships between static lower extremity alignment and hip muscle activation were not observed.
- Static lower extremity alignment may not influence hip muscle activation in controlling joint motion during a single-leg squat.

Multiple factors contribute to the increased risk of noncontact anterior cruciate ligament (ACL) injury. In fact, a recent consensus statement[1] has highlighted the need for a more integrated approach across risk-factor categories (eg, anatomical, neuromuscular, and biomechanical). A more comprehensive approach to risk-factor assessment may allow clinicians to accurately identify and understand those relevant risk factors that may contribute to "at-risk" knee positions during dynamic activity.

Among the many risk factors suggested to contribute to ACL injury, neuromuscular function (strength and activation) of the hip musculature has received increased attention because it is essential to providing proximal stability for lower extremity motion.[2,3] Neuromuscular deficits may compromise the stability of the hip when it is loaded during weight bearing, resulting in faulty dynamic alignment of the lower extremity and potentially increasing the risk of injury. Authors[4–10] of retrospective studies have reported decreased strength and activation of the hip abductors in those with low back pain and lower extremity injuries; however, prospective investigations of the relationship between hip muscle function and lower extremity injury are limited. Only one group[11] prospectively examined the relationship between hip strength and lower extremity injury in collegiate basketball and track athletes; those who were injured over the course of the season had less hip abduction and hip extension strength than the uninjured athletes. The authors[11] suggested that the decreased strength of the hip musculature reduced the ability to stabilize the hip, resulting in adduction and rotation of the lower extremity and, thus, faulty alignment, which contributed to lower extremity injury. This faulty dynamic alignment, commonly termed "functional valgus collapse"[12,13] and characterized by adduction and internal rotation of the hip and knee valgus, predicts ACL-injury risk.[14] Whether a relationship exists between decreased neuromuscular hip muscle function and increased functional valgus collapse is currently unknown.

In addition, static lower extremity alignment (LEA) has been proposed as an independent, intrinsic risk factor for ACL injury.[12,15–18] Authors[19–22] of retrospective studies have reported greater pronation, pelvic angle, and genu recurvatum in ACL-injured individuals. These and other LEA characteristics that increase static hip and knee angles may predispose individuals to increased inward collapse of the knee during dynamic activities.

The limitation of previous examinations of the relationship between anatomical alignment and neuromuscular function of the hip musculature is that only one LEA characteristic or select LEA characteristics were examined. No published studies have addressed the relationship among LEA, neuromuscular function of the hip, and dynamic hip and knee motion using a collective set of anatomic alignment variables that are sufficiently descriptive of lower extremity posture. This relationship may be important because one skeletal malalignment may cause compensatory alignment changes at other bony segments, resulting in abnormal stress patterns or compensatory motions along the kinetic chain.

Given the potential link between decreased neuromuscular function of the hip musculature and increased functional valgus collapse, injury-prevention programs have been developed to target the hip musculature.[23] However, the underlying causes for this neuromuscular dysfunction of the hip musculature have received little attention. Differences in LEA may alter neuromuscular function of the hip muscles and contribute to functional valgus collapse. This premise is based on research showing that changes in the length, tension, and orientation of the hip musculature directly influence the internal-moment arms of the muscle, resulting in changes in hip muscle functions.[24–26]

Few authors have examined the direct influence of LEA on hip muscle function, but differences in LEA may be related to changes in the force and activation of the hip musculature. Using a simulated hip model, an increase in gluteus medius (G_{med}) force was necessary to maintain a level pelvis when the femur was positioned in a more internally rotated position (a position associated with femoral anteversion) compared with neutral alignment.[27] Further, decreased activation of the G_{med} as measured by surface electromyography (sEMG) amplitude was demonstrated in those with increased relative femoral anteversion during isometric strength testing.[28] Collectively, these findings indicate that individuals with increased femoral anteversion require increased force production to control the hip and pelvis, yet they demonstrate decreased activation; together, these factors may severely reduce frontal-plane and transverse-plane hip control during functional activities. Whether other alignment factors at the pelvis, knee, lower leg, and foot that promote a more inwardly rotated or adducted hip posture further compromise hip muscle function is unknown.

Although it is tenable that differences in LEA characteristics may change the position of the femur relative to the pelvis, thus potentially altering the length, tension, and orientation of the muscles and their ultimate torque-producing capabilities about a joint, these assumptions are based primarily on findings from a static model. Whether these relationships would hold in a dynamic and constantly changing joint during functional activities is unclear.

Therefore, we examined whether static LEA characteristics and hip muscle activation were related to hip and knee kinematics during a single-leg squat, while accounting for sex and hip strength. Based on retrospective evidence that ACL-injured individuals had greater magnitudes of static LEA[19–22] and the potential for alignment to influence the neuromuscular function of the lower extremity muscles,[27,28] we wanted to explore both the direct relationships of LEA and hip muscle activation on lower extremity kinematics and the potential for indirect relationships between LEA and lower extremity kinematics based on the association of LEA with hip muscle activation. Specifically, we hypothesized that (1) greater magnitudes of static alignment of the lower extremity and decreased hip muscle activation would directly predict greater functional valgus collapse (increased hip adduction and internal rotation, knee external rotation, and valgus excursion) during a single-leg squat and (2) indirect relationships would also occur such that greater magnitudes of static LEA would predict decreased G_{med} and gluteus maximus (G_{max}) activation (abduction and extension) and collectively predict greater functional valgus collapse.

METHODS

Thirty men (age = 23.9 ± 3.6 years, height = 178.5 ± 9.9 cm, mass = 82.0 ± 14.1 kg) and 30 women (age = 22.2 ± 2.6 years, height = 162.4 ± 6.3 cm, mass = 60.3 ± 8.1 kg) were recruited from the university and the surrounding community to participate in the study. Each volunteer provided informed consent as approved by the university's institutional review board. Participants had no history of surgery to either lower extremity and no previous hip joint or knee joint injury within the last 6 months. All measurements were taken on the dominant-stance limb (ie, the stance extremity when kicking a ball).

Alignment Measurements

We measured 6 alignment characteristics on the pelvis and lower extremity. These alignment characteristics were based on commonly identified variables suggested to influence dynamic motion and the risk of lower extremity injuries. All measurement procedures were performed by a single examiner who had previously established good to excellent test-retest reliability on all measures (intraclass correlation coefficient [ICC][2,3] ≥ 0.87),[23,29] using techniques that have been previously described in detail.[29–32] All standing measures were taken in a standardized stance, with the left and right feet spaced equal to the width between the left and right acromial processes and toes facing forward. The stance was achieved by instructing participants to march in place and then take a step forward. They were advised to look straight ahead during all standing measures, with weight evenly distributed over both feet. Pelvic angle was measured in a standing position using an inclinometer and represented the angle formed by a line from the anterior-superior iliac spine to the posterior-superior iliac spine relative to the horizontal plane.[33] Femoral anteversion was measured in a prone position using the Craig test.[34] Quadriceps angle was measured in a standing position and represented the angle formed by a line from the anterior-superior iliac spine to the patella center and a line from the patella center to the tibial tuberosity. Tibiofemoral angle was measured in a standing position and represented the angle formed by the anatomical axis of the femur and tibia in the frontal plane.[29] Genu recurvatum was measured in supine position with a bolster positioned under the distal tibia and represented the sagittal-plane alignment of the femur and tibia.[29] Navicular drop was measured in a standing position and represented the difference between the height of the navicular in subtalar joint neutral and a relaxed stance.[29] Each measure was repeated 3 times.

Electromyography Procedures

Surface electromyography signals of the G_{med} and G_{max} were obtained using a 16-channel Myopac telemetric system (Run Technologies Company, Mission Viejo, CA) with an amplification of 1 mV/V, frequency bandwidth of 10 to 1000 Hz, common mode rejection ratio of 90 dB minimum at 60 Hz, input resistance of 1 MΩ, and an internal sampling rate of 8 KHz. The sEMG signals were detected with 10-mm bipolar Ag-AgCl surface electrodes (Blue Sensor N-00-S; Ambu Products, Ølstykke, Denmark; diameter = 44.8 × 22 mm; skin contact size = 30 × 22 mm) with a center-to-center distance of 20 mm and the electrodes were positioned according to procedures described by Cram and Kasman.[35] Electrodes were placed on the G_{med} at a position one-third the distance from the greater trochanter to the iliac crest. Electrode placement on the G_{max} was midway between the greater trochanter and the first sacral vertebrae. The sEMG electrodes were oriented perpendicular to the length of the muscle fibers and placed over the midbelly. The reference electrode was secured to the medial aspect of the tibia. Before the electrodes were attached, we thoroughly cleaned all skin areas with isopropyl alcohol. Myoelectric data were acquired, stored, and analyzed using DataPac 2K2 laboratory application software (version 3.13; Run Technologies Company) during the maximal voluntary isometric contractions (MVICs) and the single-leg squat.

Strength Assessment

A dynamometer (model 3; Biodex Medical Systems, Inc, Shirley, NY) was used to record hip abduction and hip extension MVICs. Participants performed 3 trials of a 3-second MVIC for each muscle, with a 30-second rest period separating trials. We modified a technique described by Carcia et al[36] to measure hip abduction torque in weight bearing. Volunteers stood adjacent to the dynamometer, looking straight ahead, with the trunk erect, feet facing forward, and arms crossed over the chest. The dynamometer axis was aligned with the head of the femur, determined by the intersection of a medially directed horizontal line from the greater trochanter and a distally directed vertical line from the anterior-superior iliac spine.[37] The resistance arm of the dynamometer was positioned on the lateral side of the nonstance leg, with the distal edge of the pad approximately 5 cm proximal to the lateral joint line and the hip positioned in approximately 5° of abduction. Each participant performed the MVIC by abducting the hip while supporting his or her body weight on the dominant-stance limb and maintaining an erect posture. For assessment of hip extension torque, each individual performed hip extension in the supine position, with the hip flexed to 90° and the dynamometer axis aligned with the greater trochanter. The resistance arm was positioned on the posterior thigh just proximal to the knee joint line. Previous work in our laboratory using these identical MVIC measurement protocols demonstrated good to excellent day-to-day reliability of torque production for standing hip abduction (ICC[2,k] = 0.91, SEM = 0.03 N·m/kg) and hip extension (ICC[2,k] = 0.80, SEM = 0.46 N·m/kg).

Kinematic Analysis

Kinematic data for the pelvis, thigh, shank, and foot were sampled at 100 Hz using 6–degrees-of-freedom electromagnetic sensors (Ascension Technology Corporation, Burlington, VT) and Motion Monitor Software (Innovative Sports Training, Inc, Chicago, IL) during the single-leg squat. Electromagnetic position sensors were attached with double-sided tape and elastic wrap over the anterior midshaft of the third metatarsal, the midshaft of the medial tibia, and the lateral aspect of the midshaft of the femur of the dominant-stance limb. An additional sensor was secured on the sacrum. Digitization procedures were performed using the default selection with a segmental reference system defining body segments: the positive x-axis was defined as the posterior-to-anterior axis, the positive y-axis was defined as the distal-to-proximal longitudinal axis, and the positive z-axis was defined as the medial-to-lateral axis. An initial neutral position was established in a standardized stance with the left and right feet spaced equal to the width between the left and right acromion processes and the toes facing forward. The ankle and knee joint centers were estimated using the centroid method, whereby the ankle joint center was calculated as the midpoint between the digitized medial and lateral malleoli, and the knee joint center was calculated by the midpoint between the digitized medial and lateral femoral epicondyles. The hip joint center was determined by the Leardini et al[38] method.

The starting position for participants was feet shoulder-width apart, hips and knees extended, toes facing forward, equal weight on both feet, and thumbs lightly touching the iliac crests (Figure 1). A plywood board was positioned at a distance anterior to the knee while volunteers performed a double-leg squat to 60° of knee flexion based on real-time goniometer values. The plywood board was positioned to provide individuals with feedback indicating that they had reached 60° of knee flexion during each trial and while performing a double-leg squat to ensure proper placement of the board. They then performed a single-leg squat with instructions to squat straight down until they touched the board with the knee while looking straight ahead. A string was positioned perpendicular to the first toe at the level of the chest to monitor forward flexion of the trunk (Figure 2). Participants were instructed to maintain an upright position without flexing the trunk forward or to the side in order to limit the influence of trunk motion on the hip musculature. Although we recognize that this is a constrained task, the rationale for this standardized positioning was to account for a potential confounding factor that may have contributed to conflicting results in previous studies of hip muscle activation dur-

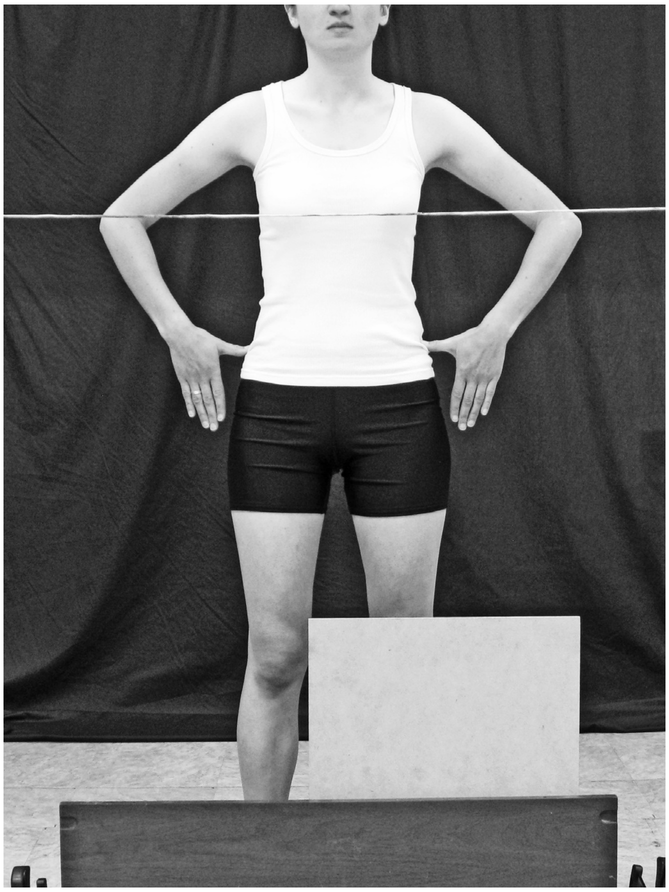

Figure 1. Starting position for the kinematic data collection with feet shoulder-width apart, hips and knees extended, toes facing forward, equal weight on both feet, and thumbs lightly touching the iliac crests.

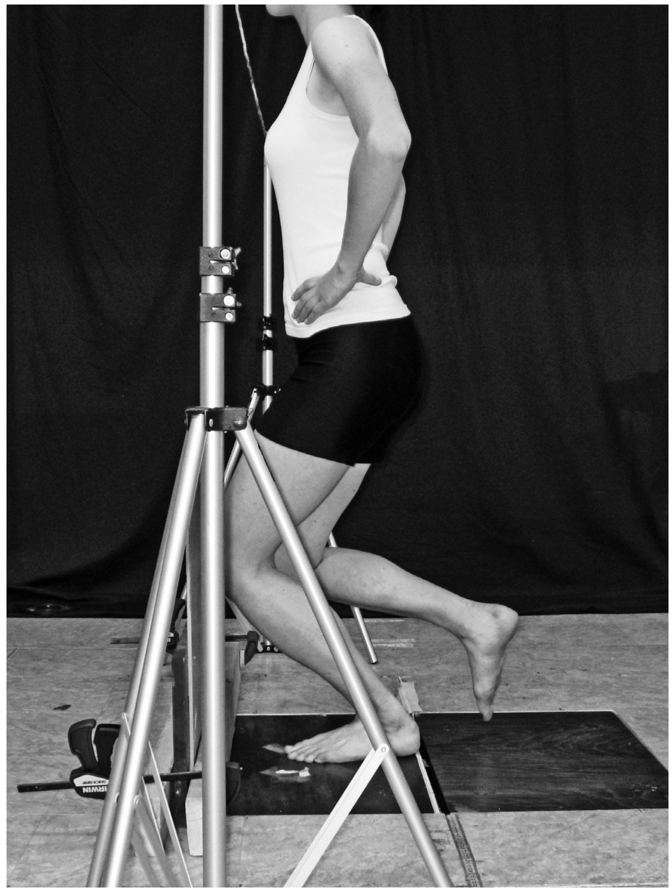

Figure 2. The single-leg squat was performed to 60° of knee flexion. A string was positioned perpendicular to the first toe at the level of the chest to monitor forward flexion of the trunk during the single-leg squat.

ing dynamic tasks.[39,40] Compared with men, women had greater G_{max} activation during a single-leg squat[39] but less activation during single-leg landings.[40] Small sample sizes and methodologic considerations in performing the tasks may explain these contrasting findings. Specifically, trunk motion, which has a direct influence on activation of the hip musculature, did not appear to be controlled in these studies.[41]

Each single-leg squat trial was initiated by a verbal command from the examiner and performed at a speed of 5 seconds from the starting position to 60° of knee flexion. The rate of the task was controlled by a metronome set at a cadence of 60 beats per minute. Participants transitioned from bilateral stance to single-leg stance during the first 2 beats with the nonstance knee and hip flexed approximately 45° and 0°, respectively. The squat then began on the third beat and ended at 60° of knee flexion on the fifth beat (total squat time = 2 seconds). A force plate marked the transition from double-leg stance to single-leg stance, and 60° of knee flexion marked the end of the trial. Volunteers were allowed sufficient practice to ensure that the task was performed properly, and data were then collected during 5 acceptable trials. A trial was deemed unacceptable if the individual (1) touched the string (indicating increased forward flexion of the trunk), (2) touched the nonstance leg to the ground or the stance leg, (3) lifted either hand off the iliac crest, or (4) failed to reach 60° of knee flexion as confirmed by real-time goniometry.

Data Reduction and Analyses

The average of 3 measurements for each LEA characteristic was used for analyses. Dynamometer torque data were recorded as the maximum peak torque obtained from 3 MVIC trials each for hip abduction and hip extension. Peak torque was then normalized to the participant's body mass and reported in newton-meters per kilogram of body mass. Kinematic signals from the position sensors were low-pass filtered at 12 Hz using a fourth-order, zero-lag Butterworth filter. Hip and knee angles were calculated using Euler angle definitions with a rotational sequence of Z X′ Y″.[42] Initial joint angles were calculated as the average joint positions during the first second after transition from double-leg to single-leg stance. Final joint angles were determined as the value when participants achieved 60° of knee flexion. Single-leg squat joint excursions were calculated as the difference (final minus initial) for each trial, and the average across 5 trials was used for statistical analysis.

The sEMG of the G_{med} and G_{max} during the MVIC and single-leg squat trials was filtered from 10 Hz to 350 Hz using a fourth-order, zero-lag Butterworth filter and then processed using a centered root mean square (RMS) algorithm with 100-millisecond time constant. The peak RMS value obtained over 3 MVIC trials for each muscle was used to normalize the sEMG data during the single-leg squat. The average RMS amplitude of the 5 single-leg squat trials across the entire trial (after transition to single-leg weight bearing to 60°) was then normalized to the individual's MVIC peak RMS value and reported as a percentage of the MVIC.

Structural equation modeling was used to evaluate whether increased LEA and decreased hip muscle activation (G_{med} and G_{max}, considered separately) predicted greater functional valgus collapse (characterized by increased hip adduction and internal rotation, knee external rotation, and valgus excursion) during a single-leg squat while accounting for the individual's sex and hip strength. Our rationale in accounting for these additional variables was that LEA characteristics[31] and hip strength[11,43–45] are known to differ by sex and that muscle-activation amplitude of the primary hip abductor (G_{med}) and hip extensor (G_{max}) muscles may, in part, depend on their absolute force-producing capabilities.[46] Hip abduction and hip extension strength were included only in the specific path models that examined the relationships of G_{med} and G_{max} activation, respectively, as they are the primary muscles that perform hip abduction and hip extension. The path diagram examining these relationships is illustrated in Figure 3.

Path analysis is an extension of multiple linear regressions with the purpose of modeling explanatory chained relationships between observed variables. It provides estimates of the magnitude and significance of hypothesized causal connections among sets of variables. Path analysis provides a statistical approach to understanding comparative strengths of direct and indirect relationships among a set of variables.[47] Because the total number of variables being estimated was greater than the total sample size (resulting in the variable estimates being highly unreliable), each full model was reduced to a more stable model by first removing the dependent measures that had no statistically significant paths (ie, variables that had no significant predictors), followed by removing the predictor variables that did not approach significance or were nonsignificant in explaining any of the remaining outcome measures (dependent variables). Statistical significance was determined by the *t*-value statistic, which reflects the ratio of the variable estimate to its standard error. A *t* value greater than +2 or less than −2 is considered statistically significant.[47] All path analyses were performed using LISREL (version 8.72; Scientific Software International, Inc, Lincolnwood, IL).

RESULTS

Measures of LEA, hip muscle activation, joint excursion during the single-leg squat, and hip torque are summarized in Table 1. The mean static alignment values are within the range of normal values reported in healthy adults using identical measurement methods.[29–31] Sex was related to LEA characteristics and hip muscle activation (all $P < .05$): women had greater pelvic angle ($t = 2.23$), femoral anteversion ($t = 4.60$), quadriceps

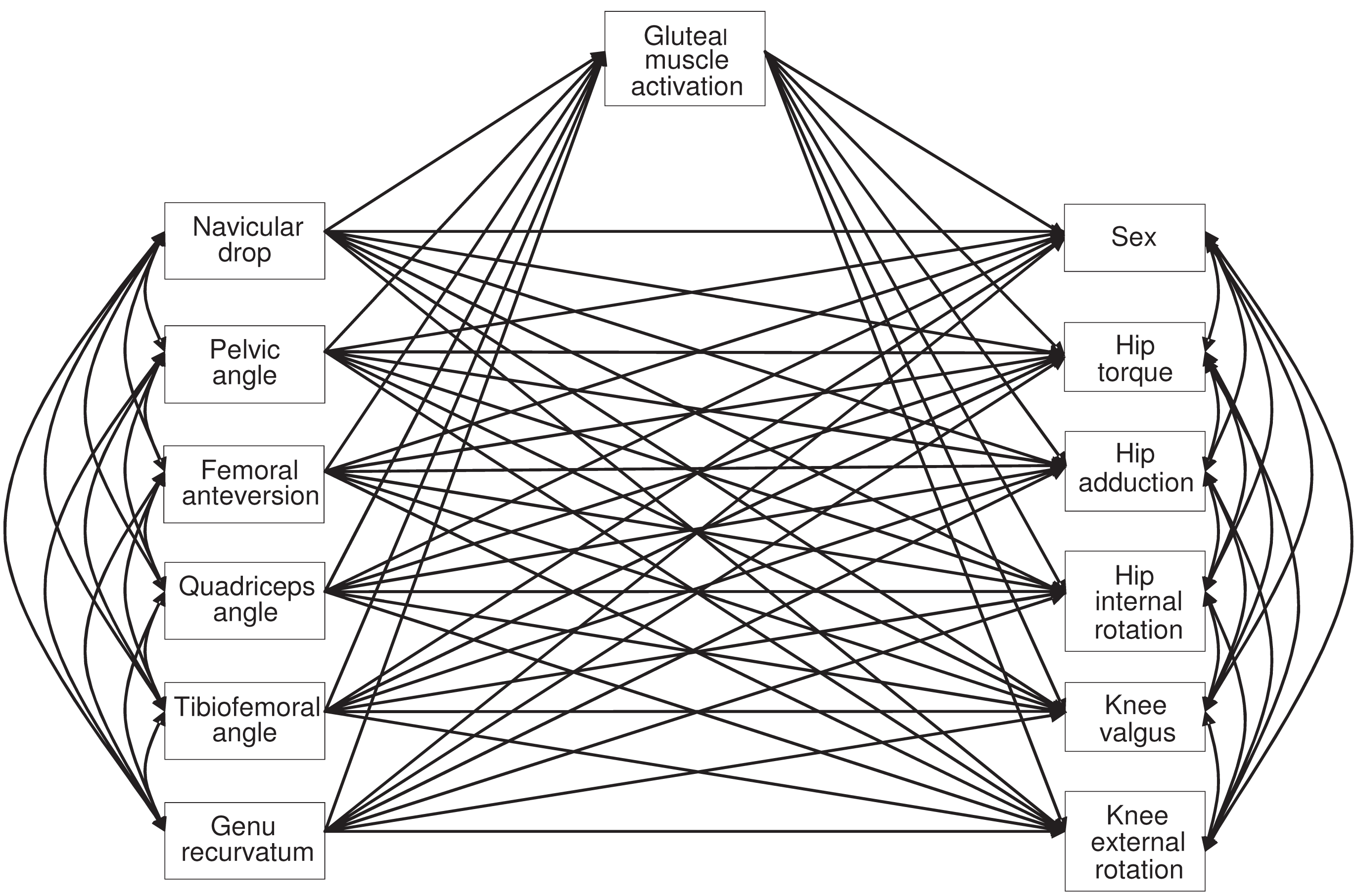

Figure 3. Full path model for the dependent variables gluteal muscle activation and functional valgus collapse.

Table 1. Descriptive Statistics for Dependent and Predictor Variables

Measure	Mean ± SD	Median	Range
Lower extremity alignment			
Pelvic angle, °	11.1 ± 4.6	11.0	0.0 to 21.0
Hip anteversion, °	10.7 ± 5.2	9.8	1.0 to 27.7
Quadriceps angle, °	12.9 ± 5.6	12.0	1.0 to 29.0
Tibiofemoral angle, °	10.7 ± 2.0	10.7	5.0 to 15.3
Genu recurvatum, °	3.8 ± 3.8	3.0	−1.3 to 14.3
Navicular drop, mm	6.6 ± 6.0	6.3	−4.0 to 25.7
Muscle activation, % maximum voluntary isometric contraction			
Gluteus medius	0.27 ± 0.13	0.23	0.11 to 0.72
Gluteus maximus	0.20 ± 0.19	0.14	0.03 to 1.04
Joint excursion, °			
Hip adduction	11.4 ± 10.4	12.0	−15.3 to 35.5
Hip internal rotation	−2.3 ± 5.9	−1.6	−16.4 to 12.8
Knee valgus	−0.1 ± 8.0	−0.4	−23.5 to 17.0
Knee external rotation	2.7 ± 6.1	2.2	−9.8 to 20.2
Hip strength, N·m/kg			
Hip-abduction torque	0.69 ± 0.19	0.66	0.37 to 1.33
Hip-extension torque	3.46 ± 1.05	3.43	1.87 to 5.80

angle ($t = 2.58$), tibiofemoral angle ($t = 3.09$), genu recurvatum ($t = 3.84$), and G_{max} activation ($t = 2.44$) than men. The inferential goodness-of-fit index indicated that both full models were a perfect fit ($\chi^2_0 = 0.00$, $P = 1.00$, RMS error of approximation = 0.00) because the model was saturated with 0 degrees of freedom.

Relationship Among LEA, G_{med} Activation, and Joint Excursion

The full model used to examine the extent to which LEA characteristics predicted G_{med} activation and the variables' collective influence on dynamic alignment during a single-leg squat while accounting for sex and hip abduction torque was reduced to a more stable model (Figure 4). The variables that remained in the model were the dependent variables of hip internal-rotation and knee external-rotation excursions and the predictor variables of pelvic angle, femoral anteversion, tibiofemoral angle, and navicular drop. The coefficients, standard errors of the coefficients, and *t* statistics for paths P_1–P_{15} that represent the relationships among the remaining variables are shown in Table 2.

The model explained 17% of the variance in hip internal-rotation excursion and 24% of the variance in knee external-rotation excursion during the single-leg squat. Smaller pelvic angle (P_6) and greater navicular drop (P_5) predicted greater hip internal-rotation excursion, whereas smaller pelvic angle (P_{10}) and greater femoral anteversion (P_{11}) and tibiofemoral angle (P_{12}) predicted greater knee external-rotation excursion during the single-leg squat. The model did not identify any indirect (ie, "sequential" or "chained") relationships between LEA and G_{med} activation in predicting joint excursion during the single-leg squat.

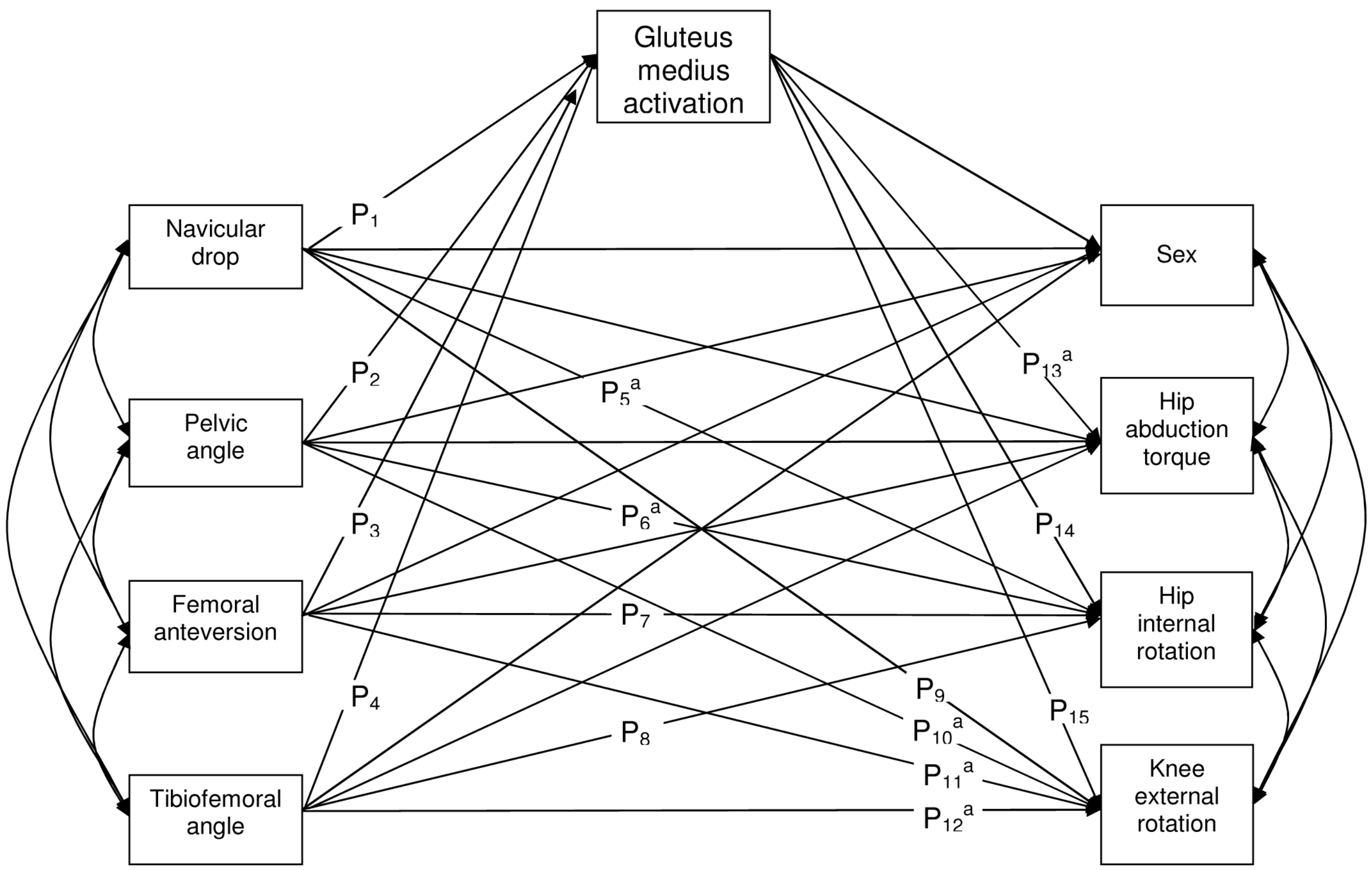

Figure 4. Final model for the dependent variables gluteus medius activation and dynamic valgus alignment. [a] Indicates significant path coefficient. See Table 2 for path coefficient values.

Relationship Among LEA, G_{max} Activation, and Joint Excursion

The full model used to examine the extent to which static LEA predicted G_{max} activation and the variables' collective influence on dynamic alignment during a single-leg squat while accounting for sex and hip extension torque was also reduced to a more stable model (Figure 5). The variables that remained in the model were the dependent variables of hip internal-rotation, knee valgus, and knee external-rotation excursion and the predictor variables of pelvic angle, femoral anteversion, tibiofemoral angle, and navicular drop. The coefficients, standard errors of the coefficients, and *t* statistics for paths P_1–P_{20} that represent the relationships among the remaining variables are shown in Table 3.

The model explained 27% of the variance in hip internal-rotation excursion, 17% of the variance in knee valgus excursion, and 20% of the variance in knee external-rotation excursion during the single-leg squat. Smaller pelvic angle (P_6) and greater femoral anteversion (P_7) and navicular drop (P_5) predicted greater hip internal-rotation excursion, whereas smaller pelvic angle (P_{14}) and greater femoral anteversion (P_{15}) and tibiofemoral angle (P_{16}) predicted greater knee external-rotation excursion during the single-leg squat. Decreased G_{max} activation predicted greater hip internal-rotation (P_{18}) and decreased knee valgus (P_{19}) excursion. Similar to the previous model, we did not identify any indirect relationships between LEA and G_{max} activation in predicting joint excursion during the single-leg squat.

DISCUSSION

The primary findings were that LEA characteristics were directly related to dynamic alignment during a single-leg squat, with greater femoral anteversion, tibiofemoral angle, and navicular drop predicting greater hip internal-rotation excursion and knee external-rotation excursion. Interestingly, greater pelvic angle predicted decreased hip and knee rotation. Direct relationships were also noted between gluteal activation and dynamic alignment, with decreased G_{max} activation predicting greater hip internal-rotation excursion but decreased knee valgus excursion. These results provide empirical support for previous theories that differences in static LEA and gluteal muscle activation contribute to greater hip joint and knee joint excursions during functional activities. However, no indirect (ie, sequential or chained) relationships were noted between LEA and gluteal activation in predicting dynamic motion: no LEA characteristic predicted G_{med} or G_{max} muscle activation during the single-leg squat once an individual's sex and muscle strength were accounted for.

Effects of LEA and Hip Muscle Activation on Lower Extremity Joint Excursion

Based on prevailing theories, greater static hip and knee alignment and decreased hip activation were hypothesized to predict greater frontal- and transverse-plane joint excursion during the single-leg squat. Specifically, individuals with more femoral anteversion and navicular drop went into more

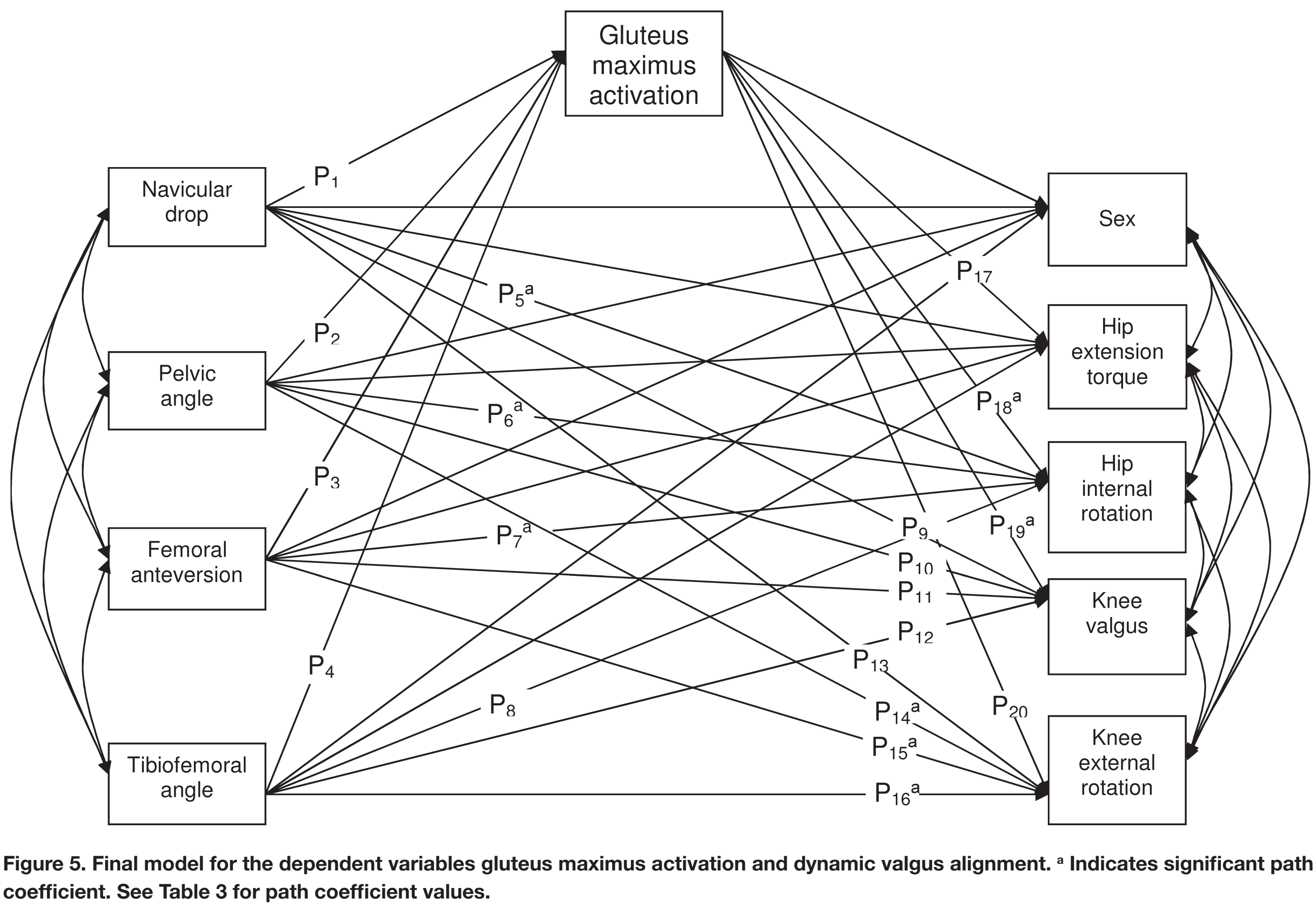

Figure 5. Final model for the dependent variables gluteus maximus activation and dynamic valgus alignment. [a] Indicates significant path coefficient. See Table 3 for path coefficient values.

Table 2. Path Coefficients of Lower Extremity Alignment Predicting Gluteus Medius Activation, Hip Internal Rotation, and Knee External Rotation

Lower Extremity Alignment	Gluteus Medius Activation				Hip Internal Rotation				Knee External Rotation			
	Path	Path Coefficient	Standard Error	*t* Value	Path	Path Coefficient	Standard Error	*t* Value	Path	Path Coefficient	Standard Error	*t* Value
Navicular drop	P_1	0.13	0.15	0.87	P_5	0.36	0.14	2.67[a]	P_9	0.17	0.13	1.33
Pelvic angle	P_2	−0.03	0.14	−0.21	P_6	−0.30	0.13	−2.29[a]	P_{10}	−0.29	0.13	−2.31[a]
Femoral anteversion	P_3	0.04	0.14	0.31	P_7	0.21	0.13	1.60	P_{11}	0.34	0.12	2.77[a]
Tibiofemoral angle	P_4	0.13	0.14	0.92	P_8	−0.03	0.13	−0.21	P_{12}	0.27	0.12	2.14[a]
Gluteus medius activation					P_{14}	−0.03	0.12	−0.20	P_{15}	0.21	0.12	1.73

[a] Significant path coefficient ($P < .05$).

Table 3. Path Coefficients of Lower Extremity Alignment Predicting Gluteus Maximus Activation, Hip Internal Rotation, Knee Valgus, and Knee External Rotation

Lower Extremity Alignment	Gluteus Medius Activation				Hip Internal Rotation				Knee Valgus				Knee External Rotation			
	Path	Path Coefficient	Standard Error	*t* Value	Path	Path Coefficient	Standard Error	*t* Value	Path	Path Coefficient	Standard Error	*t* Value	Path	Path Coefficient	Standard Error	*t* Value
Navicular drop	P_1	−0.03	0.14	−0.19	P_5	0.35	0.13	2.76[a]	P_9	0.09	0.14	0.68	P_{13}	0.20	0.13	1.50
Pelvic angle	P_2	0.14	0.14	1.01	P_6	−0.26	0.13	−2.04[a]	P_{10}	0.14	0.13	1.08	P_{14}	−0.30	0.13	−2.26[a]
Femoral anteversion	P_3	0.19	0.14	1.42	P_7	0.27	0.12	2.17[a]	P_{11}	0.03	0.13	0.19	P_{15}	0.36	0.13	2.74[a]
Tibiofemoral angle	P_4	0.04	0.14	0.31	P_8	−0.02	0.12	−0.14	P_{12}	0.13	0.13	1.04	P_{16}	0.29	0.13	2.32[a]
Gluteus maximus activation					P_{18}	−0.32	0.12	−2.70[a]	P_{19}	0.31	0.13	2.41[a]	P_{20}	−0.01	0.13	−0.10

[a] Significant path coefficient ($P < .05$).

hip internal-rotation excursion and individuals with greater tibiofemoral angle and femoral anteversion went into greater knee external-rotation excursion, with both motions considered important components of functional valgus collapse.[12] The direct relationship between greater femoral anteversion and greater rotation of both the hip and knee during dynamic motion seems logical given that more femoral anteversion has previously been associated with hip internal rotation and contributes to a compensatory increase in knee external rotation.[48] These observed relationships suggest that static LEA characteristics may directly influence dynamic hip and knee angles during functional activities and may offer a potential mechanism by which greater navicular drop and static knee valgus angles were associated with ACL injury.[19–22] An explanation for greater pelvic angle predicting decreased hip internal-rotation and knee external-rotation excursion is unclear. Based on retrospective evidence[21] that suggests a relationship between greater anterior pelvic angle and ACL injury, our expectation was that more anterior pelvic tilt would be related to more dynamic joint excursion. Additional work is needed to better understand the interaction between the pelvis and the femur and its influence on dynamic alignment and ACL injury.

The hypothesized relationship between hip muscle activation and functional valgus collapse was partially supported. Decreased G_{max} activation predicted greater hip internal-rotation excursion. Although we found no studies that directly examined the relationship between hip muscle activation and joint motion in healthy individuals, this observed relationship does support current theories that decreased hip muscle activation may affect dynamic stability of the hip, resulting in an inability to maintain neutral alignment during single-limb weight-bearing activities.[39,49–51] However, the positive relationship of greater G_{max} activation predicting greater knee valgus excursion is the opposite of what we expected. An explanation of this positive relationship is unclear, but it may be that hip activation strategies are different when controlling motions at the hip compared with motions at the knee. Dynamic knee valgus observed during functional tasks may reflect a combined motion of knee valgus and hip internal rotation, which would further suggest a positive relationship between G_{max} activation and these motions. However, further examination of our data indicated that hip internal rotation was negatively correlated with knee valgus excursion ($r = -0.370$, $P = .004$). This observed relationship between hip joint and knee joint motion may be specific to a single-leg squat task, and, therefore, further studies are needed to determine whether the observed relationships between hip muscle activation and lower extremity kinematics are consistent across functional tasks.

Although we observed direct relationships between LEA and joint excursion, it is unclear from these data alone if static LEA directly predisposes individuals to the rotational hip and knee components of functional valgus collapse or whether these postural effects act through resulting biomechanical changes (ie, decreased hip muscle activation) to increase dynamic hip and knee malalignments. The use of a path analysis model was a novel approach toward examining multiple risk factors, which allowed us to examine the indirect relationships between LEA and functional valgus collapse by way of their effects on hip muscle activation. We hypothesized that static malalignments would directly predict decreased hip muscle activation, which would further predict increased joint excursion.

However, this sequential or chained relationship was not observed: no static LEA characteristic was related to dynamic hip muscle activation. Relationships between LEA and hip muscle function have been observed using static models, but our results do not support this relationship during dynamic activities when joint position is constantly changing. These findings suggest that static LEA alone may predispose individuals to greater hip and knee rotations during dynamic activity, independent of G_{max} or G_{med} activation during dynamic tasks.

Accounting for Sex and Hip Muscle Strength

We chose to account for sex in the path-analysis models because many of the LEA characteristics[31] and hip muscle-activation measures[39,40] we examined are known to differ by sex. By accounting for sex in the model, we confirmed that sex was related to LEA characteristics and hip muscle activation such that women had greater pelvic angle, femoral anteversion, quadriceps angle, tibiofemoral angle, genu recurvatum, and G_{max} activation than men. These sex differences in LEA characteristics and hip muscle activation may in part explain why females demonstrate greater dynamic knee angles and an increased risk of ACL injury. Future authors should examine males and females separately because the relationships between many of the postulated risk factors and ACL injury may not be the same for each sex.

The purpose of accounting for hip abduction and hip extension strength in the path analyses was to better clarify the relationship between hip muscle activation and functional valgus collapse by taking into consideration variations in the levels of hip strength among participants, which may itself explain differences in functional valgus collapse. Although authors have examined activation of the hip musculature during functional activities such as single-leg landings and single-leg squats, either kinematic data were not collected[40] or hip strength was not reported.[39,40] Based on these studies, the relationship between posterior-lateral hip muscle function and dynamic joint motion remains unclear. In theory, greater hip muscle activation would be necessary to successfully perform a desired motion in the presence of reduced hip muscle strength. The negative relationships we observed between hip abduction torque and G_{med} activation ($r = -0.275$, $P = .034$) and between hip extension torque and G_{max} activation ($r = -0.612$, $P < .001$) confirm that greater posterior-lateral hip muscle activation was required in those individuals with decreased hip strength to successfully perform the single-leg squat. This inverse relationship between hip muscle strength and activation suggests that relative increases in gluteal muscle activation may or may not, by themselves, indicate better hip control, depending on the actual torque-producing capabilities of the muscles.

Limitations

We acknowledge that measurement of femoral anteversion using clinical methods has the potential for inconsistencies, with a range of reliabilities and validities of this measure reported in the literature. The measurement technique we used was based on original work by Ruwe et al,[34] who reported good reliability between testers and high correlations with intraoperative measurements. Consistent with other authors who have reported high intratester[29,52] and intertester reliability,[52] the tester in this study had more than 10 years of clinical experience and had established a high level of reliability on this measure.

However, a recent group[53] has since reported that clinical measurements of femoral anteversion were underestimates compared with values obtained via magnetic resonance imaging, questioning the validity of the Craig test in assessing femoral anteversion. Our observed relationships between femoral anteversion and dynamic alignment, which were consistent with our hypotheses, indicate that the clinical measurement of femoral anteversion represents some anatomical aspect of hip rotation and remains an important factor to consider when examining risk of ACL injury. Further work is needed to identify the underlying characteristics being assessed using the clinical measurement method.

Aside from femoral anteversion, all primary variables were assessed while the participants were weight bearing in an effort to better represent a functional position. However, hip extension torque was measured nonweight bearing, and more work is required to confirm if relationships between strength and G_{max} activation would remain consistent if both were assessed in a more functional position. Our findings are limited to the dominant-stance limb of healthy, college-aged adults and should not be generalized to other populations. Further, these findings are limited to a controlled, functional single-leg squat task performed in an upright position. Although we felt it was important to control the influence of various trunk positions on hip muscle activation[41] that might have contributed to inconsistent findings from previous studies,[39,40] we acknowledge that this upright position may not be fully representative of more unconstrained dynamic tasks potentially associated with ACL injury.

CONCLUSIONS

A more integrated approach to risk-factor assessment is needed to accurately identify and understand those relevant risk factors that may contribute to at-risk knee positions during dynamic activity. The overall findings of this study revealed that LEA characteristics clinically associated with static malalignment and hip muscle activation were directly related to commonly observed components of functional valgus collapse during the single-leg squat. However, this exploratory analysis did not identify any indirect relationships between LEA and G_{max} activation in predicting joint excursion and suggests that LEA does not influence hip muscle activation in controlling joint motion during a single-leg squat. Future researchers should continue to examine the other factors that influence hip muscle activation and the mechanisms that explain the relationships between static and dynamic malalignments.

Although the identified relationships were statistically significant, the associated path coefficients were somewhat low, which indicates that other factors could combine with LEA and hip muscle activation to further affect dynamic motion. Future investigators should confirm whether the relationship among LEA, hip muscle activation, and dynamic malalignment is consistent across a variety of functional tasks. In addition, continued examination of differences in LEA characteristics among both older and younger individuals is needed to determine whether these postures change with maturity. This research will aid clinicians in determining the most appropriate time to initiate posterior-lateral hip strengthening programs with the goal of reducing injury. Continued work in these areas will help clinicians more effectively identify those at greater risk for injury and, therefore, help us to develop intervention strategies to reduce the risk of noncontact ACL injury.

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original research

Differential Ability of Selected Postural-Control Measures in the Prediction of Chronic Ankle Instability Status

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Context: Chronic ankle instability (CAI) is a term used to identify a condition associated with recurrent ankle sprains and persistent symptoms. Balance deficits, evaluated using center-of-pressure (COP) force-plate measurements, have been shown to occur in people with CAI.

Objective: To determine the differential abilities of selected force-plate postural-control measures to assess CAI.

Design: Case-control study.

Setting: Laboratory.

Patients or Other Participants: A total of 63 individuals with CAI (30 men, 33 women: age = 22.3 ± 3.7 years, height = 169.8 ± 9.6 cm, mass = 70.7 ± 14.3 kg) and 46 healthy controls (22 men, 24 women: age = 21.2 ± 4.1 years, height = 173.3 ± 9.2 cm, mass = 69.2 ± 13.2 kg) volunteered.

Intervention(s): Participants performed 3 10-second trials of quiet, single-limb stance on a force plate under 2 conditions: eyes open and eyes closed.

Main Outcome Measure(s): Measures of COP area, COP velocity, COP SD, COP range of excursion, percentage of COP range used, time-to-boundary absolute minimum, time-to-boundary mean of the minima, and time-to-boundary SD of the minima were calculated. All measures with the exception of COP area were calculated in both the mediolateral (ML) and anteroposterior directions. For each measure, a receiver operator curve analysis was created, and the corresponding area under the curve was tested. The optimal diagnostic threshold value for each measure was determined, and the corresponding positive and negative likelihood ratios were calculated.

Results: Three eyes-closed, single-limb force-plate measures (COP ML SD, ML percentage of COP range used, and time-to-boundary absolute minimum) predicted CAI status. However, all 3 measures had positive likelihood ratios associated with only small shifts in the probability of a patient with a positive test having CAI and negative likelihood ratios associated with very small shifts in the probability of a patient with a negative test not having CAI.

Conclusions: No single force-plate measure was very effective in predicting if an individual had CAI or not.

Key Words: balance, force plate, time to boundary

Key Points

- Selected single-limb, eyes-closed force-plate measures predicted chronic ankle instability status: SD of mediolateral center of pressure, percentage of mediolateral center-of-pressure excursion, and time-to-boundary mediolateral minimum. However, none of the likelihood ratios were clinically meaningful.
- Single-limb, quiet-standing force-plate measures of postural control may be more useful for tracking outcome measures in patients with chronic ankle instability than they are for serving as diagnostic tools.

Chronic ankle instability (CAI) is a clinical condition associated with recurrent ankle sprains and persistent symptoms, such as feelings of "giving way," and can cause significant ankle pain, loss of function, and limitation of movement.[1–3] In previous research,[4–6] notable differences in single-leg static balance have been shown between those with and without CAI, but conflicting findings abound. Differences in results may be attributed to the variety of static balance measurements used as well as variations in the definition of CAI.

More than 30 different force-plate measurements have been used to evaluate postural-control deficits related to ankle sprain and CAI.[4,7,8] Hertel and Olmsted-Kramer[7] evaluated postural control in single-leg stance in participants with and without CAI using traditional center-of-pressure (COP) measures, such as mean COP velocity, SD, range, and percentage of range used, and more novel time-to-boundary (TTB) measures, such as the absolute minimum (smallest of the minima), mean of minimum samples, and SD of the minimum samples. All measures were calculated in the mediolateral (ML) and anteroposterior (AP) directions. The CAI group had lower scores for 5 of the 6 TTB measures. Conversely, using traditional force-plate measures, only AP COP velocity was different between the CAI group and the control group. The authors[7] concluded that because the TTB measures showed more differences than the traditional measures, the TTB measures might be better able to detect more subtle postural-control deficits associated with CAI. Briefly, the TTB measures are boundary-relevant measures of postural control that assess only the data points at which a volunteer is closest in time to losing his or her balance unless a postural correction is made, whereas the traditional measures are composites that assess all data points in a trial equally.

Currently the reference standard for determining if a person has CAI is based on subjective information, such as injury history questionnaires and subjective reporting of repetitive sprains and bouts of feelings of "giving way."[9] Because no single definition is considered the "gold standard" for CAI, it can be very difficult to compare results among different studies. Researchers currently use different subjective questions to classify patients, which can introduce biases into the study. Recall bias and individual interpretation of questions can potentially incorrectly include or exclude participants. Although researchers have identified group differences in various postural-control measures between CAI and healthy control groups, we are unaware of any investigators who have sought to determine if deficits on a specific force-plate measure of postural control can predict whether or not an individual has CAI. If a single force-plate measurement can objectively determine CAI status, we could be less reliant on subjective information for determining CAI status and, thus, be better able to identify patients with CAI for future studies. Therefore, the purpose of our study was to identify the best force-plate measure of postural control in single-limb stance to predict CAI status.

METHODS

A case-control study was selected to compare force-plate measures of postural-control performance in single-limb stance in participants with or without CAI. Receiver operator curve (ROC) analysis was used to identify which postural-control measure was best at predicting CAI status.

Participants

A total of 63 individuals with CAI (30 men, 33 women: age = 22.3 ± 3.7 years, height = 169.8 ± 9.6 cm, mass = 70.7 ± 14.3 kg) and 46 healthy controls (22 men, 24 women: age = 21.2 ± 4.1 years, height = 173.3 ± 9.2 cm, mass = 69.2 ± 13.2 kg) volunteered. Some data from these participants have been previously reported,[7,10,11] but the data compiled for this study underwent novel analysis. All volunteers were physically active young adults who participated in some form of physical activity for at least 20 minutes per day, 3 days per week. Inclusion criteria for the CAI group were a history of more than 1 ankle sprain, with the original injury occurring at least 12 months prior, and residual symptoms, as quantified by 4 or more *yes* responses on the Ankle Instability Instrument.[12] Additionally, participants had to have self-reported symptoms of disability due to ankle sprains of 90% or less on the Foot and Ankle Disability Index (FADI) and FADI Sport surveys (FADI = 85.56 ± 8.13, FADI Sport = 44.53 ± 25.44).[13] Volunteers were excluded if they had sustained a lower extremity injury, including ankle sprain, within the past 6 weeks or had a history of lower extremity surgery, balance disorder, neuropathy, diabetes, or other conditions known to affect balance. If a participant with CAI reported bilateral ankle instability, the self-reported worst limb was used for analysis. Control participants had no history of ankle sprain in either limb (FADI = 100 ± 0, FADI Sport = 100 ± 0). Limbs chosen for analysis of the control group were randomly matched with the injured limbs of the CAI group based on the involved left and right percentages. The study was approved by the university's institutional review board, and all volunteers signed an informed consent form before data collection.

Instruments

Postural control was assessed with the AccuSway Plus force plate (Advanced Mechanical Technology, Inc, Watertown, MA). Three-dimensional force and moment signals arising from the foot–force-plate interface were filtered using a fourth-order, low zero lag, low-pass filter with a cutoff frequency of 5 Hz. The COP was calculated from the force and moment signals through Balance Clinic software (Advanced Medical Technology, Inc) and sampled at a rate of 50 Hz.

Testing Procedures

Participants performed 3 trials of barefoot, quiet, single-limb stance on each leg, with eyes open and then with eyes closed, on the force plate for 10 seconds each. They were instructed to stand as still as possible during testing, with arms folded across their chests, holding the opposite limb at approximately 45° of knee flexion and 30° of hip flexion, in accordance with a previously established protocol.[14] All individuals were given 1 practice trial in each condition to familiarize themselves with the task. If they touched down with the opposite limb, made contact with the stance limb, or were unable to maintain standing posture during the 10-second trial, the trial was terminated and repeated.

Data Processing

To calculate TTB measures, the foot was modeled as a rectangle to allow for separation of the AP and ML components of COP, as suggested by van Wegen et al.[15] The COP data files were processed using a custom MATLAB software program (The MathWorks, Inc, Natick, MA).[8] For each COP ML data point, the COP ML position and velocity (depicted with a subscript "i") were used to calculate TTBML. If the COP ML_i was moving medially, the distance between COP ML_i and the medial border of the foot was calculated. This distance was then divided by the corresponding velocity of COP ML_i to calculate the time it would take the COP ML_i to reach the medial border of the foot if it was to continue moving in the same direction with no acceleration or deceleration. If the COP ML_i was moving laterally, the distance between COP ML_i and the lateral border of the foot was calculated and divided by the corresponding velocity of COP ML_i. Thus, a time series of TTBML measures was generated. A time series of corresponding TTBAP measures was similarly generated by determining the time it would take COP AP_i to reach either the anterior or posterior boundary of the foot.[8]

A typical TTB series shows a sequence of peaks and valleys, with each valley representing an instant in time when the participant is close, in the time domain, to losing his or her balance if a postural correction is not made. We identified TTB measures at the valleys, or minima, in each trial. The valleys in the data may be viewed as points of potential postural instability, whereas the peaks represent points of postural stability. To identify these minima, derivatives of the TTB measures were computed using first-order finite difference equations. The first derivative values were used to identify minima and maxima, and the second derivative values were used to compute the minima. Because of problems associated with accurately calculating derivatives, the software performed a local search around the derivative-identified minima to precisely locate the minima.[8]

The traditional COP-based dependent variables included the mean velocity (total COP excursion length in centimeters divided by the time of the trial [10 seconds]), SD of COP excursions, COP area (95% confidence ellipse), range of COP excursions (distance between the minimum and maximum COP positions), and percentage of available range used (range divided by width or length of the foot, respectively) in the ML and AP directions.[7] The TTB dependent variables were the absolute minima, mean of the minima, and SD of the minima in the AP and ML directions.

Statistical Analysis

An ROC analysis was used to determine whether or not a measurement was useful for evaluation purposes. The ROC curve used the sensitivity and specificity values of the individual force-plate measurements to determine the diagnostic accuracy of the experimental test, in comparison with the reference standard, for diagnosing the condition of interest. Thus, for each dependent variable, sensitivity and specificity were calculated. The reference standard was CAI status, as determined by our subjective inclusion and exclusion criteria. An ROC curve was constructed for each dependent variable, plotting sensitivity versus 1 − specificity. The score with the combination of highest sensitivity and lowest 1 − specificity, determined to be the most "northwest" point on the ROC curve, was designated as the threshold value. Statistical significance of the predictive ability of the threshold value was assessed by area-under-the-curve (AUC) analysis. An AUC value of 1.0 indicates perfect accuracy of discriminating ankle groups, whereas a value less than or equal to 0.50 indicates poor predictive accuracy.[16] Significance was set at $P \leq .05$. For each measure, positive and negative likelihood ratios (LRs) were also calculated using the threshold values.

Table 1. Outcome Measures

Outcome Measure	Control Mean ± SD	CAI Mean ± SD
Center-of-pressure area, cm^2		
Eyes open	6.49 ± 2.83	6.69 ± 3.03
Eyes closed	25.20 ± 7.26	28.46 ± 10.66
Center-of-pressure mean velocity, m/s		
Mediolateral, eyes open	0.99 ± 0.28	1.01 ± 0.26
Anteroposterior, eyes open	0.81 ± 0.22	0.87 ± 0.26
Mediolateral, eyes closed	2.05 ± 0.41	2.21 ± 0.50
Anteroposterior, eyes closed	1.92 ± 0.58	2.08 ± 0.64
SD of center of pressure, cm^2		
Mediolateral, eyes open	0.19 ± 0.04	0.20 ± 0.04
Anteroposterior, eyes open	0.26 ± 0.06	0.28 ± 0.08
Mediolateral, eyes closed	0.42 ± 0.06	0.45 ± 0.08
Anteroposterior, eyes closed	0.48 ± 0.11	0.53 ± 0.13
Center-of-pressure range, cm		
Mediolateral, eyes open	0.91 ± 0.17	0.94 ± 0.18
Anteroposterior, eyes open	1.22 ± 0.28	1.30 ± 0.37
Mediolateral, eyes closed	1.67 ± 0.18	1.75 ± 0.27
Anteroposterior, eyes closed	2.41 ± 0.56	2.63 ± 0.68
Range of center of pressure used, %		
Mediolateral, eyes open	9.50 ± 1.76	10.09 ± 2.01
Anteroposterior, eyes open	4.85 ± 1.11	5.17 ± 1.50
Mediolateral, eyes closed	17.41 ± 1.88	18.74 ± 2.65
Anteroposterior, eyes closed	9.60 ± 2.16	10.50 ± 2.72
Time-to-boundary absolute minimum, s		
Mediolateral, eyes open	1.08 ± 0.27	1.10 ± 0.29
Anteroposterior, eyes open	3.67 ± 1.00	3.58 ± 1.17
Mediolateral, eyes closed	0.52 ± 0.09	0.49 ± 0.11
Anteroposterior, eyes closed	1.58 ± 0.51	1.46 ± 0.50
Time-to-boundary mean minimum, s		
Mediolateral, eyes open	4.02 ± 1.38	4.10 ± 1.31
Anteroposterior, eyes open	12.24 ± 3.59	12.26 ± 3.46
Mediolateral, eyes closed	1.97 ± 0.54	1.86 ± 0.51
Anteroposterior, eyes closed	5.35 ± 1.64	4.95 ± 1.40
SD of time-to-boundary minimum, s		
Mediolateral, eyes open	3.16 ± 1.68	3.08 ± 1.25
Anteroposterior, eyes open	7.76 ± 2.70	8.03 ± 2.50
Mediolateral, eyes closed	1.75 ± 0.68	1.70 ± 0.73
Anteroposterior, eyes closed	3.35 ± 1.19	3.08 ± 0.92

Abbreviation: CAI, chronic ankle instability.

RESULTS

Outcome measures for each group are reported in Table 1. The optimum threshold values, sensitivity, specificity, and LRs for each measure are shown in Table 2. Three measures were predictors of CAI status, based on the ROC analysis: (1) eyes-closed COP SD in the ML direction (Figure 1), (2) eyes-closed percentage of COP range used in the ML direction (Figure 2), and (3) eyes-closed TTB absolute minimum in the ML direction (Figure 3). None of the other measures had significant AUC results ($P > .05$).

DISCUSSION

Currently, CAI status is most often identified only through subjective measures such as injury history or self-reported symptoms on questionnaires. The purpose of our study was to identify objective force-plate measures that could categorize individuals as having CAI. Although differences were noted in the force-plate measures between the CAI and healthy groups, our most important finding was that no single force-plate measure of postural control in single-limb stance was effective in conclusively predicting whether an individual had CAI or not. This was evident from the highest positive LR of 2.67, a value that is considered to show only small and sometimes clinically important results in posttest probability that the target condition is present.[17]

All 3 of the significant measures (COP SD, percentage of COP range used, and TTB absolute minimum) were performed with eyes closed and represented ML excursions. This information in and of itself is valuable to clinicians because it shows a pattern of impaired postural control in the ML direction in the absence of vision in patients with CAI. Unfortunately, the positive LRs associated with these 3 measures ranged only from 2.19 to 2.67. A positive finding on a diagnostic test with a positive LR between 2 and 5 is thought to demonstrate a small shift in the probability of a patient having the target disorder and to only sometimes yield clinically important results. Additionally,

Table 2. Sensitivity, Specificity, and Likelihood Ratios

Variable	Cutoff Value	Sensitivity	Specificity	Positive Likelihood Ratio	Negative Likelihood Ratio	Area	*P* Value
Center-of-pressure area, cm^2							
Eyes open	5.55	0.63	0.50	1.26	0.74	0.52	0.76
Eyes closed	31.01	0.37	0.88	2.97	0.72	0.59	0.16
Center-of-pressure mean velocity, m/s							
Mediolateral, eyes open	0.97	0.54	0.57	1.24	0.81	0.52	0.68
Anteroposterior, eyes open	0.78	0.64	0.52	1.33	0.70	0.55	0.34
Mediolateral, eyes closed	2.23	0.46	0.78	2.12	0.69	0.60	0.09
Anteroposterior, eyes closed	2.00	0.56	0.63	1.50	0.70	0.57	0.23
SD of center of pressure, cm^2							
Mediolateral, eyes open	0.18	0.78	0.41	1.33	0.54	0.56	0.26
Anteroposterior, eyes open	0.23	0.78	0.37	1.23	0.60	0.57	0.23
Mediolateral, eyes closed[a]	**0.47**	**0.41**	**0.83**	**2.37**	**0.71**	**0.61**	**0.04**
Anteroposterior, eyes closed	0.56	0.43	0.83	2.47	0.69	0.60	0.07
Center-of-pressure range, cm							
Mediolateral, eyes open	0.86	0.67	0.48	1.28	0.70	0.56	0.31
Anteroposterior, eyes open	1.39	0.40	0.80	2.03	0.75	0.56	0.31
Mediolateral, eyes closed	1.91	0.24	0.96	5.53	0.80	0.58	0.18
Anteroposterior, eyes closed	2.75	0.40	0.83	2.28	0.73	0.59	0.11
Range of center of pressure used, %							
Mediolateral, eyes open	9.09	0.71	0.48	1.37	0.60	0.58	0.15
Anteroposterior, eyes open	5.72	0.35	0.83	2.01	0.79	0.55	0.38
Mediolateral, eyes closed[a]	**18.80**	**0.48**	**0.78**	**2.19**	**0.67**	**0.65**	**0.01**
Anteroposterior, eyes closed	10.69	0.48	0.74	1.82	0.71	0.60	0.09
Time-to-boundary absolute minimum, s							
Mediolateral, eyes open	0.91	0.32	0.80	1.62	0.85	0.50	0.95
Anteroposterior, eyes open	3.50	0.57	0.57	1.31	0.76	0.54	0.47
Mediolateral, eyes closed[a]	**0.46**	**0.52**	**0.80**	**2.67**	**0.59**	**0.63**	**0.03**
Anteroposterior, eyes closed	1.71	0.75	0.41	1.27	0.62	0.57	0.19
Time-to-boundary mean minimum, s							
Mediolateral, eyes open	4.12	0.62	0.43	1.09	0.88	0.48	0.77
Anteroposterior, eyes open	12.13	0.62	0.48	1.18	0.80	0.49	0.85
Mediolateral, eyes closed	1.49	0.32	0.87	2.38	0.79	0.56	0.31
Anteroposterior, eyes closed	5.45	0.67	0.51	1.36	0.65	0.57	0.20
SD of time-to-boundary minimum, s							
Mediolateral, eyes open	1.74	0.14	0.93	2.10	0.92	0.49	0.83
Anteroposterior, eyes open	8.29	0.68	0.46	1.25	0.70	0.47	0.61
Mediolateral, eyes closed	1.61	0.59	0.60	1.47	0.69	0.54	0.47
Anteroposterior, eyes closed	3.60	0.71	0.41	1.22	0.69	0.55	0.38

[a] Bold font indicates significance at the .05 level.

none of the measures we evaluated had clinically meaningful negative LRs (all were >0.5), and, therefore, no single measurement would be useful in ruling out CAI status.

Currently, several force-plate measurements have been shown[7,8] to detect group differences between participants previously screened as CAI and controls. However, the present study shows that those measures cannot be effectively used to determine CAI status as an individual diagnostic tool. Postural-control measures, such as those we evaluated, appear to be more effectively used as outcome measures to track changes in health status (rather than as diagnostic tools).[11]

The lack of significant results may reflect the possibility that people with CAI use a variety of compensatory mechanisms to maintain balance. We used quiet standing in single-limb stance, which is a relatively easy task for many otherwise-healthy individuals. The sensitivity of traditional COP postural-control measurements has been questioned when detecting deficits associated with CAI.[18] In a 2006 study,[9] TTB measures appeared to show the most sensitivity in demonstrating differences between groups with and without CAI. In order to determine compensations, more difficult postural tasks, such as time to stabilization,[4] should be considered because more demanding tasks may cause greater compensation. Alternately, combining force-plate measures with other evaluations, such as 3-dimensional kinematics of the entire lower quarter, may provide a more comprehensive assessment of balance performance. Such measures may allow us to group individuals by compensation patterns so that force-plate comparisons can be made. Classifying the degree of functional impairment may also reveal different compensation patterns.

Our study has a limitation in relation to spectrum bias because we only compared the balance performance in healthy and CAI participants. We did not compare the CAI individuals with those experiencing other foot and ankle conditions who may also present with balance deficits. Regardless of balance-performance measures, taking a thorough foot and ankle injury history should always remain a central component of the diagnosis of CAI.

In conclusion, measures of eyes-closed COP SD ML, percentage of COP ML range used, and TTB ML absolute mini-

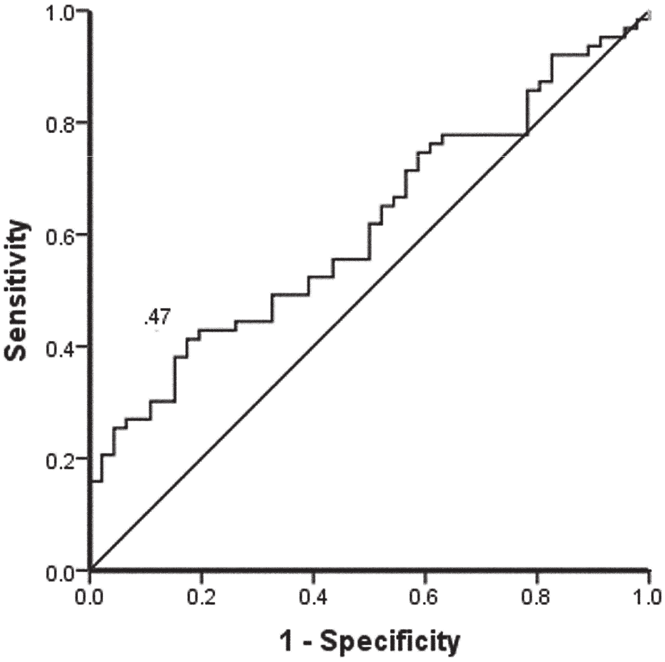

Figure 1. Receiver operating curve for the SD of center of pressure, mediolateral, eyes closed, injured foot. Sensitivity was 0.41, specificity was 0.83, and cutoff point was 0.47 cm^2. Positive likelihood ratio value was 2.37, and negative likelihood ratio was 0.71.

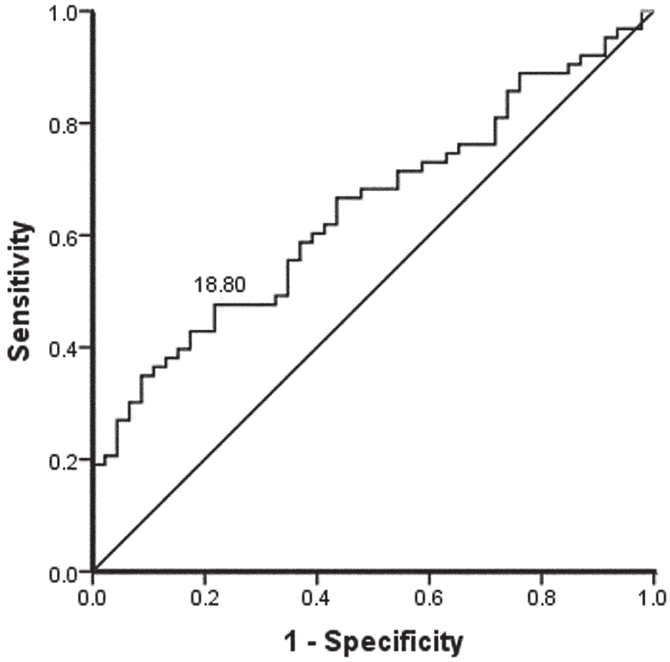

Figure 3. Receiver operating curve for the time-to-boundary minimum, mediolateral, eyes closed, injured foot. Sensitivity was 0.52, specificity was 0.80, and cutoff point was 0.46 seconds. Positive likelihood ratio was 2.67, and negative likelihood ratio was 0.59.

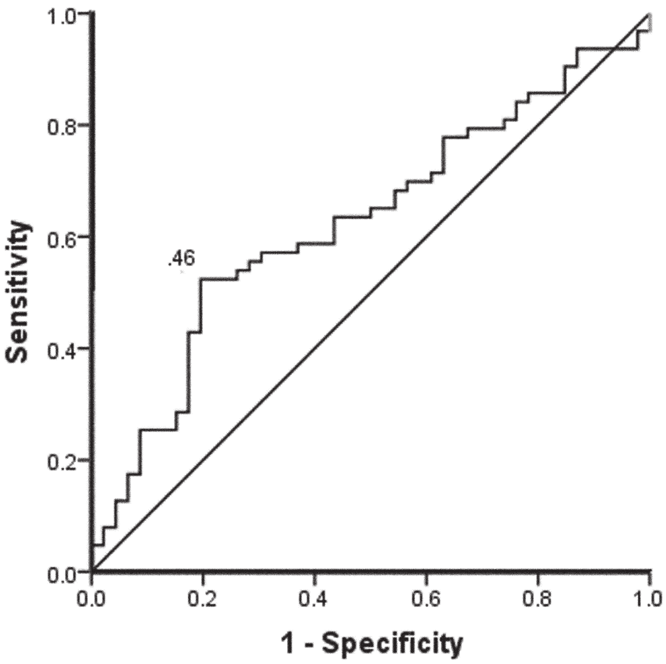

Figure 2. Receiver operating curve for the percentage of center-of-pressure range, mediolateral, eyes closed, injured foot. Sensitivity was 0.48, specificity was 0.78, and cutoff point was 18.80%. Positive likelihood ratio was 2.19, and negative likelihood ratio was 0.67.

mum predicted CAI status, but based on the LRs associated with these measures, we determined that no single force-plate measure was clinically valuable in predicting CAI status. With regard to CAI, force-plate measures of postural control in single-limb quiet standing may be more effective as a means of tracking outcome measures than as diagnostic tools.

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original research

Motor-Neuron Pool Excitability of the Lower Leg Muscles After Acute Lateral Ankle Sprain

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Context: Neuromuscular deficits in leg muscles that are associated with arthrogenic muscle inhibition have been reported in people with chronic ankle instability, yet whether these neuromuscular alterations are present in individuals with acute sprains is unknown.

Objective: To compare the effect of acute lateral ankle sprain on the motor-neuron pool excitability (MNPE) of injured leg muscles with that of uninjured contralateral leg muscles and the leg muscles of healthy controls.

Design: Case-control study.

Setting: Laboratory.

Patients or Other Participants: Ten individuals with acute ankle sprains (6 females, 4 males; age = 19.2 ± 3.8 years, height = 169.4 ± 8.5 cm, mass = 66.3 ± 11.6 kg) and 10 healthy individuals (6 females, 4 males; age = 20.6 ± 4.0 years, height = 169.9 ± 10.6 cm, mass = 66.3 ± 10.2 kg) participated.

Intervention(s): The independent variables were group (acute ankle sprain, healthy) and limb (injured, uninjured). Separate dependent *t* tests were used to determine differences in MNPE between legs.

Main Outcome Measure(s): The MNPE of the soleus, fibularis longus, and tibialis anterior was measured by the maximal Hoffmann reflex (H_{max}) and maximal muscle response (M_{max}) and was then normalized using the H_{max}:M_{max} ratio.

Results: The soleus MNPE in the ankle-sprain group was higher in the injured limb (H_{max}:M_{max} = 0.63; 95% confidence interval [CI], 0.46, 0.80) than in the uninjured limb (H_{max}:M_{max} = 0.47; 95% CI, 0.08, 0.93) (t_6 = 3.62, P = .01). In the acute ankle-sprain group, tibialis anterior MNPE tended to be lower in the injured ankle (H_{max}:M_{max} = 0.06; 95% CI, 0.01, 0.10) than in the uninjured ankle (H_{max}:M_{max} = 0.22; 95% CI, 0.09, 0.35), but this finding was not different (t_9 = −2.01, P = .07). No differences were detected between injured (0.22; 95% CI, 0.14, 0.29) and uninjured (0.25; 95% CI, 0.12, 0.38) ankles for the fibularis longus in the ankle-sprain group (t_9 = −0.739, P = .48). We found no side-to-side differences in any muscle among the healthy group.

Conclusions: Facilitated MNPE was present in the involved soleus muscle of patients with acute ankle sprains, but no differences were found in the fibularis longus or tibialis anterior muscles.

Key Words: arthrogenic muscle response, Hoffmann reflex, fibularis longus, soleus, tibialis anterior

Key Points

- Arthrogenic muscle response seemed to be present in the ipsilateral musculature of patients after acute lateral ankle sprains and manifested as a facilitation of the soleus and an inhibition of the tibialis anterior in between-legs scores.
- The maximal Hoffmann reflex to maximal muscle response ratio was greater in the soleus, was not different in the fibularis longus, and was smaller in the tibialis anterior musculature of the injured limbs of participants with acute ankle sprains compared with their contralateral uninjured limbs and compared with the injury-matched and contralateral limbs of healthy participants.

The ankle is the most commonly injured joint in the lower extremity.[1,2] A history of ankle sprain is the leading risk factor for recurrent ankle sprains.[3] Researchers[4] have reported that up to 30% of patients experiencing an initial ankle sprain develop chronic ankle instability. Chronic ankle instability is associated with increased risk of degenerative osteoarthritis[5] and decreased self-reported function.[6] Currently, the exact factors that contribute to pathogenesis of chronic ankle instability are unclear, yet investigators[7,8] have suggested that neuromuscular factors contribute to ankle instability by possibly disrupting the normal function of the muscles surrounding the injured joint. Understanding the neuromuscular response of the extrinsic ankle muscles to ankle joint injury might provide vital information that leads to improved treatment protocols.

Arthrogenic muscle inhibition is a consequence of joint injury often overlooked by clinicians and is defined as an ongoing reflex inhibition of the uninjured musculature surrounding an injured or distended joint,[9] which might contribute to the dysfunction reported after joint injury.[10] Although arthrogenic muscle inhibition has been hypothesized[11] to be a natural protective mechanism that decreases excessive forces acting on an injured joint, it is a limiting factor in rehabilitation.[9] It has been reported[7] in the soleus and fibularis longus muscles of functionally unstable ankles, whereas facilitated or increased neural excitability has been found[12] in lower leg muscles after an artificial effusion of ankle joints in healthy volunteers.

Altered motor-neuron pool excitability (MNPE) is a hallmark characteristic of the arthrogenic muscle response, which involves a decrease or increase in the number of motor neurons capable of responding to an excitatory stimulus within a given motor-neuron pool.[13,14] The Hoffmann reflex (H-reflex) is used to measure the excitability of α motor neurons located within a targeted motor-neuron pool.[14,15] In addition to the afferent and efferent pathways that contribute to the H-reflex, electric stimulation of the peripheral nerve evokes a purely efferent response along the α motor neuron in the muscle, which is known as the *muscle response* (M-response).[15] The M-response represents the maximal excitability of the motor-neuron pool as measured by the response of the muscle to the stimulated motor neurons.[14]

Although evidence supports the presence of increased reflex MNPE in the leg muscles after ankle-effusion models[12] and inhibited MNPE in participants with functionally unstable ankles,[7] limited evidence is available to confirm the motor-neuron pool response of the soleus, fibularis longus, or tibialis anterior muscle after acute ankle sprains.[16] It is important to determine if acutely sprained ankles exhibit differences in lower extremity MNPE when compared with uninjured contralateral ankles. If differences in MNPE are detected, this information might aid in the immediate treatment provided by athletic trainers.

Therefore, the primary purpose of our study was to determine the effect of acute lateral ankle sprains on MNPE of the soleus, fibularis longus, and tibialis anterior compared with the contralateral uninjured leg and with the legs of healthy participants. Investigating the confounding factors that might contribute to arthrogenic muscle inhibition after an acute ankle sprain also was important, so we secondarily examined the relationships among pain, effusion, and joint damage and alterations in MNPE because they are poorly understood.

METHODS

This case-control study had 2 independent variables: limb (injured, uninjured) and group (acute ankle sprain, healthy). The main outcome measure was MNPE in the soleus, fibularis longus, and tibialis anterior, as measured by normalizing the H-reflex to the M-response. Specifically, maximal H-reflexes (H_{max}) were normalized to maximal M-responses (M_{max}) and expressed as an H_{max}:M_{max} ratio. Subjective pain scores assessed using a visual analog scale, ankle-girth measurements, and self-reported function evaluated with the Foot and Ankle Ability Measure (FAAM)[17] were collected for each participant.

Participants

Twenty people volunteered for this study and were separated into 2 groups (Table 1). The experimental group consisted of patients with acute ankle sprains. The healthy group consisted of participants who were matched for age, sex, mass, height, and activity; who had no history of ankle injury or lower extremity fractures or surgery; and who were not seeking medical attention for any lower extremity injury. The inclusion criterion for the acute ankle-sprain group was operationally defined as all lateral ankle sprains occurring from 24 to 72 hours before the study. Participants were recruited from local public and private high schools, the university student and student-athlete populations, and the general population through referrals and advertisements. All individuals with ankle sprains were included, regardless of the severity of their injuries, and their injured ankles were evaluated by an athletic trainer using a standard ankle-injury evaluation form. The ankle-injury evaluation was used to grade the current condition of each participant's ankle injury. All volunteers were informed of the potential influence of cryotherapy and transcutaneous electric neuromuscular stimulation on MNPE and were instructed to discontinue treatment at least 6 hours before participation in the study. In addition, compression wraps and braces were removed 1 hour before testing. Potential participants with suspected syndesmotic ankle sprains or any previous diagnosis of associated lower extremity fracture, neurologic condition, or cancer were excluded from the study. A single certified athletic trainer (L.W.K.) used our laboratory's standardized grading form to indicate the severity of the ankle sprain, which is a recommended practice.[18] (Ankle sprains included 6 grade I and 4 grade II sprains.) The injury-matched ankle in the healthy group was side matched to his or her injured counterpart. Therefore, if the left ankle of the participant in the ankle-sprain group was sprained, the left ankle of the matched control participant in the healthy group was considered involved or injured. Before testing, written informed consent was obtained for all adults, and minor and parental consent were obtained for all minors (<18 years of age). The study was approved by the institutional review board of the University of Virginia.

Instrumentation

The H-reflex and M-response measurements were collected with disposable, 10-mm, pregelled Ag/AgCl surface electromyography (EMG) electrodes (BIOPAC Systems, Inc, Goleta, CA). The electrodes were positioned 1.75 mm apart over the muscle bellies of the soleus, fibularis longus, and tibialis anterior.[12] Analog-to-digital signal conversion was processed with a 16-bit converter (MP150; BIOPAC Systems, Inc). Acq*Knowl-*

Table 1. Participant Demographics (Mean [95% Confidence Interval])

Variable	Group: Acute Ankle Sprain	Group: Healthy
Participants, No.	10	10
Sex, No.		
Female	6	6
Male	4	4
Height, cm	169.4 (164, 174.7)	169.9 (163, 176.5)
Mass, kg	66.3 (59.1, 73.5)	66.3 (59.9, 72.6)
Body mass index	23.2 (21, 25.4)	22.8 (21.5, 24.1)
Age, y	19.2 (16.8, 21.6)	20.6 (18.1, 23.1)
Involved limb		
Right	4	NA
Left	6	NA

Abbreviation: NA, not applicable.

edge software (version 3.7.3; BIOPAC Systems, Inc) was used to visualize the signals and to manipulate the stimuli. The EMG signals were sampled at 2000 Hz, and EMG amplification was set at a gain of 1000 (EMG100C; BIOPAC Systems, Inc). The common-mode rejection ratio of our EMG amplifier was 100 dB, and the input impedance was 2 MΩ. Reflexes were elicited using the stimulator module (STM100A; BIOPAC Systems, Inc) interfaced with a 200-V maximum stimulus isolation adaptor (STMISOC; BIOPAC Systems, Inc); a 2-mm shield disk electrode (EL254S; BIOPAC Systems, Inc); and a 7-cm, carbon-impregnated dispersive pad.

Ankle Evaluation

A licensed certified athletic trainer (L.W.K.) performed an orthopaedic ankle evaluation on all participants. All ankle-sprain data for participants were collected between 24 hours and 72 hours after injury (mean = 50.6 ± 20.9 hours).

Two 100-mm visual analog scales were used to assess ankle pain. The first visual analog scale was used to assess the greatest amount of pain the participant felt in the 24 hours before the study, whereas the second visual analog scale evaluated the participant's current level of ankle pain. The visual analog scale measurements were collected with the participant seated after the standard ankle evaluation.

A flexible tape measure was used to assess ankle circumference for both the injured and uninjured ankles in the experimental group and for the injury-matched and healthy legs in the healthy group. The percentage change in circumference between the injured ankle and the uninjured ankle was used to determine the amount of ankle effusion. The figure-of-8 method was performed with the participant seated, the knee in complete extension, and the ankle in neutral position. The measurement was performed with the "zero" of the tape measure maintained in the middle point between the articular projection of the anterior tibial tendon and the lateral malleolus. The tape measure was guided to the center of the foot along the medial longitudinal arch on the navicular bone, to the lateral malleolus and calcaneal tendon, to the medial malleolus, and to the zero point of the tape measure. The average of 3 measurements was used for data analysis.[19] Effusion was determined by subtracting the girth of the uninjured leg from that of the injured leg.

The FAAM is used to quantify the impairment, activity limitations, and participation restrictions with regard to foot and ankle injury.[17] The form consists of 3 components: activities of daily living (21 items), FAAM sport scale (8 items), and single-assessment numeric evaluation scores for both the FAAM and the FAAM sport scale. These data were collected in all participants for injured and healthy matched legs.

MNPE Measurement

Participants were positioned prone on a table in a quiet, dimly lit room with their knees slightly flexed (15°) and their ankles supported on a foam roller (Figure). We used a commercial platform (Oakworks Inc, New Freedom, PA) to position the participant's head in a neutral position with his or her face down. Participants were instructed to relax and focus on a fixed object on the floor during testing. The recording sites over the soleus, tibialis anterior, and fibularis longus were shaved, debrided, and cleaned with isopropyl alcohol. In addition, a reference electrode was placed on the medial malleolus of the uninjured leg of the experimental participant and of the matched leg of the healthy participant. Two recording electrodes were positioned 1.75 mm apart over the soleus muscle belly 2 to 3 cm distal to the head of the medial gastrocnemius, over the fibularis longus 2 to 3 cm distal to the fibular head, and at the approximate midpoint of the tibialis anterior.[12] We used a strip of hypoallergenic tape to secure the simulating electrode over the superior popliteal fossa proximal to the bifurcation of the tibial and common fibular nerves. The dispersive electrode was positioned on the anterior thigh.

We used previously reported methods[7] to locate the optimal positioning for the stimulating electrode. The stimulating electrode was placed at the fibular head, and a 1-millisecond square-wave pulse with an intensity designed to elicit an M-response and H-reflex in the tibialis anterior and the peroneus longus was administered. The electrode was moved manually in a superomedial direction, periodically administering stimulation to the common fibular nerve. We continued to move the electrode until an M-response could be elicited in all 3 muscles, indicating that the stimulating electrode was over the sciatic nerve before its bifurcation.

A 1-millisecond square-wave stimulus was administered to the sciatic nerve at increasing intensities until H_{max} and M_{max} were found for all 3 muscles. Three H_{max} and M_{max} measurements were taken for each of the muscles. The procedure was performed on both legs. Peak-to-peak values for H_{max} and M_{max} were used to calculate the H_{max}:M_{max} ratio. The investigator (LW.K.) assessing MNPE was not blinded to the group or leg of the participant because placing the electrodes in the appropriate locations without noticing edema or ecchymosis from an injured ankle was nearly impossible.

The H_{max} and M_{max} were processed by a blinded, experienced, independent investigator (B.G.P.) who assessed peak-to-peak amplitudes of both the H_{max} and M_{max} measurements in all 3 muscles. When a peak was observed for both the H_{max} and M_{max}, 3 acceptable measurements were obtained and used for data analysis. During data analysis, waveforms were inspected visually, and any H_{max}:M_{max} ratios greater than 1.0 were removed from the data set and were not used for analysis because this measurement was not physiologically possible and likely represented extraneous measurement error. During this process, we excluded 3 soleus measurements from separate individuals in the ankle-sprain group and 2 soleus measurements from individuals in the healthy group. One fibularis longus measurement was excluded from an individual in the healthy group because tracings could not be interpreted.

Statistical Analysis

Sample size was estimated a priori using means and SDs from a previous study[7] in which the soleus H_{max}:M_{max} ratio was assessed in patients with chronic ankle instability and in healthy people (mean difference = 0.05, pooled SD = 0.2). If a weak effect size was present between legs (Cohen d = 0.36), 9 participants would be needed in both the injured and healthy groups to reach a difference with the α level set at .05 and a $1-\beta$ level of .80. Means and SDs were calculated for H_{max} and M_{max}. Two-tailed dependent-samples *t* tests were used to assess differences in H_{max}:M_{max} ratios between injured and uninjured legs in the acute ankle-sprain group and in H_{max}:M_{max} ratios between the injury-matched and healthy legs of the healthy participants for all 3 muscles. Side-to-side differences in the H_{max}:M_{max} ratios for all 3 muscles were calculated in the acute ankle-sprain group (injured versus uninjured ankles) and in the

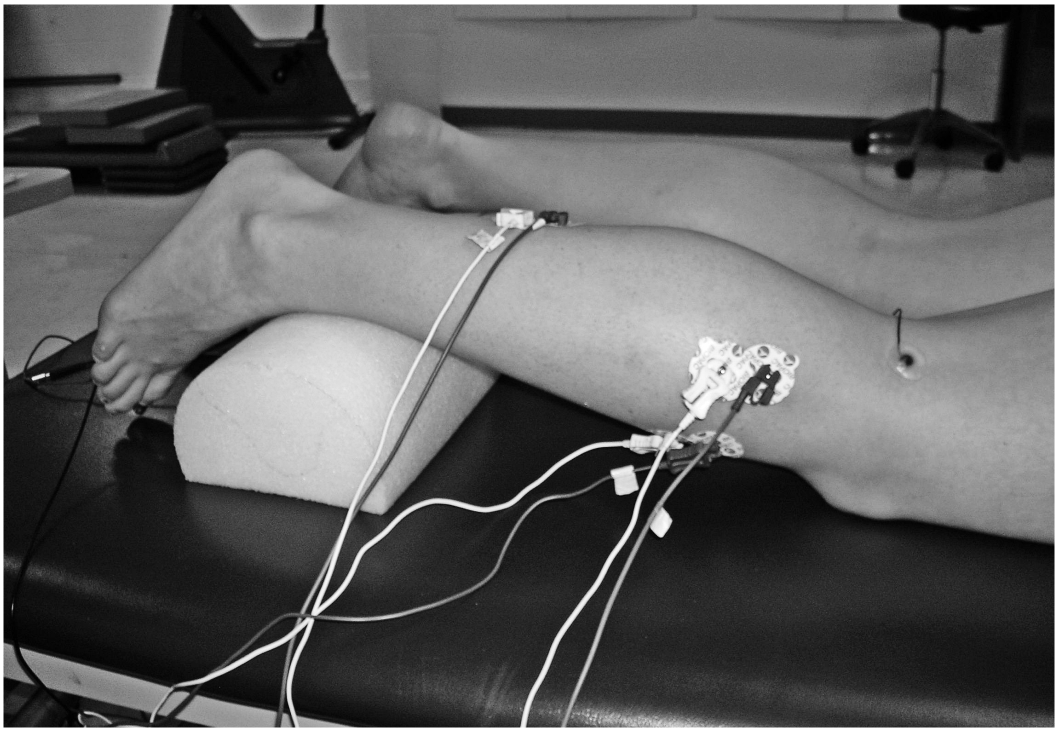

Figure. Placement of the surface electromyography electrodes. The participant was positioned prone with half of a foam roller supporting the dome of the talus in the involved leg. The surface electromyography was applied to standardized placement sites on the soleus, tibialis anterior, and fibularis longus muscles. The stimulating electrode was applied to the superior popliteal fossa proximal to the bifurcation of the tibial and common peroneal nerve, and the dispersive electrode was applied to the anterior quadriceps muscle superior to the patella.

healthy group (injury-matched versus contralateral ankle) by subtracting the injured leg score from the uninjured leg score. Three separate independent-samples *t* tests were used to assess the side-to-side difference scores in H_{max}:M_{max} ratios between the acute ankle-sprain group and the healthy group. In addition, Pearson product moment correlation coefficients were calculated and squared to determine the variance in effusion and pain that was explained by the variance in MNPE. Standardized effect sizes were calculated to assess magnitude of differences in between-legs H_{max}:M_{max} ratios between the acute ankle-sprain group and the healthy group. The effect sizes were calculated by subtracting the between-legs H_{max}:M_{max} ratios of the acute ankle-sprain group from those of the healthy group and dividing by the pooled SD. The strengths of the effect sizes were interpreted using the guidelines described by Cohen,[20] with values less than 0.5 interpreted as *weak*; values from 0.5 to 0.79 interpreted as *moderate*; and values greater than 0.8 interpreted as *strong*. The α level was set a priori at .05. All statistical analyses were performed using SPSS (version 16.0 for Windows; SPSS Inc, Chicago, IL).

RESULTS

MNPE Measurements in Acute Ankle Sprains

The descriptive measures for the MNPE results are shown in Table 2. The soleus H_{max}:M_{max} ratios in the acute ankle-sprain group were larger in the injured limb than in the uninjured limb (t_6 = 3.62, P = .01). No differences were detected for H_{max}:M_{max} ratios between the injured and uninjured ankles for the fibularis longus (t_9 = –0.738, P = .48) and tibialis anterior (t_9 = –2.07, P = .07) MNPE in the acute ankle-sprain group. A moderate effect was found between legs in the soleus (Cohen d = 0.69; 95% confidence interval [CI], –0.39, 1.76; t_{14} = 0.735, P = .01), indicating increased soleus MNPE in the ankle-sprain group. A strong effect size was found for the tibialis anterior (Cohen d = –1.01; 95% CI, –1.94, –0.08; t_{18} = –2.19, P = .04), with a negative sign indicating decreased MNPE in the acute ankle-sprain group. A weak effect size was found for the fibularis longus (Cohen d = –0.21; 95% CI, –1.09, 0.67; t_{14} = –0.38, P = .71), indicating a clinically irrelevant decrease in the fibularis longus MNPE of the individuals with acute ankle sprains compared with the healthy participants. The tibialis anterior was the only muscle with a 95% CI for effect size that did not cross zero, indicating a definitive effect in inhibition was present, but the width of all the CIs was large, indicating wide variability in the reflex measurements.

MNPE Measurements in Healthy Controls

No differences were found between legs for the H_{max}:M_{max} ratios of the soleus (t_7 = 0.693, P = .51), fibularis longus (t_8 = –0.235, P = .82), and tibialis anterior (t_9 = –0.729, P = .48) in the healthy group (Table 2).

MNPE Differences Between Groups

We found no differences when comparing the side-to-side differences in H_{max}:M_{max} ratios for the soleus between the ankle-injury (15.6; 95% CI, 7.2–24.1) and healthy (6.4; 95% CI,

Table 2. Maximal Hoffmann Reflex to Maximal Muscle Pooled Response Ratios Between Groups (Mean ± SD [95% Confidence Interval])

	Group			
	Acute Ankle Sprain		Injury Matched	
Muscle	Injured	Healthy	Uninjured	Healthy
Soleus	0.47 ± 0.24 (0.08–0.93)	0.63 ± 0.23 (0.46–0.80)[a]	0.58 ± 0.24 (0.42–0.76)	0.54 ± 0.25 (0.37–0.72)
Fibularis longus	0.25 ± 0.22 (0.12–0.38)	0.22 ± 0.12 (0.14–0.29)	0.24 ± 0.11 (0.17–0.31)	0.24 ± 0.18 (0.13–0.36)
Tibialis anterior	0.22 ± 0.22 (0.09–0.35)	0.06 ± 0.07 (0.01–0.10)[b]	0.15 ± 0.08 (0.1–0.20)	0.18 ± 0.18 (0.07–0.29)

[a] Indicates greater than the uninjured limb (*P* = .01).
[b] Indicates less than the uninjured limb (*P* = .07).

−14 to 26.9) groups (t_{14} = 0.735, *P* = .48). We also found no differences for the fibularis longus between the ankle-injury (−3.7; 95% CI, −13.5, 6.1) and healthy (−1.4; 95% CI, −7.3, 4.5) groups (t_{17} = −0.378, *P* = .71). However, we found a difference for the tibialis anterior between the acute ankle-sprain (−16; 95% CI, −31.4, −0.8) and healthy (2.6; 95% CI, −4.5, 9.8) groups (t_{18} = −2.19, *P* = .04).

Pain

Scores for both the current visual analog scale and visual analog scale in the 24 hours before the study were larger for the injured ankle than for the uninjured ankle in the acute ankle-sprain group (Table 3). The FAAM activities of daily living, FAAM activities of daily living single-assessment numeric evaluation, FAAM sport, and FAAM sport single-assessment numeric evaluation scores were lower in the ankle-sprain group than in the healthy group (Table 4).

Pain, Effusion, and MNPE

The variance in the current visual analog scale pain scores explained a large amount of variance in the tibialis anterior MNPE in the injured legs of the acute ankle-sprain group (r^2 = 0.74, *P* = .001). However, it did not explain a large amount of variance in the MNPE of the soleus (r^2 = 0.41, *P* = .76) or fibularis longus (r^2 = 0.27, *P* = .11) in the injured legs of the acute ankle-sprain group. The amount of effusion in the ankle-sprain group, as measured by ankle girth, did not explain a large amount of variance in the between-legs differences in $H_{max}:M_{max}$ ratios of the soleus (r^2 = 0.266, *P* = .13), tibialis anterior (r^2 = 0.001, *P* = .93), or fibularis longus (r^2 = 0.136, *P* = .29) in the acute ankle-sprain group.

DISCUSSION

We conducted this study to determine the effect of an acute lateral ankle sprain on MNPE of the soleus, fibularis longus, and tibialis anterior compared with the contralateral uninjured ankle and with injury-matched and contralateral ankles in a healthy group. In the ankle-sprain group, soleus MNPE was greater in the injured than in the uninjured ankle. Between-legs change scores did not differ between the acute ankle-sprain and healthy groups. In the ankle-sprain group, tibialis anterior MNPE tended to be lower in the injured than in the uninjured limb, and between-legs change scores were different between the acute ankle-sprain and healthy groups. Interestingly, we found no differences in MNPE for the fibularis longus between injured and uninjured limbs in the acute ankle-sprain group or between the injury-matched and contralateral limbs in the healthy group, and we found no differences when comparing side-to-side differences in MNPE between groups. Our results are unique because MNPE measures have not been reported in leg muscles after acute ankle sprain.

Comprehensive analyses of lower leg MNPE have been conducted in people with functional ankle instability[7] and healthy volunteers with artificially induced ankle joint effusion.[12] Interestingly, these 2 populations produced different results. The artificial-effusion model displayed a marked facilitation of MNPE in the lower leg muscles, which was interpreted as a splinting mechanism at the joint.[12] The lower leg muscles in functionally unstable ankles had decreased MNPE, which is an inhibition hypothesized to contribute to recurrent ankle injury.[7] From these results, we can hypothesize that the amount of effusion might influence the nature of the arthrogenic muscle response, yet our results indicated that no relationship existed between ankle girth and MNPE, indicating that swelling did not contribute to MNPE in people 72 hours after an initial ankle sprain.

Table 3. Visual Analog Scale and Figure-of-8 Measures, Mean ± SD (95% Confidence Interval)

	Group			
	Acute Ankle Sprain		Injury Matched	
Muscle	Injured	Healthy	Uninjured	Healthy
Visual analog scale for pain in 24 h before study, mm	47 ± 22 (32, 60)[a]	0.2 ± 0.6 (−0.19, 0.6)	0.3 ± 0.7 (−0.11, 0.71)	0.1 ± 0.3 (−0.1, 0.3)
Visual analog scale for current pain level, mm	18 ± 15 (−0.11, 0.71)[a]	0.0 ± 0.0 (0, 0)	0.3 ± 0.7 (−0.10, 0.3)	0.1 ± 0.4 (−0.1, 0.3)
Figure-of-8, cm	53 ± 4.0 (50, 55)	51 ± 3.8 (48, 53)	53 ± 3.8 (50.7, 55.3)	53 ± 4.0 (51, 55)

[a] Indicates greater than the uninjured limb (*P* = .01).

Table 4. Foot and Ankle Ability Measure Measurements (FAAM), Mean ± SD (95% Confidence Interval)

	Group	
Measure	Acute Ankle Sprain	Healthy
FAAM	63.1 ± 17.2 (51, 75)[a]	100 ± 0.0 (100, 100)
FAAM SANE	68.9 ± 19.0 (57, 80)[a]	99 ± 0.6 (99, 100)
FAAM sport scale	35.0 ± 27.5 (17.9, 52)[a]	100 ± 0.0 (100, 100)
FAAM sport SANE	51.0 ± 24.6 (34.9, 67)[a]	99 ± 63 (99, 100)

Abbreviation: SANE, single-assessment numeric evaluation.
[a] Indicates lower than the control group ($P \leq .001$).

The amount of effusion in the people we tested did not correlate directly with the magnitude of the change in MNPE. With previous hypotheses, researchers[11] have suggested that joint mechanoreceptors stimulated by an injured or distended joint capsule might cause these reflexive muscle changes after injury. Authors have confirmed that effusing the ankle[12] and knee[21,22] results in MNPE changes around the effused joint. Conversely, aspirating the joint or removing effusion at the knee also has resulted in changes in MNPE,[10] providing evidence that immediate changes in effusion volume are related to MNPE. We can hypothesize that while immediately altering effusion might cause dramatic changes in MNPE, different mechanisms might drive changes in MNPE at 24 to 72 hours after injury. We can speculate that supraspinal mechanisms might be more influential in modulating MNPE at 24 to 72 hours after acute sprains but that reflexive mechanisms driven by, predominantly, mechanoreceptor stimulation might be responsible for altering MNPE directly after immediate changes in effusion.

A moderate to strong relationship ($r^2 = 0.74$, $P = .001$) was present only between tibialis anterior MNPE and current visual analog pain scores for the tibialis anterior in the injured ankle of the acute ankle-sprain group. The relationship between pain and muscle inhibition often is questioned, but the link between them might not be as strong as is thought intuitively. Although little evidence is available to establish the relationship between pain and changes in MNPE of muscles around the ankle after an acute ankle sprain, some evidence[23] has indicated that pain does not affect muscle activation in the quadriceps after knee injury. We also know from previous experimental joint-effusion models[12,21,22] that changes in MNPE can occur independent of pain. Although suggesting that pain might alter MNPE is still very reasonable, more research is needed to determine the nature of this relationship, as well as which neural pathways and mechanisms are responsible for these changes.

Our results indicated an up-regulation or facilitation of the soleus MNPE coupled with an inhibition of the tibialis anterior. We can interpret this as a possible reflexive response aimed at positioning the injured ankle joint in a plantar-flexed, loose-packed position to increase comfort after trauma. We can speculate that this specific acute arthrogenic muscle response might position the ankle in slight plantar flexion and might contribute to instability at the joint. This reflexive positioning of the ankle into plantar flexion might be linked to previously reported dorsiflexion range-of-motion and posterior talar glide deficits in individuals with chronic ankle instability, which also have been hypothesized[24,25] to contribute to recurrent ankle sprains. Conversely, these results differ from those associated with effusion models, which have indicated facilitation in the soleus, fibularis, and tibialis anterior muscles that has been interpreted as a splinting mechanism.[12]

It is important to not overly generalize these results, which were obtained with participants in a relaxed, nonfunctional position. If testing was performed during weight-bearing activities, results might differ, and involvement of the fibularis longus might be more descriptive. A larger participant population and progressive tracking of the ankle-healing response beyond the acute inflammatory phase also might provide more insight into the progression of healing after ankle sprain.

These data might help the clinician understand the neuromuscular response of the extrinsic ankle muscles to the acutely sprained ankle. Because the soleus is the main plantar flexor of the ankle and because plantar flexion is an inherently more unstable position, avoiding positions of plantar flexion and inversion is better for the ankle. Consequently, increased activation of the soleus might predispose the ankle to injury by situating the joint in an open-packed position, which might be more apt to invert. In addition, the tibialis anterior is responsible for dorsiflexion and eccentric control of plantar flexion. If the tibialis anterior was to be inhibited after an acute ankle injury, this also could place the ankle at greater risk for injury because the tibialis anterior cannot prevent the ankle from moving into an unstable position. Interestingly, fibularis longus MNPE does not seem to be altered immediately after an acute ankle sprain, which, in the presence of a plantar-flexed ankle, might increase the risk of a subsequent inversion ankle sprain. Future study might be needed to determine if a facilitated fibularis longus would be protective immediately after an acute ankle sprain.

Interventions, such as focal joint cooling, transcutaneous electric nerve stimulation, and transcranial magnetic stimulation, have been reported[26,27] to affect MNPE or muscle activation in muscles of the lower extremity after joint injury or effusion. Although investigators[28] have suggested using these modalities to disinhibit motor neurons before or during therapeutic exercise to achieve optimal neuromuscular benefits, little research has been conducted with these modalities at the ankle. We also do not know how facilitated motor-neuron pools would react to a disinhibitory modality, and future research should focus on whether, and when in the healing process, these modalities should be administered after acute ankle sprain.

Our study had limitations. First, the retrospective case-control study design relied on data without preinjury H_{max}:M_{max} ratios for participant normalization measures. Second, patients were tested in a relaxed, nonfunctional, prone position, which provided a stable environment for reflex testing but might have supplied limited information about how reflex excitability is different during activity. Third, progressive tracking of the ankle healing response during recovery was absent. Fourth, although we could not ethically suggest that participants discontinue all treatment, we did attempt to decrease the influence of the effects of interventions known to alter MNPE, such as cryotherapy and transcutaneous electric nerve stimulation,[26,27] by instructing them to discontinue these treatments at least 6 hours before testing. Regardless, we do not know how cumulative interventions applied immediately after the ankle sprain could have altered MNPE assessed hours to days after treatment. The design of future research on acute ankle sprains should take these limitations into consideration.

CONCLUSIONS

From the results of our study, we concluded that arthrogenic muscle response was present in the ipsilateral musculature of patients exhibiting acute lateral ankle sprains. Specifically, this arthrogenic muscle response manifested as a facilitation of the soleus and an inhibition of the tibialis anterior, which were found with between-legs comparisons. Furthermore, the soleus musculature had an increased H_{max}:M_{max} ratio. We also found no difference in the H_{max}:M_{max} ratio of the fibularis longus and identified a trend toward a decrease in the H_{max}:M_{max} ratio of the tibialis anterior in the injured limbs of patients with acute ankle sprains. Our results are the first to provide insight into the arthrogenic muscle response associated with acute ankle sprain.

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Microdialysis and Delivery of Iontophoresis-Driven Lidocaine Into the Human Gastrocnemius Muscle

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Context: Iontophoresis is used frequently in physical medicine and rehabilitation, but many research techniques do not adequately measure it for depth of medicine delivery.

Objective: To determine if iontophoresis delivers lidocaine 5 mm under the surface of human skin.

Design: Descriptive laboratory study.

Setting: Therapeutic modalities research laboratory.

Patients or Other Participants: Eight men and 5 women volunteers (age range = 21 ± 2.3 years) who had less than 5 mm of adipose tissue in the area we measured participated in the study.

Intervention(s): We inserted a microdialysis probe 5 mm under the skin of both legs and into the triceps surae muscle groups of 10 participants. Microdialysis was performed for 60 minutes to allow a recovery period for local skin blood flow to return to baseline. We then delivered 2 mL of 1% lidocaine to the treatment leg via iontophoresis at 40 mA/min. Next, microdialysis was performed continuously in both legs during the treatment and for 30 minutes posttreatment to collect the lidocaine samples. After we had gathered the samples, several saline solutions with various amounts of lidocaine (0.005%, 0.025%, 0.05%, and 0.1%) were prepared in vitro and analyzed. Although we did not intend to do so as a part of the original study, we also performed an identical follow-up study at 3 mm in 3 participants.

Main Outcome Measure(s): Both in vitro and in vivo samples were analyzed via reverse-phase high-performance liquid chromatography (RP-HPLC). A protocol for detection and quantification of lidocaine using RP-HPLC was followed.

Results: We did not detect any measurable levels or concentrations of lidocaine in the 10 control samples. According to the RP-HPLC analysis, the 10 treatment samples also were negative for the presence of lidocaine. However, when we performed the study at 3 mm, microdialysis detected lidocaine in the 3 participants at this depth in the treatment leg only.

Conclusions: Measurable levels of lidocaine were not detected at 5 mm but were found at 3 mm. More studies are needed to determine the efficacy of microdialysis in measuring iontophoresis-delivered compounds.

Key Words: drug delivery, electricity

Key Points

- Microdialysis did not detect 1% lidocaine at a depth of 5 mm in the participants' legs.
- Microdialysis is an appropriate method to use to determine and quantify the presence of 1% lidocaine in the human calf at a depth of 3 mm when delivered via iontophoresis.

Therapeutic drug use can have undesirable side effects, such as organ and tissue damage due to oral medication or pain, infection, and scarring due to needle injection. Iontophoresis was developed nearly 50 years ago as a less painful way to deliver medication to a specific area via electrodes.[1] The use of iontophoresis for transdermal drug delivery is common.[2–6] In physical medicine and rehabilitation, the most commonly used drugs are acetate, dexamethasone, hydrocortisone, and lidocaine. Traditionally, the dose used to bring about the desired effects has been 40 mA/min.

The principle behind iontophoresis involves using electric repulsion to drive an ionic compound through the skin by placing a like-charged electrode over the compound.[3] Although still contested, researchers think the ionic compound follows the electric current into the skin using pores (especially of the sweat glands) as pathways. The movement of the compound beyond the subcutaneous layers is thought to occur as a result of blood flow and diffusion.[3,7–9]

However, some researchers have doubts about the success of this method in delivering medication to the desired treatment area. One major concern hinges on the ability of the medication to penetrate the skin and reach the targeted tissue.[9–13] The mixed results from previous research might be attributed in part to the many different treatment variables used (time, dose, electrode size) and the various methods of collecting and analyzing the drug compound.[9,10]

Microdialysis is a technique that uses the *dialysis* (from Greek, meaning to separate) principle, by which a probe that is permeable to water and small solutes is inserted into the tissue to collect or sample various compounds. The probe is perfused with a liquid (typically saline) that equilibrates with the fluid outside its membrane by diffusion in both directions. This method allows the extracellular fluid (ECF) composition and response to exogenous agents to be observed and analyzed.[14,15] It includes the sampling of ECF, either to assess the concentration of local chemical compounds or to perfuse drugs directly into small clusters of cells.

Microdialysis is a semi-invasive sampling technique that is used in preclinical and clinical pharmacokinetic studies for continuous measurement of free, protein-unbound concentrations in extracellular tissue fluids by means of a microdialysis catheter (or probe). The microdialysis probe consists of a semipermeable hollow-fiber membrane that is perfused constantly with a solution (perfusate) at a low rate of approximately 0.1 to 5 μL/min. After insertion into the tissue or the body fluid of interest, small molecules can cross the semipermeable membrane by passive diffusion. The microdialysis principle was first used in the early 1960s to study biochemistry in animal tissues, especially rodent brains.[1] During the 1970s, the microdialysis catheter was improved greatly and eventually resulted in today's most prevalent shape, the needle probe.[2]

During microdialysis, molecules in the tissues diffuse into the perfusate as it is pumped slowly through the microdialysis probe. The dialysate then is collected and analyzed to determine the identities and concentrations of molecules that were in the ECF. The concentration in the dialysate of any given substance normally is much lower than the concentration present in the ECF, especially for substances with a relatively high molecular weight. Typically, the concentration of a peptide collected by microdialysis is just 5% to 10% of the original concentration. This depends on the charge and size of the molecule in question and on the dialysis speed.

Microdialysis has been adopted for studies in man to investigate free concentrations of various substances in the extravascular and extracellular spaces.[16] It has been used to study dopamine neurotransmission[17] in the injured human brain.[16,18] Microdialysis also is commonly used to deliver drugs to organs, to measure blood flow, and to measure the rate of sweating.[19] Currently, neuroscientists use microdialysis to study the release of neurotransmitters in the brain.[17]

Regardless of the use, the desired solution needs to be analyzed after it is collected. One accurate and objective measure of the compound of interest can be performed using reverse-phase high-performance liquid chromatography (RP-HPLC). This process is used to detect and quantify the amount of a compound in liquid solution. It accomplishes this by separating molecules in a liquid solution based on their various levels of hydrophobicity. The RP-HPLC method has been shown[17] to represent both a reliable and valid way to detect and quantify lidocaine in solution.

Therefore, the purpose of our study was to determine if microdialysis could recover lidocaine in subcutaneous tissue during iontophoretic delivery. We hypothesized that microdialysis followed by RP-HPLC analysis would be an effective method by which to not only detect, but also quantify, the amount of 1% lidocaine delivered during an iontophoresis treatment.

METHODS

In Vitro Drug Delivery

Before participant recruitment and data collection, we performed several in vitro experiments. These "bench-top" experiments were conducted for the following reasons: (1) to ensure that if the lidocaine penetrated to the depth of the microdialysis probe, the drug could be collected and recovered by the probe; (2) to assess the possibility of protein binding blocking the recovery of lidocaine via the microdialysis probe; and (3) to develop a linear relationship between percentage of lidocaine administered and the amount recovered.

During the first bench-top experiment, a microdialysis probe was connected to an infusion pump (model Pump 11 VPF; Harvard Apparatus, Holliston, MA) and placed in a petri dish filled with saline solution (0.9% NaCl). A collecting vial (1.5-mL microcentrifuge, Safe-Lock tube; Eppendorf, Hamburg, Germany) was placed at the opposite end of the probe to collect the diasylate during infusion. Two milliliters of 10 mg/mL lidocaine was added directly to the saline solution in the petri dish. During collection, saline solution (0.9% NaCl) was pumped through the probe at a constant rate of 0.011 mL/min and collected in the vial for analysis. This was repeated several times with various concentrations in separate petri dishes. The different samples were analyzed using RP-HPLC to detect and quantify the presence of lidocaine. A previously established RP-HPLC protocol[17] for detection and quantification of lidocaine was followed. The results revealed that the microdialysis probe could recover lidocaine and that the RP-HPLC analysis could detect lidocaine concentrations equal to or greater than 0.05 mg/mL.

The second series of bench-top experiments involved procedures similar to the first. However, this time blood plasma also was added to the saline solution in the petri dish to assess the possible effects of protein binding on the recovery of lidocaine. In the absence of blood plasma, microdialysis recovered approximately 6.5 mg/mL of the 1% lidocaine that was administered. With the presence of plasma in the solution, microdialysis recovered only 1.6 mg/mL. Although the high concentration of blood plasma had a huge effect on the ability of the microdialysis probe to recover the lidocaine, it did not completely block recovery (Figure 1).

The last in vitro experiment involved diluting the treatment solution of lidocaine to various concentrations (1, 0.5, 0.25, and 0.05 mg/mL) with saline. This was done for 2 reasons. First, we wanted to have an idea of how sensitive the RP-HPLC analysis was. Second, we wanted to generate a standard curve, which would allow us to quantify the amount of lidocaine detected in the subsequent samples. The RP-HPLC analysis was able to detect the presence of lidocaine at the 0.05-mg/mL concentration. A line of best fit was generated from the standard curve ($y = 155615x - 76.687$, $R^2 = 0.9999$), allowing us to determine the linear relationship between the area under lidocaine's RP-HPLC peak and percentage of lidocaine (Figure 2). With this linear relationship established and the success of our in vitro experiments, we were confident that microdialysis in conjunction with RP-HPLC analysis could detect and quantify the presence of lidocaine in a subcutaneous environment.

Participants

Participants, whom we recruited from exercise science classes, reported to the University Human Performance Research Center for screening. Skinfold measures of the calf were taken. The skin was folded during the measurement, and participants were excluded from the study if they had more than 10 mm of skinfold thickness (ie, less than 5 mm of cutaneous tissue).

Other inclusion criteria included the following: area free of any injury, swelling, or infection for at least 3 months before the study and no allergies to lidocaine. The first 13 participants

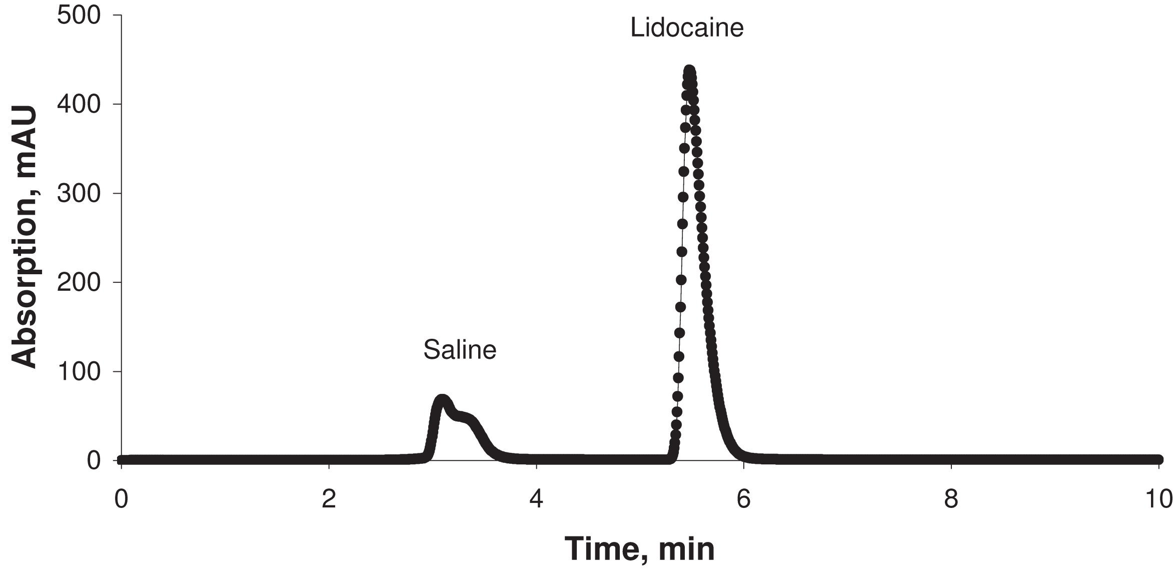

Figure 1. High-performance liquid chromatography analysis profile of in vitro results in high plasma concentration.

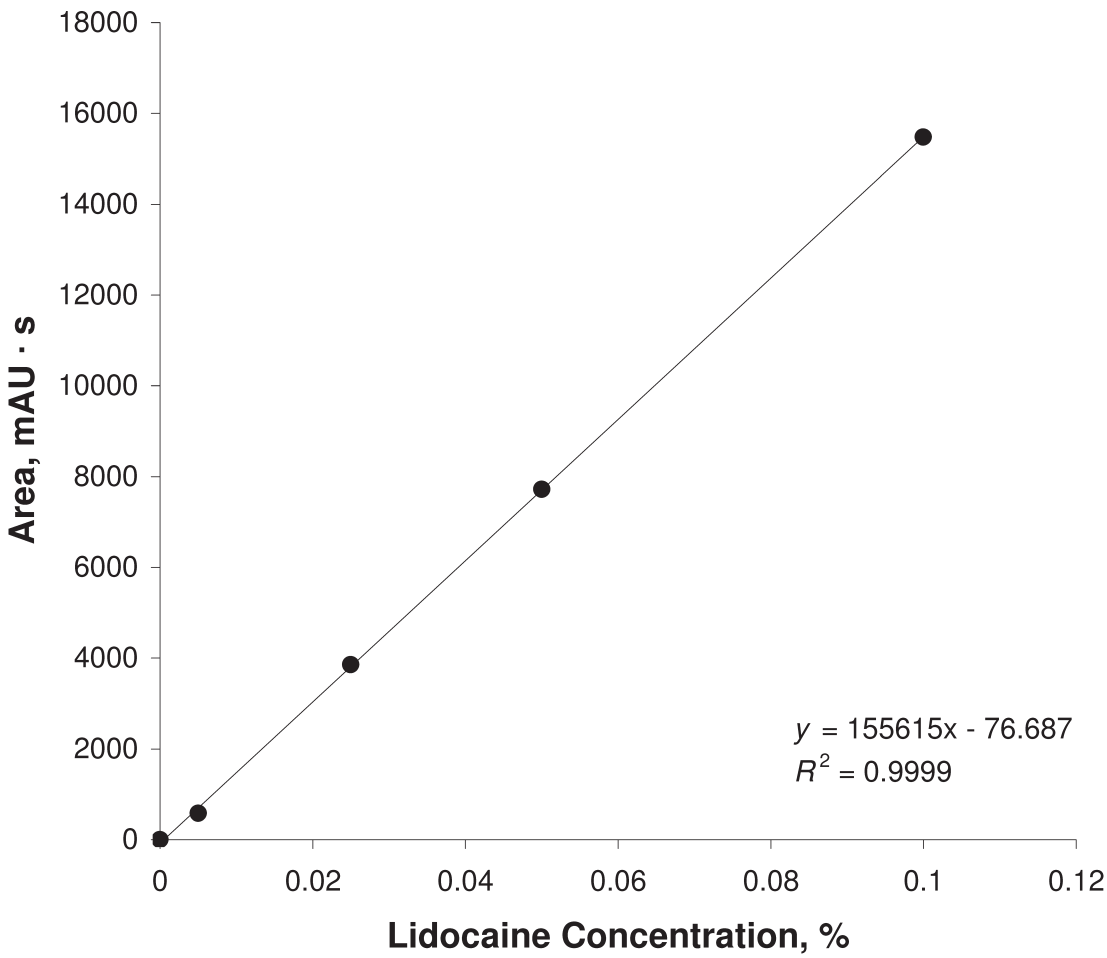

Figure 2. Standard curve with line of best fit.

(8 men, 5 women; age range = 21 ± 2.3 years) who met our criteria were included in the study; 10 were involved in the originally planned portion of the study, and 3 were involved in an unplanned follow-up portion of the study. Participants provided written informed consent, and the study was approved by the institutional review board at Brigham Young University.

Instruments

An iontophoresis device (ActivaTek, Salt Lake City, UT) was used to deliver the lidocaine. One electrode carried the drug to the treatment site, and one electrode served as the dispersive electrode (both electrodes: Trivarion; ActivaTek). The infusion of the microdialysis probe was performed using an infusion pump (model Pump 11 VPF; Harvard Apparatus). The microdialysis probes were manufactured in our university's laboratory (Figure 3).

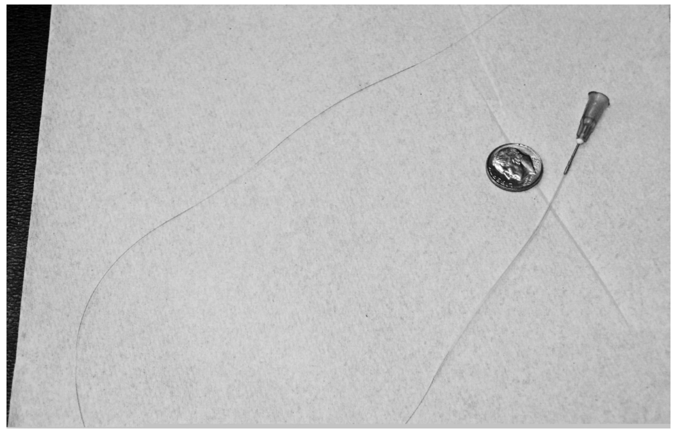

Figure 3. The microdialysis probe used to collect the drug compound.

Probe Placement. Each probe was gas sterilized with ethylene oxide before the study. Sterile technique was followed throughout data collection for all participants. The treatment site was cleaned with a povidone-iodine swab and an alcohol preparation wipe before insertion of a 27-gauge spinal needle. A microdialysis probe was inserted 5 mm below the surface of the skin of both legs (at the site of greatest calf girth) using the 27-gauge spinal needle as a guide cannula for 10 participants and, during the follow-up portion of the study, 3 mm below the skin's surface for 3 participants. The entrance and exit sites of the skin were separated by 5 cm to allow adequate spacing for the treatment electrode's reservoir. After feeding the probe through the spinal needle, we removed the cannula, leaving the probe in place. Before removal of the spinal needle, diagnostic ultrasound (LOGIQ P6; GE Healthcare, Wauwatosa, WI) was used to verify the depth of the guide cannula. After placement of the microdialysis probe, infusion was performed for 60 minutes at a constant rate of 0.011 mL/min to allow for a recovery period. This allowed local skin blood flow to return to near-normal levels after tissue irritation due to probe placement.

Drug Delivery Treatment In Vivo. After probe insertion and the recovery period, the infusion rate was changed to match the rate of our in vitro experiments (0.0055 mL/min), and a new collecting vial was connected to the probe. The drug-delivery electrode (positive) was prepared with 2 mL of 1% lidocaine (positive charge) and placed on the treatment site directly over the microdialysis probe. The 14-cm^2 delivery electrode had a 2.0-mL reservoir. The larger (37-cm^2) dispersive electrode was placed 6 in (15.2 cm) proximal to the drug-delivery electrode. After the electrode leads were secured, the phoresor was set

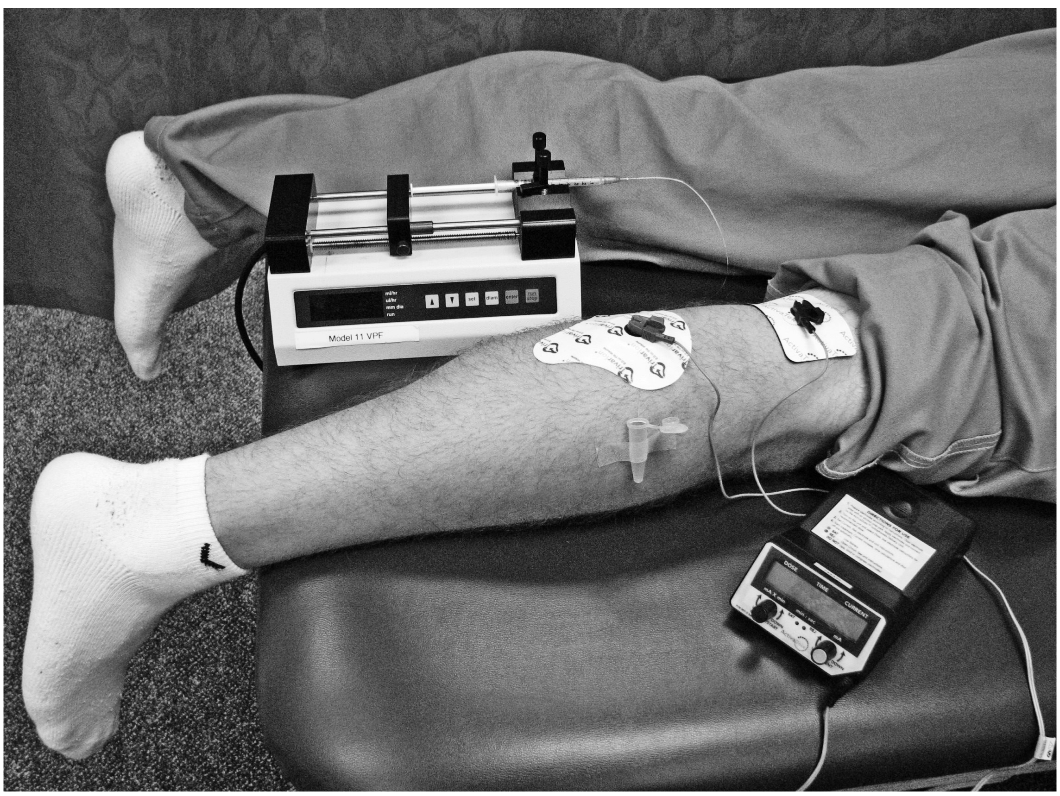

Figure 4. The experimentation setup for microdialysis and iontophoresis.

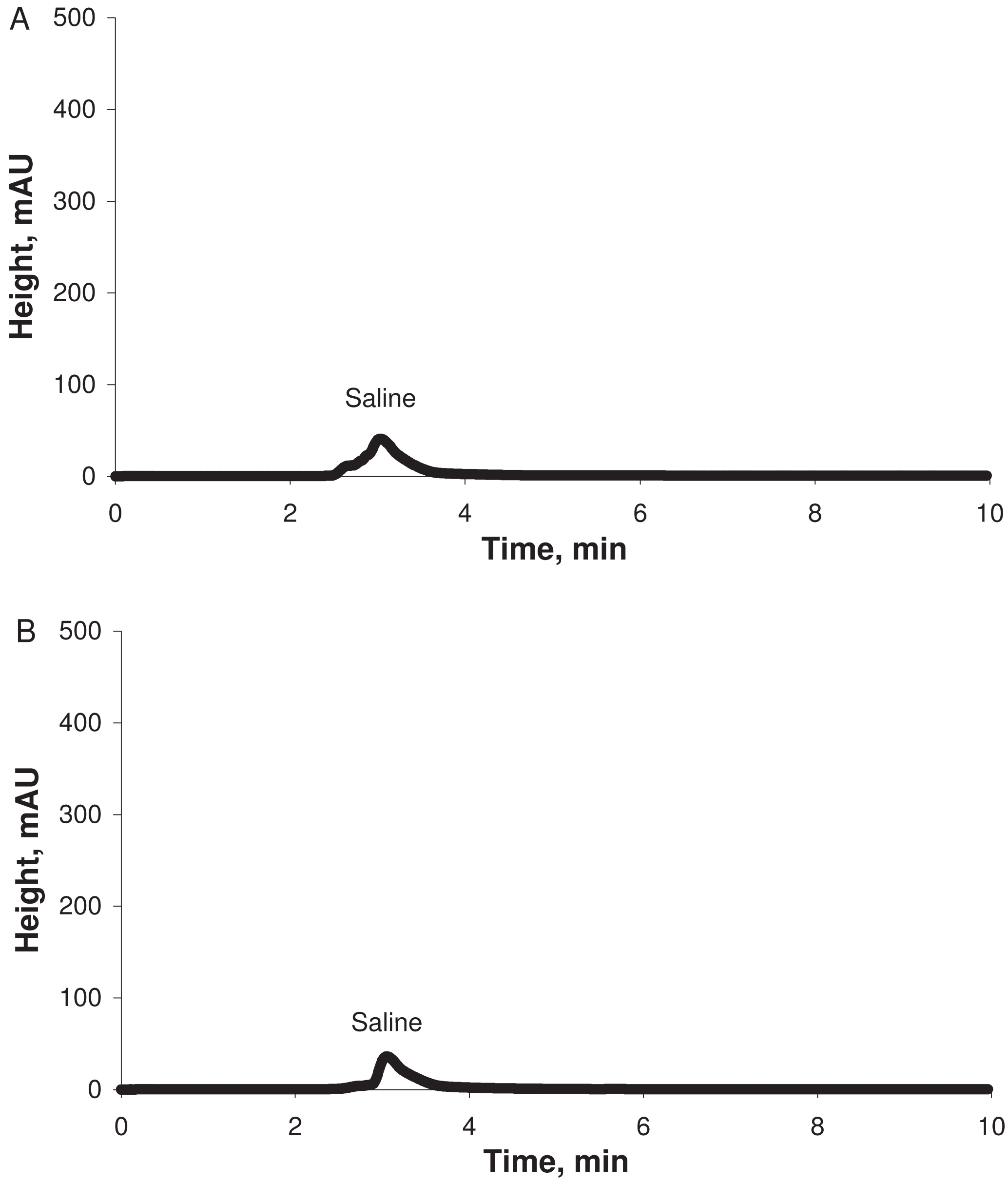

Figure 5. A, Negative high-performance liquid chromatography results at the 5-mm depth for the control leg. B, Negative high-performance liquid chromatography results at the 5-mm depth for the treatment leg.

at a current charge of 40 mA/min (Figure 4). This dose was delivered in approximately 10.5 minutes for all participants. At the end of the treatment, the iontophoresis device automatically shut off (the control leg did not receive treatment), and data collection continued for a total of 40.5 minutes (10.5 minutes during treatment and 30 minutes posttreatment). During this 60-minute interval, perfusate from the microdialysis probes in both legs was collected into separate vials for analysis. At the conclusion of the treatment, the electrodes and probes were removed from the participants. The treatment site and all portal sites were cleaned thoroughly and treated with triple antibiotic ointment. If necessary, portal sites were covered with bandages. Before dismissal, each participant was given a basic wound-care guide and our contact information. The in vivo samples were analyzed using the same RP-HPLC protocol that was used for the in vitro samples.

Statistical Analysis

When we found lidocaine present, we used paired *t* tests to compare the treatment and control legs. The α level was set a priori at .05. We used SPSS (version 17.0; SPSS Inc, Chicago, IL) for statistical analysis.

RESULTS

According to the RP-HPLC analysis, the 20 samples (10 control + 10 treatment samples) were negative for the presence of lidocaine at the 5-mm depth (Figure 5). Because lidocaine was not found in either leg, no statistical analysis to compare groups was necessary. However, the 3 treatment samples from the 3-mm depth were positive for the presence of lidocaine. Average recovery of the 1% lidocaine at the 3-mm depth was different between the treatment (0.5 mg/mL; range, 0.2–0.8 mg/mL) and control (0 mg/mL) legs ($t_9 = 88.655$, $P < .01$).

DISCUSSION

The use of microdialysis to measure drug-ion delivery via iontophoresis has not been discussed in the literature. Therefore, our main purpose was to verify that microdialysis was an effective tool to measure the presence of drug ions delivered via iontophoresis. We had several reasons for studying 3 instead of 10 participants at the 3-mm depth. We found the drug present in all 3 participants tested at this depth and, thus, had addressed the purpose of our experiment. In addition, because we were not comparing the 5-mm and 3-mm depths, we believed that collecting more samples was not necessary.

Difficulties With the Technique

Microdialysis generally is viewed as a practical and useful analytic technique for elucidating the concentration of key low–molecular-weight components in the ECF; however, several practical considerations need to be considered. The absolute concentration of an analyzed substance in the ECF is very difficult to determine using microdialysis. If the dialysate has a relatively high flow rate, then the analyte most likely will not fully equilibrate between perfusate (the exiting fluid from the probe) and the ECF. Therefore, HPLC, capillary electrophoresis, or other analytical measurements of the dialysate will underestimate the concentration of the analyte in the ECF.[20]

Because of this constraint, most efforts in this field have been focused on increasing the recovered analyte concentration in the dialysate. This can be done by either increasing the probe membrane surface area or reducing the flow rate, allowing more time for molecules to diffuse into the dialysate. However, increasing the probe size means that it might cause more damage to the tissue and that measurements will be less spatially precise. Reducing the flow rate reduces the temporal resolution of measurements. We considered using a larger-diameter probe; however, because such probes cost twice as much (US$200 each) as the smaller probe that we used, their use was cost prohibitive.

One way to overcome the difficulties in loss of temporal resolution with a slower flow rate is to develop better analytic techniques. Currently, the most widely used analytic technique to determine analyte concentrations in the perfusate is RP-HPLC. An ultra-slow technique can be used to generate a high recovered fraction of analyte from the ECF while still pumping the dialysate. This generates very low volumes and concentrations of dialysate, but the relative amount of analyte more closely resembles the amount of ECF. We used this technique to ensure more accurate concentrations and to minimize the loss of temporal resolution.

Limitations

Our study had some limitations, one of which was the amount and percentage of the lidocaine that was collected in the plasma solution. We were only able to measure 16% of the lidocaine added to the solution. Thus, one might ask how applicable our results are to clinical decisions. However, based on the results of the bench-top experiments, we believe that if lidocaine penetrated to the depth of the probe, the microdialysis probe would be able to collect and recover the drug even in a protein-rich environment. We are also confident that the RP-HPLC protocol used was sensitive enough to detect even small traces of lidocaine (0.005%).

Another limitation of this study may have been the absence of epinephrine in the lidocaine. Epinephrine might have helped the treatment drug reach the probe at the 5-mm depth because of its ability to cause vasoconstriction. In the future, researchers should consider using epinephrine with lidocaine when trying to detect lidocaine at levels deeper than 3 mm.

Other research in this area could involve the study of iontophoresis in other tissues, in different doses, and for longer collection times posttreatment. Future research also might involve testing topical patches, other medications, other depths, other strengths of lidocaine, and various medication compounds (eg, lidocaine with epinephrine).

Clinical Application

These results are important to the clinician who desires to numb a superficial area before needle injection or other shallow applications up to a 3-mm depth. This technique also might be applicable before cross-friction massage, myofascial release, or other unpleasant techniques used in physical medicine and rehabilitation.

CONCLUSIONS

Research regarding the effectiveness and depth of drug delivery via iontophoresis is conflicting, in part, because of less-than-ideal treatment variables, sampling, and research methods. The purpose of our study was to determine if microdialysis could recover lidocaine in the human tissues during iontophoretic delivery. Initially we attempted to do this by determining if microdialysis could detect lidocaine at 5-mm depth in the human calf. We found that microdialysis was unable to detect lidocaine at this depth. However, microdialysis detected lidocaine in all 3 participants tested at 3 mm in depth. Based on this result, we believe that microdialysis is an appropriate method to determine if lidocaine is absorbed in the human calf at a depth of 3 mm when delivered via iontophoresis.

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Absorption of Iontophoresis-Driven 2% Lidocaine With Epinephrine in the Tissues at 5 mm Below the Surface of the Skin

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Context: In a recent study, we were unable to measure lidocaine in the human calf at a 5-mm depth via iontophoresis. We surmised that this might be due to a lack of epinephrine in the compound. Because epinephrine is a vasoconstrictor, it might allow the drug to pass beyond the capillaries and be delivered to the deeper tissues.

Objective: To determine if iontophoresis could deliver lidocaine with epinephrine 5 mm under the surface of human skin, as measured by microdialysis.

Design: Descriptive laboratory study.

Setting: Therapeutic modalities research laboratory.

Patients or Other Participants: Ten volunteers (5 males, 5 females; age, 15–28 years) with less than 5 mm of adipose tissue in the area we measured and with no allergies to lidocaine participated. The measurement area had been free of any injury, swelling, or infection for at least 3 months before the study.

Intervention(s): We inserted a microdialysis probe 0.5 cm under the skin of the right lower leg. Next, microdialysis was performed through this area for 60 minutes, which allowed local skin blood flow to return to baseline. We then performed iontophoresis at 40 mA/min using 2 mL of 2% lidocaine. Iontophoresis was performed over this area for 10.5 minutes to collect the lidocaine samples. After this stage, the electrode was left in place for another 50 minutes for a total of 60 minutes.

Main Outcome Measure(s): The samples of the drug were analyzed via reverse-phase high-performance liquid chromatography (RP-HPLC) in the chemistry department.

Results: The RP-HPLC analysis confirmed the presence of lidocaine in all 10 participants. The mean concentration of lidocaine detected at the 5-mm depth was calculated as 3.63 mg/mL (greater than 18% of delivered concentration).

Conclusions: We found that 2% lidocaine can be delivered up to 5 mm below the surface of the skin when the drug compound contains epinephrine and when passive delivery occurs for at least 50 minutes after the active delivery has terminated.

Key Words: drug delivery, diffusion, passive diffusion

Key Points

- Iontophoresis can be absorbed in tissues to a depth of at least 5 mm.
- Microdialysis is an effective tool with which to measure absorption of iontophoretic medication.

Iontophoresis is a method of local transfer (phoresis) or delivery of ionized (ionto) medicated and nonmedicated solutions into the skin and through local microcirculation. It involves the use of electric energy for ion transfer through the skin and is implemented using the traditional wire programmable devices and newer wireless or nonprogrammable patches.[1] Iontophoresis is used widely in physical medicine and rehabilitation. In 2009, one company reported more than 3.8 million treatments (Empi administrator, oral communication, 2009).

Researchers have doubts about the success of iontophoresis in delivering medication to the desired treatment area. One of their major concerns involves the ability of the medication to penetrate the skin and reach the tendon, muscle, bursa, etc.[2–4] The literature includes studies in which investigators have measured delivery depths as shallow as 3 mm to as deep as 15 mm into human tissue[5–8] and as deep as 17 mm in monkeys.[9]

One way of determining how much drug compound has reached the target tissue from iontophoresis is to use microdialysis. Microdialysis is a method of studying extracellular fluid composition and response to exogenous agents using an approximately 30-gauge tubular probe with a dialysis membrane and fluid flow rates of 1 to 3 μL/min into tissues.[10] It includes the sampling of extracellular fluid either to assess the concentration of local chemical components or to perfuse drugs directly into small clusters of cells. Neuroscientists use microdialysis to study the release of neurotransmitters in the brain,[11] exercise physiologists to measure the rate of sweating,[12] and medical doctors to deliver drugs to organs and to measure blood flow.[11] We have used microdialysis to measure drug delivery via iontophoresis.

As we have pointed out, researchers have reported a wide range of depths that iontophoresis has reached, but not all measuring techniques were optimal.[3–5,8,9] Reaching the target tissue is critical when the goal is to deliver medication to the inflamed or injured site. Microdialysis has been shown to be effective in measuring chemical compounds in tissues. Therefore, the purpose of our study was to determine if iontophoresis using the following variables could deliver 2% lidocaine with epinephrine 5 mm past the skin's surface: 40 mA/min, 10 minutes, 50 minutes posttreatment diffusion time. We hypothesized that the introduction of epinephrine into the lidocaine and the longer passive delivery of the drug would result in the drug being absorbed in the tissues at depths equal to 5 mm.

METHODS

Design

This descriptive study included the independent variable of depth and the dependent variable of volume of the drug compound recovered at a depth of 5 mm.

Participants

Five male and 5 female (ages, 15–28 years) volunteers participated in the study. The treatment area had been free of any injury, swelling, or infection for at least 3 months before the study, and no participant had an allergy to lidocaine. Participants had less than 5-mm skin thickness in the treatment area. All participants provided written informed consent, and the study was approved by the institutional review board at Brigham Young University.

Instruments

We used an iontophoresis unit (ActivaTek, Salt Lake City, UT) to deliver the lidocaine with epinephrine. One of the 2 electrodes (Trivarion; ActivaTek) carried the drug to the treatment site, and the other was used as a dispersive electrode. We used an infusion pump (model Pump 11 VPF; Harvard Apparatus, Holliston, MA) to perform the microdialysis. The microdialysis probes were manufactured in our university's laboratory (Figure 1, and see figure 3 in Coglianese et al[15])

Procedures

We used ethylene oxide to gas sterilize each probe before the study. The chief data collector (M.C.) donned surgical gloves before preparing the site. The skin was cleaned with a povidone-iodine swab and an alcohol preparation wipe. Before handling the spinal needle or the probe, the data collector also donned sterile gloves. A 27-gauge spinal needle was placed 5 mm under the skin at the thickest aspect of the gastrocnemius muscle of the right leg. Five centimeters of skin separated the entrance and exit sites. The microdialysis probe was inserted through the guide cannula, which was placed horizontally in the dermis. Next, the cannula was removed from the leg, and the probe was left in place. After placement, microdialysis was performed through the leg for 60 minutes to allow for a recovery period because of probe insertion and related soft tissue trauma. This permitted local skin blood flow to return to baseline. The probe was perfused continuously with 0.9% bacteriostatic saline at a rate of 5 μL/min with the infusion pump.

Drug Delivery. After probe insertion and the recovery period, the drug-delivery electrode was prepared with 2 mL of 2% lidocaine (positive charge) and epinephrine solution. It was placed on the skin directly over the microdialysis probe. The 14-cm^2 delivery electrode had a 2.0-mL reservoir. The larger dispersive electrode (negative charge) was 37 cm^2 and was placed 6 in (15.24 cm) proximal to the drug delivery site on the same leg. After the electrode leads were affixed to the skin, the unit was turned on (Figure 2). The iontophoresis (activator) unit was set at a current charge of 4 mA/min to deliver a total of 40 mA in approximately 10.5 minutes. The unit ramped up the current for 30 seconds until it reached 4 mA. At the end of the treatment, the activator beeped and automatically shut off. During the treatment, perfusate from the intramuscular microdialysis probe was collected in a collecting vial (1.5-mL microcentrifuge, Safe-Lock tube; Eppendorf, Hamburg, Germany) for analysis. At the conclusion of the treatment, the dispersive electrode was removed from the participant, and the treatment site was cleaned of any residue; however, the active electrode remained in place for 50 minutes for passive delivery. The intramuscular microdialysis probe was removed carefully immediately after the treatment ended, and portal sites were treated with triple antibiotic ointment and, if necessary, were covered with a self-adhesive bandage. Before leaving the laboratory, each participant received a basic wound-care guide and our contact information.

Data Analysis

The samples, which were taken during and 50 minutes after the iontophoresis treatment, were analyzed via reverse-phase high-performance liquid chromatography (RP-HPLC) in the

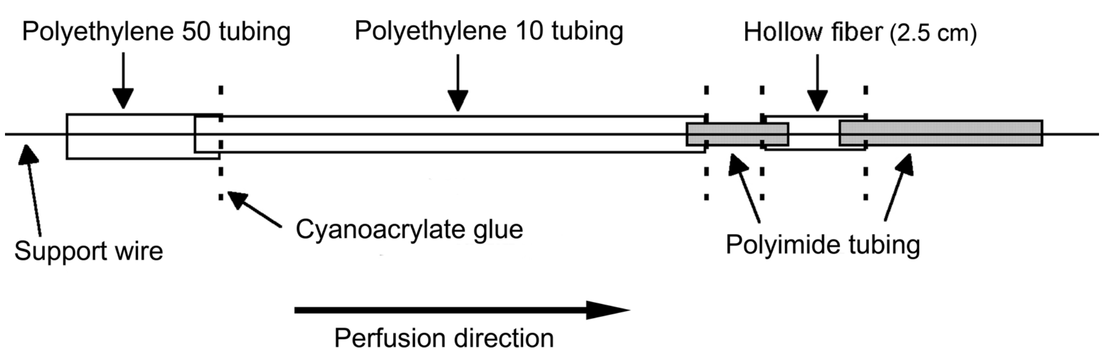

Figure 1. Construction of the microdialysis probe used to collect the drug compound.

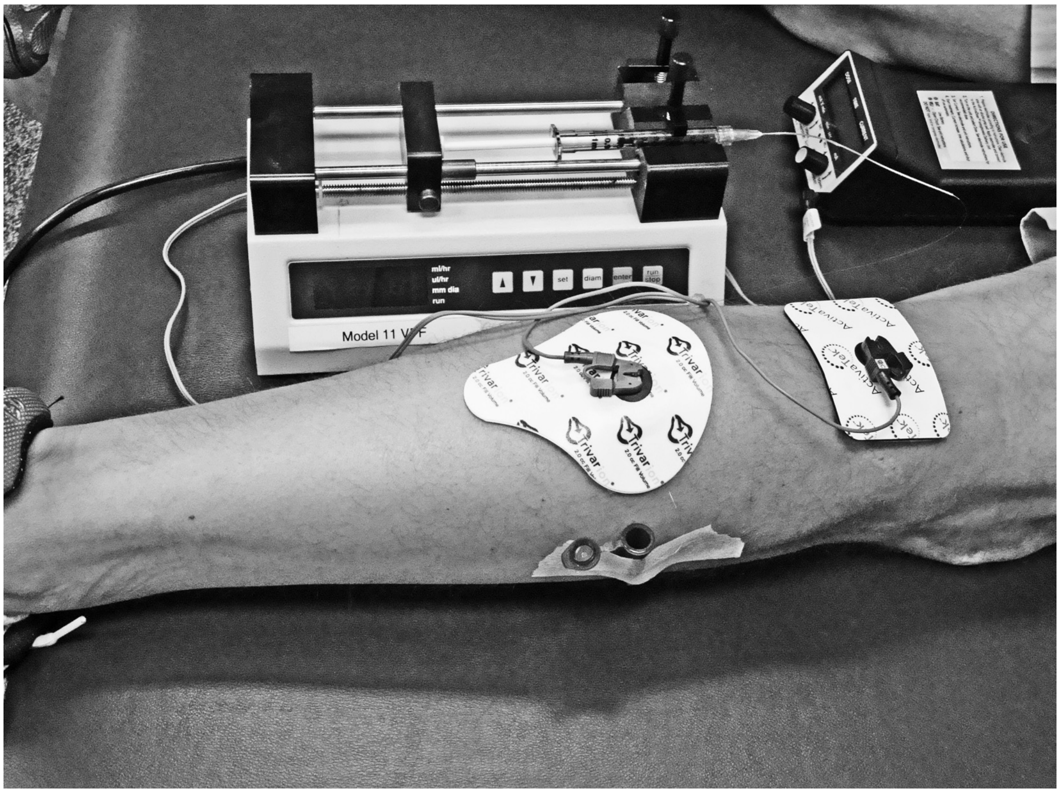

Figure 2. The experimentation setup displaying the microdialysis probe, epindorph container, iontophoresis unit, and microdialysis device.

chemistry department. A previously established protocol for detection and quantification of lidocaine using RP-HPLC was followed.[13] The 2% lidocaine standard and several diluted concentrations (1%, 0.5%, and 0.25%) also were analyzed via RP-HPLC. The results from these various concentrations were used to generate a standard curve. Our objective was not only to determine if the drug penetrated the skin and tissues up to 5 mm deep but also to quantify the percentage of lidocaine at that depth. The percentage of lidocaine in our samples was calculated using the line of best fit from the standard curve ($R^2 = 0.9964$). The results from the 10 participants were averaged, and the mean was used in the equation ($y = 22583\text{Ln}(x) + 38281$, where y is milliabsorbance units (mAU) and x is the percentage of lidocaine in the standard solution) from the standard curve to calculate the percentage of lidocaine detected.

Statistical Analysis

The percentage of lidocaine detected was analyzed using 1-way analysis of variance to determine if it was different from zero. The α level was set a priori at .05. We used SPSS (version 17; SPSS Inc, Chicago, IL) for statistical analysis.

RESULTS

The RP-HPLC analysis confirmed the presence of lidocaine in all 10 participants (Figure 3). The mean area under the lidocaine curve for the 10 participants sampled was 15440.79 mAU/s, with an SD of 550.76 mAU/s and a coefficient of variation of 3.6%. Using the mean area under the lidocaine peak for all 10 participants and the equation from the standard curve, the mean volume of lidocaine recovered at the 5-mm depth was calculated as 3.63 mg/mL (greater than 18% of the delivered 20 mg/mL). This recovered volume was determined to be different from 0 ($F_{1,19} = 1.843$[33], $P = .001$).

DISCUSSION

We detected 3.63 mg/mL mean volume of the 2% lidocaine at a 5-mm depth in the tissue. Because lidocaine is known to have therapeutic effects at less than 1.0 µg/mL, it might have a therapeutic effect at a depth of 5 mm when it is delivered at a 2% concentration with epinephrine (40 mA/min dosage, with electrode left in place 50 minutes posttreatment).[14]

Addition of Epinephrine

In a previous study, we detected 1% lidocaine using microdialysis at a depth of 3 mm below the surface of the skin, but we did not detect it at 5 mm.[15] During the present study, we found lidocaine at a 5-mm depth below the surface of the skin. We attribute these results to 3 things that we did differently compared with the previous study: (1) epinephrine (a vasoconstrictor) was included in the lidocaine compound; (2) the drug-delivery electrode remained in place for 50 minutes after the treatment, as opposed to 30 minutes; and (3) a higher concentration of lidocaine (2%) was used.

Including epinephrine in the drug solution is important because it causes vasoconstriction of the blood vessels. We believe that lidocaine has a difficult time passing through the superficial layers of the tissue owing to absorption in the superficial bloodstream. Introducing epinephrine, a vasoconstrictor, might allow drugs to pass through the bloodstream and be absorbed in the deeper tissues (such as at 5 mm).

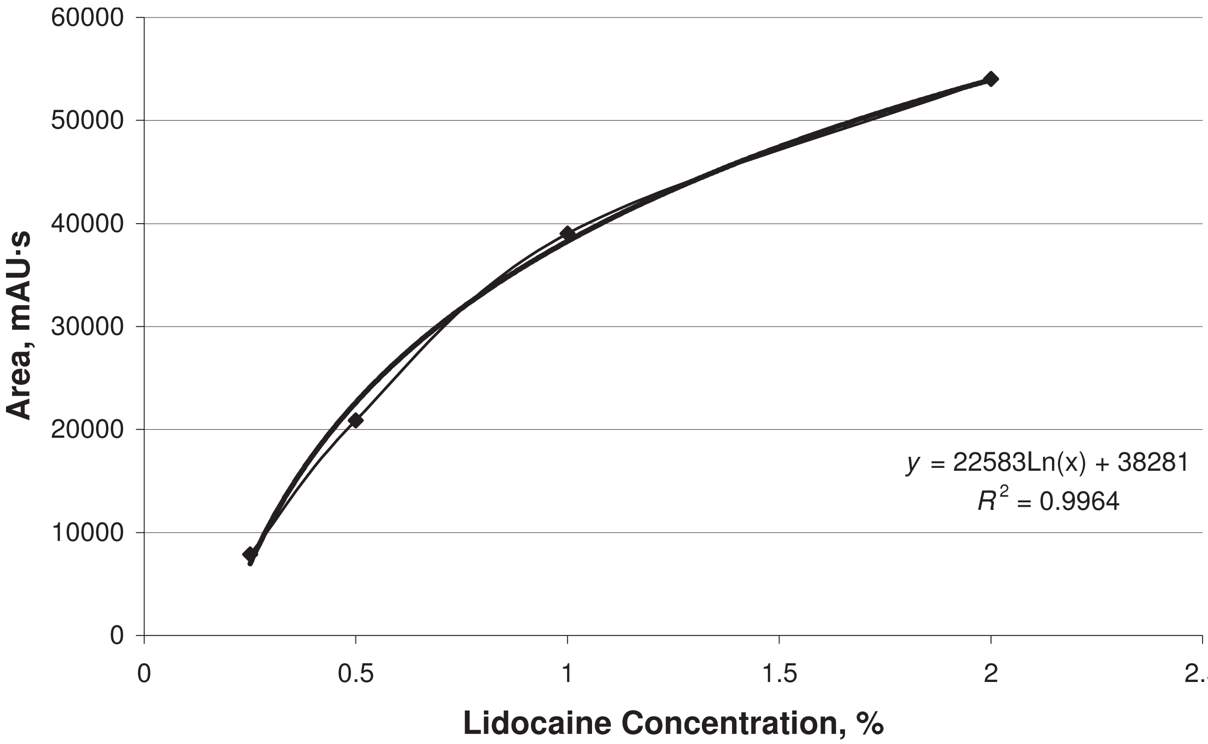

Figure 3. Standard curve for 2% lidocaine with epinephrine.

One of the limitations in our previous study[15] was the absence of epinephrine in the lidocaine. In that study we hypothesized that because epinephrine causes vasoconstriction, it might have enabled the drug to reach the microprobe at the 5-mm depth,[6,7,16] and we stated that researchers should consider using lidocaine with epinephrine in future studies involving lidocaine detection at depths greater than 3 mm. We have corrected for that limitation and believe that few limitations occurred in this study.

The molecular weight of the drug also should be considered. Epinephrine weighs 183.21 Da, whereas 2% lidocaine weighs 288.82 Da. This means that much of the epinephrine would pass through the skin and have the vasoconstriction action on the capillaries before the lidocaine passed into the area.

Passive Delivery of the Drug Posttreatment

In a related study, Smutok et al[3] did not show any measureable amounts of dexamethasone or dexamethasone phosphate in the antecubital veins of humans after iontophoresis treatment of the wrist. Variables were 2.5 mL or 4 mg/mL at 4 mA for 10 minutes and 4 mA for 20 minutes. The antecubital vein is superficial, and some might surmise that the drug would be delivered to this depth. However, others might argue that the drug reached the target tissues without being absorbed into the bloodstream. Additional possible explanations for the results of Smutok et al could be that the drug electrode was not left on long enough after the treatment or that drug detection was performed too quickly posttreatment.

On the basis of their model, Anderson et al[7] suggested that for equivalent iontophoretic dosages, the key element that enables passive diffusion is the length of time for which the drug is applied. According to them,[7] it is the time the drug is applied rather than the current amplitude that determines penetration depth. Our results concurred with their premise. However, we also believe that passive delivery of the medication posttreatment should be considered. In our previous study,[15] in which we did not discover any lidocaine at the 5-mm depth, we only left the electrode on for 30 minutes posttreatment. In this study, we increased the passive diffusion time posttreatment by 20 minutes.

Use of 2% Lidocaine

Researchers[3–5,8,9,14,17] have suggested that drug concentrations used for iontophoresis usually range from 2% to 5% aqueous solution or ointment. The drug solution should contain relatively low concentrations of medication. According to Henley[14] and Ciccone,[18] an increased concentration does not appear to increase the amount of the drug delivered; yet we found the opposite to be true. In our previous study,[15] in which we used 1% lidocaine, we did not find the drug at the 5-mm depth in the tissues; however, when we used 2% lidocaine in this study, we collected it at the 5-mm depth. Our methods are novel because the drug actually is collected in a microdialysis probe as the drug passes through the tissue. However, we still believe that passive delivery posttreatment and the effect of epinephrine on the local vasculature played major roles in allowing us to collect the drug at this depth.

As stated earlier, information provided by an administrator at the leading company indicated that sufficient devices and electrodes were sold to provide nearly 4 million treatments in 2009. Given this large number, investigators should determine if iontophoresis indeed delivers the medication deep enough to reach the injured site and have an effect.

Methods of Determining Depth

The patients in a study by Gurney et al[8] were undergoing anterior cruciate ligament repairs using the semitendinosis. Thus, the investigators measured whether the dexamethasone reached the tissue by dividing skinfold measurements, which had been taken immediately before the study, by 2. Their skinfold range was 6 to 30 mm (3–15 mm when divided by 2). Costello and Jeske[6] measured 10 mm in the gluteus muscles of rabbits to find the numbing effect of lidocaine. Anderson et al[7] used an agarose gel model to measure doses of dexamethasone 12 mm deep in the gel. Wieder[19] used acetic acid iontophoresis to decrease the size of myositis ossificans of the quadriceps muscle to show the positive effects of iontophoresis. Both Baskurt et al[20] and Demirtaş and Oner[17] were able to decrease the symptoms of lateral epicondylitis in patients when using iontophoresis with naproxen and sodium diclofenac, respectively. Each of these studies can be categorized as ranging from the most objective[8] to the most subjective.[17,20] Our previous study[15] and present studies using microdialysis are considered objective because we measured the amount of drug that actually was absorbed in the tissues and reached the target site.

CONCLUSIONS

Much conflicting research exists regarding the effectiveness and depth of drug delivery via iontophoresis. Some of this conflict is due to less-than-ideal treatment variables, sampling, and research methods. However, using microdialysis, we determined that 2% lidocaine combined with epinephrine could be detected at a 5-mm depth in the human leg. We discovered that the drug penetrated to the depth at a concentration of greater than 18% of the original drug concentration. Based on our results, we suggest that 2% lidocaine can be delivered up to 5 mm below the skin's surface when the drug compound contains epinephrine and when passive delivery occurs for at least 50 minutes after the active delivery has terminated (variables: 40 mA/min, 4 mA, 10.5 minutes). Future research could involve testing topical patches; other frequencies that might more easily penetrate the skin; other depths; and other medications, such as the more commonly used dexamethasone.[18]

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original research

A Profile of Glenohumeral Internal and External Rotation Motion in the Uninjured High School Baseball Pitcher, Part I: Motion

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Context: The magnitude of motion that is normal for the throwing shoulder in uninjured baseball pitchers has not been established. Chronologic factors contributing to adaptations in motion present in the thrower's shoulder also have not been established.

Objectives: To develop a normative profile of glenohumeral rotation motion in uninjured high school baseball pitchers and to evaluate the effect of chronologic characteristics on the development of adaptations in shoulder rotation motion.

Design: Cohort study.

Setting: Baseball playing field.

Patients or Other Participants: A total of 210 uninjured male high school baseball pitchers (age = 16 ± 1.1 years, height = 1.8 ± 0.1 m, mass = 77.5 ± 11.2 kg, pitching experience = 6 ± 2.3 years).

Intervention(s): Using standard goniometric techniques, we measured passive rotational glenohumeral range of motion bilaterally with participants in the supine position.

Main Outcome Measure(s): Paired *t* tests were performed to identify differences in motion between limbs for the group. Analysis of variance and post hoc Tukey tests were conducted to identify differences in motion by age. Linear regressions were performed to determine the influence of chronologic factors on limb motion.

Results: Rotation motion characteristics for the population were established. We found no difference between sides for external rotation (ER) at 0° of abduction ($t_{209} = 0.658$, $P = .51$), but we found side-to-side differences in ER ($t_{209} = -13.012$, $P < .001$) and internal rotation ($t_{209} = 15.304$, $P < .001$) at 90° of abduction. Age at the time of testing was a significant negative predictor of ER motion for the dominant shoulder ($R^2 = 0.019$, $P = .049$) because less ER motion occurred at the dominant shoulder with advancing age. We found no differences in rotation motion in the dominant shoulder across ages ($F_{4,205}$ range, 0.451–1.730, $P > .05$).

Conclusions: This range-of-motion profile might be used to assist with the interpretation of normal and atypical shoulder rotation motion in this population. Chronologic characteristics of athletes had no influence on range-of-motion adaptations in the thrower's shoulder.

Key Words: shoulder, throwing, range of motion

Key Points

- A normative population profile for rotational shoulder motion in the uninjured high school pitcher has been established.
- Side-to-side differences existed with external rotation and internal rotation at 90° of abduction but not with external rotation at 0° of abduction.
- Age at the time of testing was a significant negative predictor of external rotation at 90° of abduction for the dominant shoulder but was not a significant predictor of internal rotation at 90° of abduction or total shoulder motion.
- The number of years the athletes had been pitchers and the ages at which the athletes began pitching did not account for a large portion of the variability in the dominant shoulder motions tested.

Among high school baseball players, the throwing shoulder is the most common site of injury (17%).[1] The act of pitching alone accounts for more than 13% of all injuries in this group.[1] Therefore, prevention and treatment of shoulder injuries in the high school pitcher are clinical priorities. When shoulder motion is impaired, its restoration is a key component of rehabilitation.[2,3] In the general population, normal motion is determined by the motion available in the uninjured limb. However, an increase in glenohumeral external rotation (ER) and a corresponding loss of internal rotation (IR) at 90° of abduction when the throwing and nonthrowing limbs are compared is well documented in the baseball athlete.[2–12] This shift in motion (ie, ER gain and IR loss) has been attributed to repetitive microtraumatic stresses placed on the shoulder during the throwing motion.[2,3] Adaptations in rotational shoulder motion manifest during adolescence in the uninjured baseball athlete, become more pronounced with advancing age, and are greater in pitchers than positional players.[9] Therefore, when assessing the thrower's shoulder, a simple bilateral comparison is not adequate for determining whether these athletes have "normal" shoulder motion.

Limitations are associated with side-to-side comparisons when determining whether a baseball athlete has impaired rotation motion. Investigators have linked asymmetric total motion, which is defined as glenohumeral IR loss or ER gain greater than 5° on bilateral comparison, with shoulder lesions in the baseball athlete.[5,13] However, these studies were retrospective. Consequently, it is unclear whether asymmetric total motion is a risk factor contributing to injury or a response to injury. In the athlete with symmetric total motion, it is unclear if or at what point the magnitude of IR loss and ER gain becomes a risk factor for injury. Tightness of the posterior soft tissue structures causing IR deficit might contribute to an increase in anterior humeral head translation.[2,3] Excessive ER as a consequence of anterior shoulder laxity might result in similar humeral head kinematics. Although considered normal adaptations in the overhead athlete, these soft tissue imbalances and joint pathomechanics have been implicated in throwing injuries, including functional (anterior) shoulder instability and internal impingement.[2,3] Development of a normative population data set for glenohumeral ER and IR motion is necessary to aid in the interpretation of shoulder range-of-motion measurements for the baseball athlete.

Researchers have described shoulder motion for large samples of youth baseball athletes. Meister et al[8] reported shoulder motion in 294 uninjured baseball players aged 8 to 16 years. Levine et al[9] reported shoulder range of motion in 298 uninjured baseball athletes aged 8 to 28 years. Consistent with previous reports, both groups of investigators reported increases in ER and losses of IR at 90° of abduction in the throwing limb compared with the nonthrowing limb.[8,9] Although they studied large samples, Meister et al[8] and Levine et al[9] included a broad range of ages and did not discriminate between pitchers and positional players. Therefore, these studies have limited usefulness in establishing a normative profile of shoulder motion in the high school baseball pitcher.

Factors contributing to adaptations in shoulder motion are unclear. In a study of professional baseball athletes, Bigliani et al[12] reported no relationship between the age of the player or years of professional career and shoulder range of motion. In contrast, Meister et al[8] and Levine et al[9] each reported more pronounced adaptations in shoulder motion with advancing age among adolescent baseball players. However, they did not perform statistical tests to evaluate the relationship between age and motion.[8,9] Thus, the influence of age and years of sports experience on shoulder motion remains unclear. Identification of a relationship between chronologic factors contributing to adaptations in motion might provide further insight into athletes who may be at risk for shoulder injury.

For rehabilitation specialists attempting to identify athletes at risk for injury or determining readiness for sport participation after an injury, establishing normal shoulder motion to promote successful (ie, injury-free) sport participation is critical. Therefore, the primary purpose of our study was to develop a normative profile of glenohumeral rotation motion in uninjured high school baseball pitchers, including ER at 0° of abduction and IR and ER at 90° of abduction. The secondary purpose of our study was to evaluate chronologic characteristics, including age at the time of testing, number of years competing as a pitcher, and age at which athletes began pitching, to determine what effect these factors have on the development of adaptations in shoulder rotation motion.

METHODS

Participants

Two hundred ten male high school baseball pitchers (age = 16 ± 1.1 years, range, 14–18 years; height = 1.8 ± 0.1 m, range 1.6–2.0 m; mass = 77.5 ± 11.2 kg, range, 54.4–107.3 kg) were recruited from Minnesota, California, and Arizona. Average experience as a pitcher was 6 ± 2.3 years (range, 3–14 years). Forty-eight athletes were left-hand dominant, and 162 were right-hand dominant. We defined the *dominant arm* as the arm with which the athlete threw a ball. To be eligible for study participation, the athletes were required to be 14 to 18 years old and to have pitched competitively in organized baseball in any capacity for the 3 consecutive years before the study. People reporting that they played multiple positions could participate, but their primary position had to be pitcher. Participants also had to be unrestricted in baseball activities and to have no upper extremity injury at the time of testing. They completed the *Quick*DASH Outcome Measure (Institute for Work & Health, Toronto, ON), which is a shortened version of the Disabilities of the Arm, Shoulder and Hand Outcome Measure (DASH; Institute for Work & Health). The *Quick*DASH is an 11-item self-assessment instrument that instructs participants to rate their abilities to perform daily, work, and sporting activities on a 5-point scale, ranging from 1 (*no difficulty*) to 5 (*unable*). It has been found to be a reliable substitute for the DASH for the assessment of upper extremity function.[14] A *Quick*DASH sports score of 10% or lower was required to ensure that the athletes were not limited in baseball participation secondary to symptoms affecting the throwing limb. A physical examination of both upper extremities was conducted by either a board-certified sports physical therapist (W.J.H.) or a fellowship-trained orthopaedic surgeon (K.M.K.) to confirm the absence of injury to either limb. Athletes who did not meet all eligibility criteria were disqualified from study participation. Age groups differed by mass, years of pitching experience, and number of participants per group (Table 1). We found no difference in height across age groups. Participants and parents provided written informed consent, and the study was approved by the Mayo Clinic Institutional Review Board.

Table 1. Demographics by Age

	Limb Dominance, No.		Height, m		Mass, kg		Pitching Experience, y	
Age Group, y	Right	Left	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
14 (n = 23)	19	4	1.8 ± 0.1	1.6–2.0	67.7 ± 11.0	54.4–93.0	5 ± 1	3–8
15 (n = 42)	33	9	1.8 ± 0.1	1.7–2.0	72.1 ± 11.0	56.7–95.3	6 ± 2	3–9
16 (n = 66)	55	11	1.8 ± 0.1	1.7–2.0	81.5 ± 19.0	54.4–107.3	7 ± 2	3–12
17 (n = 63)	44	19	1.8 ± 0.1	1.7–2.0	79.8 ± 8.9	54.4–99.8	7 ± 2	3–12
18 (n = 16)	11	5	1.9 ± 0.1	1.7–1.9	83.0 ± 8.3	72.1–106.6	9 ± 2	6–14

Procedures

A 5- to 10-minute warmup consisting of stretching, jogging, and short-toss activities was performed before testing began. Next, passive shoulder range of motion was conducted in a standardized order, including ER at 0° of abduction, ER at 90° of abduction, and IR at 90° of abduction on the right limb followed by the left limb. A single examiner conducted all tests. The examiner stabilized the glenohumeral joint by placing the palm of 1 hand on the anterior aspect of the shoulder over the clavicle, coracoid process, and humeral head.[4] Next, the participant's limb was taken through a full arc of passive range of motion until an end point was reached. *End of motion* was defined as a cessation of motion or the point at which scapular movement was appreciated.[13] An assistant positioned the goniometer and recorded the end-point shoulder angle. The examiner was blinded to all measurements.

All tests were conducted with participants lying supine and a towel roll positioned under the humerus to align the upper limb in a neutral position (humerus level with the acromion process).[13,15] Shoulder range of motion was measured using a standard, long-arm goniometer with a bubble level secured to the stationary arm to assist with device alignment.[4,8,13] Measurements were performed using standard goniometric techniques as described by Norkin and White[15]; the axis of the device was aligned with the olecranon, the moving arm was parallel to the forearm in alignment with the ulnar styloid process, and the reference arm was perpendicular to the ceiling (ER at 0° of abduction) or the floor (ER and IR at 90° of abduction). Two trials were performed for each motion of interest. Test-retest reliability was assessed in a sample (n = 10) of uninjured adults, and intraclass correlation coefficients ranged from 0.944 to 0.990 for all motions measured. Trial-to-trial variability for the motion measurements collected during the study was less than 5°.

Data Analyses

The peak values of the 2 trials for each motion were averaged and used for analysis. Descriptive statistics were calculated for the variables of interest, including ER at 0° of abduction, ER at 90° of abduction, and IR at 90° of abduction for each limb. In addition, the total arc of rotation motion was calculated for each limb by adding ER and IR measured at 90° of abduction. As Wilk et al[2] described, the total motion concept is an alternative means of evaluating glenohumeral rotation in the baseball athlete. This method defines normal motion as a loss of IR motion that is equivalent to the gain in ER. The total motion assessment technique permits within-person side-to-side comparisons to establish what normal shoulder motion is for each person. The throwing shoulder is considered equal to the nonthrowing shoulder when a side-to-side difference of 5° or less exists.[2] Paired *t* tests were performed to analyze motion between limbs for the group. An analysis of variance (ANOVA) was performed to analyze motion by age. When differences were identified, pairwise comparisons were performed using a post hoc Tukey test. Linear regressions were performed to determine the influence of participant age, number of years of pitching experience, and age at which the participant began pitching on limb motion. The α level was set a priori at .05. We used SPSS (version 19; SPSS Inc, Chicago, IL) for statistical analysis.

RESULTS

For the group, we found no side-to-side differences in ER at 0° of abduction ($t_{209} = 0.658$, $P = .51$) (Table 2). We found side-to-side differences in ER ($t_{209} = -13.012$, $P < .001$) and IR ($t_{209} = 15.304$, $P < .001$) at 90° of abduction because ER increased an average of 10° and IR decreased an average of 15° in the dominant limb compared with the nondominant limb (Table 2). We found a difference in total shoulder rotation motion ($t_{209} = -4.098$, $P < .001$) when comparing limbs, but this difference was 5° (Table 2).

For the group, participant age at the time of testing was a significant negative predictor of ER at 90° for the dominant shoulder ($R^2 = 0.019$, $P = .049$) because ER decreased in the dominant shoulder with advancing age; however, the amount of variability accounted for by the participant's age was small, as indicated by the R^2 value (Table 3). Age at the time of testing was not a significant predictor of IR at 90° of abduction or total shoulder rotation motion. The number of years of pitching experience and the age at which participants began pitching did not account for a large portion of the variability in any of the dominant shoulder motions tested (Table 3).

We found no differences in dominant-limb shoulder motion by age (Table 4; Figure). We found a difference across age groups in nondominant-limb motion at 90° of abduction for ER ($F_{4,205} = 2.738$, $P = .03$), IR ($F_{4,205} = 4.783$, $P = .001$), and total motion ($F_{4,205} = 5.283$, $P < .001$) (Table 4; Figure). Post hoc analysis indicated that ER at 90° of abduction was greater in the 15-year-old group than the 17-year-old group. Internal rotation at 90° of abduction was greater in the 16-year-old group than the 17-year-old group. Total motion measured at 90° of abduction was greater in both the 15- and 16-year-old groups than in the 17-year-old group.

Table 2. Group Side-to-Side Range of Motion

	Limb					
	Dominant		Nondominant			
Range of Motion	Mean ± SD, °	90% Confidence Interval, °	Mean ± SD, °	90% Confidence Interval, °	*P* Value	t_{209} Value
External rotation at 0° of abduction	84 ± 11	64, 101	84 ± 10	67, 100	.51	0.658
External rotation at 90° of abduction	130 ± 11	113, 148	120 ± 10	100, 136	<.001[a]	–13.012
Internal rotation at 90° of abduction	60 ± 11	41, 80	75 ± 11	55, 91	<.001[a]	15.304
Total motion	190 ± 15	166, 216	195 ± 15	168, 218	<.001[a]	–4.098

[a] Indicates difference.

Table 3. Influence of Age at Testing, Years of Pitching Experience, and Age at Which Athlete Began Pitching on Dominant Limb Motion at 90° of Abduction

Variable	R^2	*P* Value
Age at testing		
External rotation	0.019	.049[a]
Internal rotation	0.002	.52
Total motion	0.018	.05
Years of pitching experience		
External rotation	<0.001	.89
Internal rotation	0.001	.65
Total motion	<0.001	.80
Age at which athlete began pitching		
External rotation	0.007	.22
Internal rotation	<0.001	.88
Total motion	0.003	.44

[a] Indicates difference ($P < .05$).

Table 4. Analysis of Variance for Comparison of Motion Across Age Groups

Range of Motion	Limb	$F_{4,205}$ Value	*P* Value
External rotation at 0° of abduction	Dominant	0.451	.77
	Nondominant	1.645	.16
External rotation at 90° of abduction	Dominant	1.730	.15
	Nondominant	2.738	.03[a]
Internal rotation at 90° of abduction	Dominant	0.475	.75
	Nondominant	4.783	.001[a]
Total motion	Dominant	1.598	.18
	Nondominant	5.283	<.001[a]

[a] Indicates difference ($P < .05$).

DISCUSSION

Our results provide a profile of glenohumeral rotation motion for the uninjured high school baseball pitcher. Establishing the range and average values for internal and external shoulder motion in this population was possible because of the large sample size and participant homogeneity relative to position and level of play. This normative database might be useful in assisting with the interpretation of shoulder range of motion and guiding athlete care after rehabilitation of an injury or during performance enhancement evaluation.[16] Earlier definitions of normal shoulder motion in the baseball athlete were based on summed IR and ER within 5° on bilateral comparison. This method of defining normal motion is limited because it does not permit an assessment of ER or IR in isolation. If a bilateral difference in total motion exceeds 5°, which motion is limited might be unclear. Alternatively, total motion that is deemed symmetric might mask abnormal motion. For example, an athlete might have symmetric total motion in the presence of above-average IR and limited ER. This limitation in ER might contribute to pain during throwing or compromised sport performance. Therefore, we advocate the use of the normative population data established in our study and a bilateral comparison of total motion when interpreting shoulder motion in the baseball pitcher.

The magnitude of side-to-side differences in motion that we identified is comparable to that identified by previous researchers, who described shoulder motion in the youth baseball athlete. Reports of ER gain in the throwing shoulder compared with the nonthrowing shoulder in the adolescent player have ranged from 6° to 11°, and reports of IR loss have ranged from 2° to 13°.[8,9,17] Bilateral comparisons have indicated that the limbs are symmetric relative to total rotation motion, with side-to-side differences averaging less than 5°.[8,9,17] In comparison, we identified an average 10° ER gain and 15° IR loss when comparing the throwing and nonthrowing shoulders. Although we identified a difference in total motion when comparing limbs, it was less than 5° and was not considered clinically meaningful.

In contrast, larger ranges of glenohumeral IR and ER motion have been reported for uninjured youth baseball players (Table 5). One potential source of this disparity might be the participants' ages included in the studies. Meister et al[8] reported a decrease in total motion with advancing age when evaluating passive glenohumeral rotation in youth baseball athletes, with the most dramatic decline observed between 13- and 14-year-old athletes. Levine et al[9] did not evaluate differences in the magnitude of ER and IR motion in the dominant shoulder across age groups. However, visual inspection suggests they found clinically meaningful differences in motion between participants aged 8 to 12 years and participants aged 13 to 28 years. The results reported by Meister et al[8] and Levine et al[9] emphasize the importance of evaluating motion in a group of participants who are of equivalent physical maturity. Although we did not collect radiographic data to evaluate skeletal maturity, we found a difference of less than 5° between the 14- and 18-year-old participants for each motion assessed at both extremities. Furthermore, age at the time of testing was not a meaningful predictor of shoulder motion. This suggests that all the high school baseball pitchers (14 to 18 years) were appropriately considered as a single group.

Methodologic differences also might contribute to the range of values that has been described for shoulder motion in youth baseball athletes. We measured motion after the participants completed a warmup. This might explain, in part, why the average glenohumeral motions we reported were greater than values reported by previous investigators. However, a warmup process often is neglected in studies in which upper extremity range of motion is assessed. Peterson et al[18] measured passive shoulder ER motion in tennis players before and after a sport-specific warmup, which consisted of stretching, practice swings, and serves. They reported an increase of 7° in ER motion after the warmup. In addition, the investigators reported a difference when comparing the motion obtained during the first trial with that obtained during the third trial for both testing sessions. They concluded that shoulder range of motion is dynamic when the limb is cold.[18] We incorporated a comparable sport-specific warmup. We believe this aspect of the testing protocol allowed us to capture the true extensibility of the shoulder joint. A potential limitation of our study that might have affected the results was that we did not randomize the testing order. The soft tissue extensibility gained after the warmup might have been compromised in motions assessed at the end of the testing session. However, the time needed to complete the protocol was, on average, less than 10 minutes. Therefore, we do not believe the failure to randomize the testing order had a great effect on shoulder motion. Confirming the effect of testing sequence on shoulder mobility in this population is difficult because previous investigators[5,8,9] used similar testing sequences to assess shoulder motion.

Shoulder stabilization technique is another methodologic component that might contribute to the disparity in shoulder motion reported for the baseball athlete. Wilk et al[4] evaluated the effects of 3 stabilization approaches on shoulder IR mo-

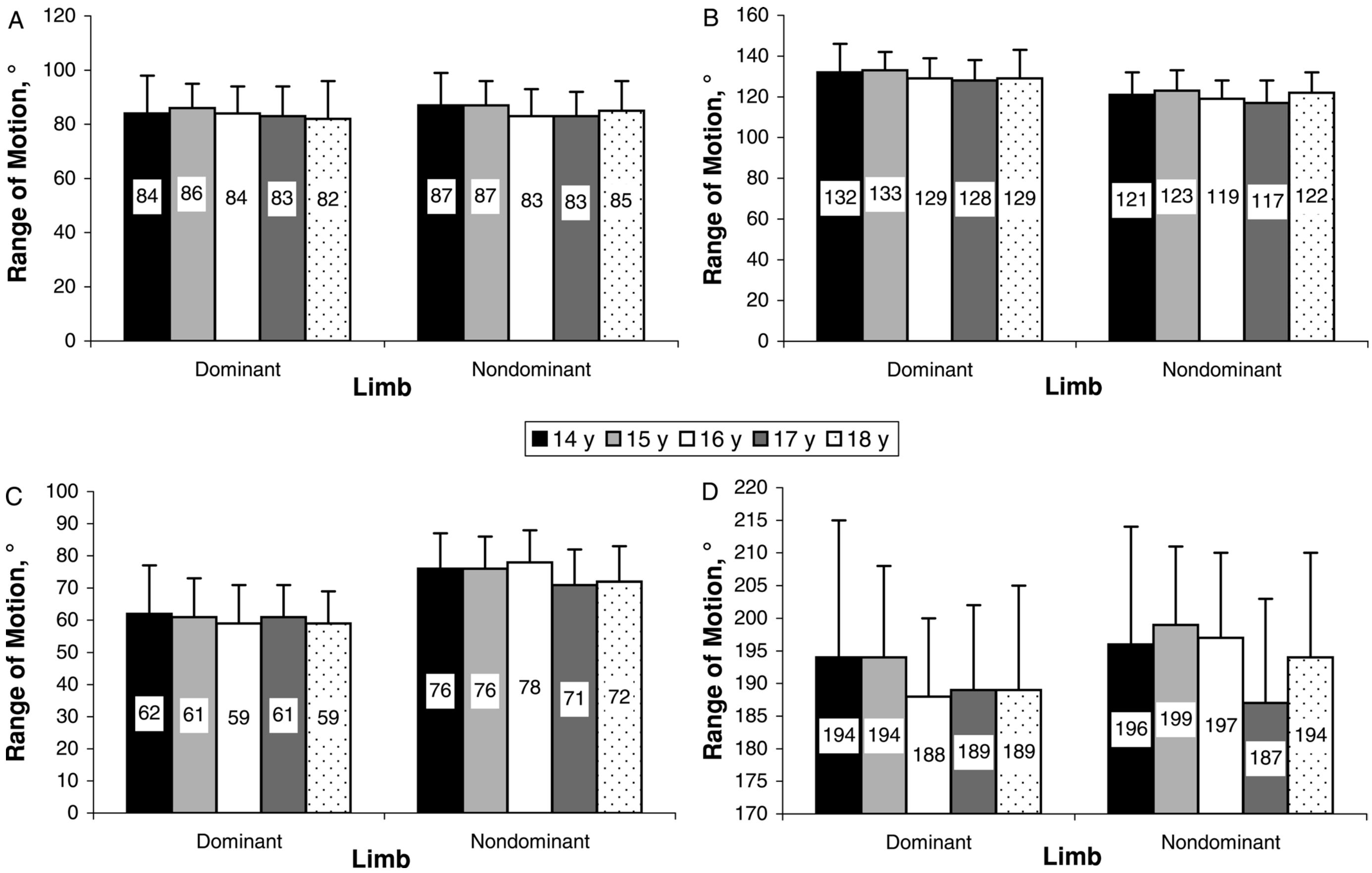

Figure. Range of motion for the dominant and nondominant limbs by age group. A, External rotation at 0° of abduction. B, External rotation at 90° of abduction. C, Internal rotation at 90° of abduction. D, Total rotation motion at 90° of abduction.

Table 5. Comparison of Mean Shoulder Motion in Youth Baseball Athletes Across Studies

Investigation	Participant Age Range, y	External Rotation at 90° of Abduction, °	Internal Rotation at 90° of Abduction, °
Our study	14–18	130	60
Meister et al[8]	8–16	143	36
Levine et al[9]	8–12	96	33
Levine et al[9]	13–14	115	40
Levine et al[9]	15–28	109	38

tion, including visual inspection of substitution to identify the motion endpoint with no shoulder stabilization; stabilization by placing the palm over the clavicle, coracoid process, and humeral head (the method we used); and stabilization by grasping the coracoid process and the spine of the scapula posteriorly. They reported differences in motion based on shoulder stabilization technique and suggested the use of a standardized approach to allow clinicians to compare patient findings and researchers to compare data. The authors advocated the use of the stabilization technique that included grasping the coracoid process and the spine of the scapula posteriorly.[4] The rationale was that this technique permitted adequate stabilization with the least effect on glenohumeral arthrokinematics. However, the authors did not have 3-dimensional data to support this statement. Furthermore, we found it difficult for a single examiner to adequately stabilize the shoulder with this approach and take the limb through a full range of motion. Consequently, we chose to stabilize the shoulder with an anterior placement of the examiner's hand. In future applications of the normative data we described, researchers should attempt to replicate the methods for comparisons to be valid.

We found no side-to-side differences in motion when measuring ER at 0º of abduction. Few researchers have described ER motion with the limb by the side among a sample of baseball athletes because motion in the throwing position in this population is of greater interest. Reagan et al[7] measured glenohumeral range of motion and humeral retroversion in 54 asymptomatic collegiate baseball athletes. Although adaptations occurred in rotation motion at the throwing shoulder with the limb in 90º of abduction, the side-to-side difference in ER with the limb by the side was less than 1º. In addition, no difference was found in IR motion measured with the limb by the side (using the spinal touch method). Reagan et al[7] did report a correlation between humeral head retroversion and rotation motion measured at 90º of abduction. These findings prompted them to conclude, in agreement with other investigators,[10,19,20] that the shift in rotation motion in the thrower's shoulder might be related more strongly to adaptive changes in osseous humeral anatomy than to changes in soft tissues. However, Reagan et al[7] did not comment on the absence of side-to-side differences at 0º of abduction or any relationships between humeral retroversion and shoulder rotation with the limb by the side. Given the large sample size and our primary purpose, we did not assess shoulder joint mobility or osseous anatomy. Future investigators should consider relationships between shoulder rotation motion and osseous anatomy with the limb in nonthrowing positions to gain further insight into mechanisms contributing to adaptations in the thrower's shoulder.

Speculating that specific capsular adaptations might be contributing to asymmetric shoulder motion as a consequence of throwing is reasonable. The anterior shoulder capsule is described as having 3 components: the superior, middle, and inferior glenohumeral ligaments, with the inferior glenohumeral ligament composed of anterior and posterior bands.[21–23] The anterior band of the inferior glenohumeral ligament limits anterior humeral head translation when the limb is abducted to 90º, which is the throwing position.[24] In contrast, the superior and middle glenohumeral ligaments are the primary restraints to anterior humeral head translation when the limb is in 0º of abduction.[25] Greater extensibility of the anterior band of the inferior glenohumeral ligament could explain, in part, why ER of the throwing limb increased in 90º of abduction but not when the limb was by the side.

However, researchers have indicated that adaptations in the anterior shoulder capsule are not the source of asymmetric shoulder motion in the baseball athlete. Using instrumented stress arthrometry, Borsa et al[11] measured bilateral passive shoulder stiffness in 34 asymptomatic professional baseball pitchers. They reported no difference in anterior joint stiffness between shoulders. In a separate study, Borsa et al[26] used ultrasound imaging to measure glenohumeral translation with the limb externally rotated to 90º of abduction in 43 asymptomatic professional baseball pitchers under stressed and nonstressed conditions. The investigators reported no differences in translation between the throwing and nonthrowing limbs. Borsa et al[26] concluded that these findings provided additional evidence to support the assertion that range-of-motion alterations are more likely because of osseous as opposed to capsular adaptations. The contribution of adaptations in osseous and soft tissue structures to the shift in rotation motion in the thrower's shoulder is unclear. The absence of side-to-side differences in rotation motion with the limb by the side suggests that the effect of these adaptations is dependent on limb position.

No differences existed in shoulder motion of the dominant limb across age groups. We found less motion in the nondominant limb of 17-year-old pitchers than in 15- and 16-year-old pitchers. Meister et al[8] reported a decline in IR shoulder motion for both limbs in baseball pitchers aged 8 to 16 years. The largest changes in rotation motion occurred between ages 12 and 13 years for the dominant limb and between ages 14 and 15 for the nondominant limb. They found no change in ER motion across ages. The authors hypothesized that the decrease in motion was a consequence of an increase in tissue stiffness associated with age-related increases in collagen. A modest decrease in shoulder motion with advancing age also has been found in nonthrowers. Jansson et al[27] studied shoulder range of motion and laxity in 1227 school children aged 9 to 12 years and reported that total rotation motion was 3º less in boys aged 12 years than in boys aged 9 years. It is possible that we did not observe greater differences in shoulder motion across age groups because of the more advanced age of the participants in our study. Interestingly, whereas the nondominant limb demonstrated less motion in athletes aged 17 years in our study than in younger athletes, the motion in the oldest participants (18 years) was not different from that in the youngest participants (14 years). The rationale for the decrease in motion for the 17-year-old group is unclear. It is possible that a transition occurred in training or sports participation at this age, contributing to changes in joint flexibility. Alternatively, we had few participants in our 18-year-old group (n = 16). A larger sample of participants this age might provide greater insight into adaptive changes in shoulder motion as baseball athletes reach their late teens. Longitudinal studies in which shoulder motion is tracked in the same athlete through maturation will provide the greatest insight into the effect of age and playing patterns on shoulder motion patterns.

None of the chronologic variables we evaluated had a meaningful effect on shoulder rotation motion. Furthermore, we did not find a difference in motion in the dominant limb across ages. The effects of the age at which the athlete began pitching, total years as a pitcher, and the athlete's age at the time of testing on shoulder motion remain controversial. In a study of professional baseball athletes, Bigliani et al[12] reported no relationship between the age of the player or years of professional career and shoulder range of motion. In contrast, Kibler et al[28] found a negative correlation between total range of motion in the dominant shoulder and years of tournament play in elite tennis players, who are overhead athletes exhibiting adaptations in shoulder motion comparable to those of baseball athletes. One potential source of the apparently contrasting findings is the average age of the athletes in the 2 studies. The athletes evaluated by Bigliani et al[12] had a mean age of 23 years and had been professional athletes for 3 years. Participants whom Kibler et al[28] studied had a mean age of 18 years and had been in tournament play for 8.8 years.

We believe the inability to capture the volume of throwing (or tennis) activities is a potential reason for the inconsistencies across studies in which the influence of athlete age and experience on shoulder motion were evaluated. Age and years of experience are intended to be indicators of how much throwing a given person has performed. The inference is that more experience participating in a given sport results in more repetitions of a given skill, yielding more pronounced adaptations. However, chronologic variables do not capture the number of pitches thrown or innings and leagues in which the athlete has participated. We do not believe these data might be obtained retrospectively with a high level of precision. Consequently, we advocate conducting studies to prospectively capture the volume of baseball activities to gain insight into factors contributing to adaptations in shoulder motion.

CONCLUSIONS

We evaluated shoulder motion in a large, homogeneous sample of high school baseball pitchers. The results obtained with this design provide a normative profile describing glenohumeral rotation motion for this population, which might be used to assist clinicians and researchers in the interpretation of shoulder rotation motion in this population. Our results are consistent with those of other researchers who described side-to-side differences in total rotation motion but did not identify an influence of athlete chronologic characteristics on range-of-motion adaptations in the thrower's shoulder.

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A Profile of Glenohumeral Internal and External Rotation Motion in the Uninjured High School Baseball Pitcher, Part II: Strength

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Context: A database describing the range of normal rotator cuff strength values in uninjured high school pitchers has not been established. Chronologic factors that contribute to adaptations in strength also have not been established.

***Objectives*:** To establish a normative profile of rotator cuff strength in uninjured high school baseball pitchers and to determine whether bilateral differences in rotator cuff strength are normal findings in this age group.

Design: Cohort study.

Setting: Baseball playing field.

Patients or Other Participants: A total of 165 uninjured male high school baseball pitchers (age = 16 ± 1 years, height = 1.8 ± 0.1 m, mass = 76.8 ± 10.1 kg, pitching experience = 7 ± 2 years).

Main Outcome Measure(s): Isometric rotator cuff strength was measured bilaterally with a handheld dynamometer. We calculated side-to-side differences in strength (external rotation [ER], internal rotation [IR], and the ratio of ER:IR at 90° of abduction), differences in strength by age, and the influence of chronologic factors (participant age, years of pitching experience) on limb strength.

Results: Side-to-side differences in strength were found for ER, IR, and ER:IR ratio at 90° of abduction. Age at the time of testing was a significant but weak predictor of both ER strength ($R^2 = 0.032$, $P = .02$) and the ER:IR ratio ($R^2 = 0.051$, $P = .004$) at 90° of abduction.

Conclusions: We established a normative profile of rotator cuff strength for the uninjured high school baseball pitcher that might be used to assist clinicians and researchers in the interpretation of muscle strength performance in this population. These data further suggested that dominant-limb adaptations in rotator cuff strength are a normal finding in this age group and did not demonstrate that these adaptations were a consequence of the age at the time of testing or the number of years of pitching experience.

Key Words: shoulder, muscle physiology, throwing

Key Points

- A normative population profile for rotational shoulder strength in uninjured high school pitchers has been established.
- Side-to-side differences existed for external rotation strength, internal rotation strength, and ratio of external rotation to internal rotation strength.
- External rotation strength and ratio of external rotation to internal rotation strength increased as age increased in the dominant limb.
- Age at the time of testing did not predict internal rotation strength.
- The number of years of pitching experience did not predict strength measurements in the dominant limb.

Shoulder injuries are prevalent among baseball athletes at all levels of play.[1–3] Pitchers are particularly vulnerable to injury, with overuse rather than trauma dominating as the primary injury mechanism.[1–5] The cause of chronic injury in this population is cumulative microtrauma from the repetitive, dynamic overhand motion used to pitch a baseball.[6–8] Muscle weakness, specifically of the rotator cuff musculature, has been proposed as a possible risk factor for developing shoulder injury.[5,9–12] In a 5-year prospective study of 207 professional baseball pitchers, Byram et al[9] reported that pitchers who exhibited external rotation (ER) muscle weakness during the preseason were more likely to experience a subsequent injury that necessitated surgery. The authors concluded that assessing preseason muscle strength might be an effective strategy for identifying athletes at risk for injury and might provide the opportunity to prescribe training programs for injury prevention.[9]

Rotator cuff strength in the uninjured baseball athlete has been described.[10–20] Bilateral strength differences, including less ER strength[10,17,20] and greater internal rotation (IR) strength[11,14,16] of the throwing shoulder than of the nonthrowing shoulder, have been reported. In addition, lower ER:IR strength ratios have been reported in the asymptomatic throwing shoulder than in the nonthrowing shoulder of the baseball athlete.[11,13,16,18,20] This difference in ER:IR strength ratios results predominantly from the presence of greater dominant-limb internal rotators without a similar dominance effect in the external rotators.[11,15] Despite the plethora of studies in which shoulder strength in baseball athletes has been described, a descriptive profile of rotator cuff strength in the uninjured high school baseball pitcher has not been established. Investigations in which researchers have described rotator cuff strength in this population have been limited by small sample sizes (range, 22–39 participants).[16,18] Such small sample sizes are inadequate for capturing the broad range of normative values that might exist in an uninjured population. Consequently, what constitutes "normal" strength values for the high school pitcher is unclear. It is also unclear whether strength adaptations identified in the throwing limbs of collegiate and professional pitchers are present in this younger group of athletes.

Because of the critical functional role of the rotator cuff muscles, objective evaluation of shoulder IR and ER strength is important during rehabilitation of the injured thrower and in preparticipation evaluations.[11] In baseball, prevention and treatment of injuries in the youth athlete provide unique opportunities to potentially minimize the likelihood of incurring degenerative injuries later in the playing career.[6] Therefore, the primary purpose of our study was to establish a normative profile of rotator cuff strength in the uninjured high school baseball pitcher and to determine whether bilateral differences in rotator cuff strength are normal findings in this age group. We hypothesized that the high school pitcher would present with asymmetric rotator cuff strength. The secondary purpose of our study was to determine the influence of age at the time of testing and years of pitching experience on rotator cuff strength in this population. Specifically, we hypothesized that greater IR and less ER strength would be associated with advancing age and years of pitching experience because strength adaptations would become more pronounced with extended baseball participation.

METHODS

Participants

Volunteers for this study (n = 165) were uninjured male high school baseball pitchers recruited from a larger study sample (n = 210) described in part I of this 2-part study.[21] Of these 165 participants (age = 16 ± 1 years, height = 1.8 ± 0.08 m, mass = 76.8 ± 10.1 kg, pitching experience = 7 ± 2 years), 37 were left-hand dominant and 128 were right-hand dominant. We defined the *dominant arm* as the arm with which the athlete threw a ball. The participants' height, mass, and years of pitching experience progressively increased as their ages increased (Table 1). To be eligible for participation in the study, the athletes were required to have competed the 3 consecutive years before the study primarily as a pitcher in organized baseball in any capacity, to be uninjured and unrestricted in baseball activities at the time of testing, and to be aged 14 to 18 years. Athletes who had a history of upper extremity injury were eligible if they had made a full return to baseball participation at the time of testing. Uncompromised sports participation was validated with a Disabilities of the Arm, Shoulder and Hand Outcome Measure (Institute for Work & Health, Toronto, ON) sports score of 10% or less, with lower scores equating to higher levels of function. A musculoskeletal examination of both upper extremities was performed by an orthopaedic surgeon (K.M.K.) or board-certified sports physical therapist (W.J.H.) to confirm the absence of injury. Participants and parents provided written informed consent, and the research protocol was approved by the Mayo Clinic Institutional Review Board.

Procedures

Before testing was initiated, all participants performed a 5- to 10-minute warmup consisting of stretching, jogging, and short-toss activities. Isometric muscle force was assessed with a handheld dynamometer (Commander PowerTrack II; JTECH Medical, Salt Lake City, UT) using a break test. The measurement range of the unit was 1 to 125 lb (0.45–56.25 kg), with a manufacturer-reported mechanical precision of 99%. Two examiners performed all strength testing, and an assistant recorded the results. The participant and examiner were blinded to the results. Trial-to-trial variability within and between examiners was less than 5 lb (2.25 kg). The validity and reliability of upper extremity strength assessment with handheld dynamometers have been established.[22–24]

The testing order was standardized and consisted of IR and ER strength of the right and left upper extremities. During testing, participants were seated on a bench or table without trunk support and with the hips and knees flexed to 90º. The seated position was chosen because it was considered more functional than the supine or prone position. During all tests, the limb was in 90º of abduction and modified neutral for shoulder rotation, with the elbow flexed to 90º (Figure 1). We chose the 90º abduction position because we considered it to be functional for the baseball athlete. Internal rotation positioning of the humerus during isometric strength testing was selected because this rotational position has been shown to promote high activity of the infraspinatus and subscapularis muscles while minimizing force contributions from other muscle groups.[25] Participants could stabilize themselves by grasping the table with the nontesting limb.[26] An assistant stabilized the distal aspect of the upper limb that was being tested[26] and the contralateral shoulder to maintain consistent participant positioning throughout testing and to minimize any attempts at substitution. The point of resistance during testing was just proximal to the radial styloid process. The dynamometer was positioned on the dorsal surface of the limb during ER strength testing and on the volar surface during IR testing. Participants were taught the testing procedures and then performed 2 maximal-effort practice trials for each muscle group before testing began. Next, participants completed 2 trials that were each approximately 5 seconds in duration at each limb position, and they rested for a minimum of 30 seconds between trials.

Table 1. Participant Demographics

	Limb Dominance, No.		Height, m		Mass, kg		Pitching Experience, y	
Age Group, y	Right	Left	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
14 (n = 19)	16	3	1.75 ± 0.09	1.60–1.96	68.20 ± 12.10	54.00–92.25	4 ± 1	3–6
15 (n = 33)	26	7	1.80 ± 0.08	1.68–1.96	73.39 ± 11.16	56.25–94.50	6 ± 2	3–9
16 (n = 59)	47	12	1.83 ± 0.07	1.65–1.98	79.39 ± 11.21	54.00–100.35	7 ± 2	3–12
17 (n = 45)	33	12	1.85 ± 0.07	1.70–2.01	81.46 ± 9.53	54.55–105.75	7 ± 2	3–12
18 (n = 9)	6	3	1.85 ± 0.08	1.70–1.93	81.62 ± 6.46	72.27–92.27	9 ± 2	7–13

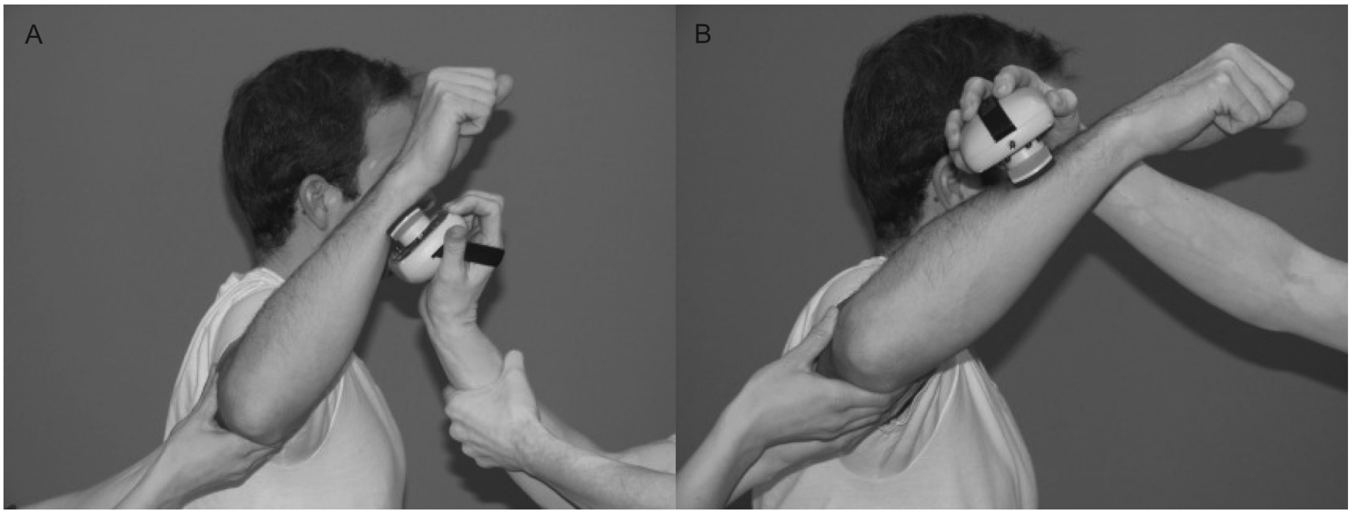

Figure 1. Participant positioning. A, Internal rotation strength testing. B, External rotation strength testing.

Data Analyses

Strength data were normalized to each person's mass to permit comparisons among participants. The peak values of the 2 trials for each motion were averaged and used for analysis. Paired *t* tests were performed to identify side-to-side differences in strength for the group. Differences in strength across age groups were evaluated with a univariate analysis of variance. When differences were identified, pairwise comparisons were performed using a post hoc Tukey test. Linear regressions were performed to determine the influence of participant age and years of pitching experience on dominant-limb strength. The α level was set a priori at .05. We used SPSS (version 19; SPSS Inc, Chicago, IL) for statistical analysis.

RESULTS

When evaluating side-to-side differences for the group, we found differences for all measures of interest (Table 2). External rotation strength was lower in the dominant than the nondominant limb ($t_{164} = 2.014$, $P = .046$). Internal rotation strength was higher in the dominant than in the nondominant limb ($t_{164} = -3.832$, $P < .001$). Finally, the ratio of ER:IR strength was higher in the nondominant than the dominant limb ($t_{164} = -5.125$, $P < .001$).

Across age groups, we found no differences in strength for the dominant limb (Table 3; Figure 2). For the nondominant limb, we found differences in the ratio of ER:IR strength ($F_{4,160} = 3.958$, $P = .004$), with the 14-year-old group demonstrating a lower ratio of ER:IR strength than the 16- and 17-year-old groups. We found no other differences in strength across age groups for the nondominant limb (Table 3; Figure 2).

Participant age at the time of testing was a significant predictor of ER strength ($R^2 = 0.032$, $P = .02$) and the strength ratio of ER:IR ($R^2 = 0.051$, $P = .004$) at 90° for the dominant shoulder (Table 4). Strength increased with advancing age; however, the amount of variability in strength accounted for by the participant's age was small. Age at the time of testing did not predict IR strength, and years of pitching experience did not predict strength measurements in the throwing limb (Table 4).

DISCUSSION

Descriptive studies are necessary to enable effective and accurate data interpretation.[27] By evaluating a large sample of athletes who were homogeneous in terms of age and position played, we provided a normative profile of rotator cuff strength in the uninjured high school baseball pitcher. Advantages of the data we reported include the ability to replicate the testing procedures in almost any setting with equipment that is widely available. Furthermore, these data add to the literature by providing an additional means for medical staff to assess rotator cuff strength beyond a side-to-side comparison. In the general population, a side-to-side comparison is often performed to identify deficits in muscle strength. Because of the demands placed on the dominant limb of an overhead athlete, strength in the dominant limb is not expected to be equivalent to that in the nondominant limb. Thus, population-specific strength data

Table 2. Group Strength Results[a]

	Dominant Limb		Nondominant Limb			
Motion at 90° of Abduction	Mean ± SD	90% Confidence Interval	Mean ± SD	90% Confidence Interval	*P* Value	t_{164} Value
External rotation	17.5 ± 4	12.2, 23.5	17.9 ± 4	11.8, 23.9	.046[b]	2.014
Internal rotation	18.7 ± 5	11.5, 27.1	17.7 ± 4	10.7, 26.8	<.001[b]	–3.832
External rotation to internal rotation ratio	96 ± 22	68.9, 132.6	105 ± 23	74.3, 135.3	<.001[b]	–5.125

[a] All strength values are reported as percentages of body mass.
[b] Indicates difference.

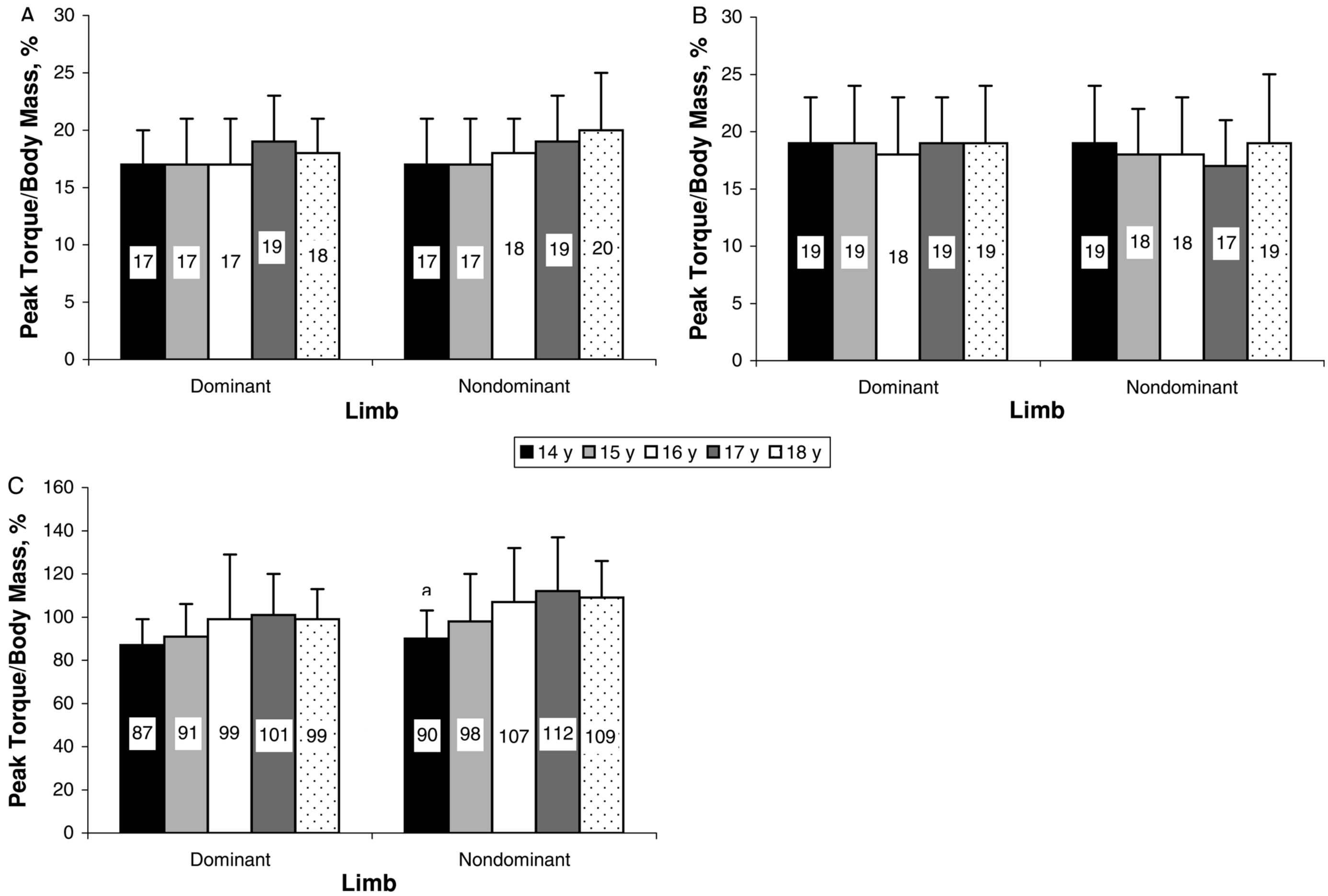

Figure 2. Strength of the dominant and nondominant limbs by age group. A, External rotation at 90° of abduction. B, Internal rotation at 90° of abduction. C, Ratio of external to internal rotation at 90° of abduction. [a]Indicates difference in strength across ages ($F_{4,160}$ = 0.004, $P < .05$).

have been recommended for use in rehabilitation and prevention of shoulder injuries.[11,28]

Consistent with previous investigations[10,11,14–18,20] and in agreement with our hypotheses, we identified side-to-side rotator cuff strength asymmetries in the uninjured baseball pitcher. External rotation strength was lower for the dominant than the nondominant limb. The opposite pattern was observed for IR strength because these muscles were stronger in the dominant limb. The 2 muscle groups function differently during the pitching motion. The internal rotators act concentrically during the acceleration phase of the pitching motion. Hinton[16] described the muscle activity of the internal rotators during pitching as resembling a plyometric type of training, in which an explosive concentric muscle contraction (acceleration) follows a maximal stretch (limb cocking). Similar types of plyometric muscle training have been found to greatly enhance muscle power.[29] In contrast, the external rotators act eccentrically during the deceleration phase of the pitching motion.[30,31] Eccentric loading has been shown to cause intramuscular connective tissue tearing, which can lead to a cycle of chronic inflammation and muscular weakness.[16,32,33] Thus, differences in the type of muscle contraction being performed during the pitching motion are potentially the source of limb-specific adaptations in muscle strength in this population.

Table 3. Analysis of Variance for Comparison of Strength Across Age Groups

Motion at 90° of Abduction	Limb	$F_{4,160}$ Value	P Value
External rotation	Dominant	2.139	.08
	Nondominant	2.364	.06
Internal rotation	Dominant	0.708	.59
	Nondominant	0.480	.75
External rotation to internal rotation ratio	Dominant	2.203	.07
	Nondominant	3.958	.004[a]

[a]Indicates difference.

Although we identified side-to-side differences in muscle strength, these differences were less than 1% for both IR and ER peak torque relative to body mass. The magnitude of these side-to-side differences falls within the range of our measurement error. Within-examiner and between-examiners variability for strength measures was less than 5 lb (2.25 kg), which translates to less than 3% peak torque/body mass measurement variability for the sample. Both examiners were trained by the primary investigator (W.J.H.), who has 16 years of experience as a physical therapist and is a board-certified sports physical therapist. Furthermore, all testing was performed under the visual supervision of the primary investigator to ensure that the same methods were used at all times.

Table 4. Influence of Age at Testing and Years of Pitching Experience on Dominant-Limb Strength at 90° of Abduction

	R^2	*P* Value
Age at testing		
External rotation	0.032	.02[a]
Internal rotation	0.001	.74
External rotation to internal rotation ratio	0.051	.004[a]
Years of pitching experience		
External rotation	0.009	.22
Internal rotation	0.001	.75
External rotation to internal rotation ratio	0.002	.55

[a] Indicates difference.

When visually inspecting the distribution of strength values, we noted that the data set exhibited a normal bell-shaped curve with no skewness or kurtosis. Thus, we believe these values represent the range of what constitutes normal strength. Given that our primary purpose was to identify the range of strength values for the population, we believe the variability inherent to our strength measures is more than acceptable. Thus, these data suggest that in the high school pitcher, the strength of the dominant limb is similar to that of the nondominant limb.

It is unclear whether bilateral symmetry in strength is adequate for long-term effective and injury-free sports performance in this group of overhead athletes. Therefore, we advocate interpreting shoulder strength in the dominant limb of a baseball athlete using both a bilateral comparison and a comparison relative to normative population data to identify any limitations in muscle performance. Future studies that incorporate a prospective design will be necessary to determine whether a point exists at which inadequate muscle strength is a risk factor for injury or negatively affects pitching effectiveness.

The ratio of ER:IR strength was lower in the dominant limb (9%) than the nondominant limb. These results are consistent with those of previous investigators,[11,13,16,18,20] who found the ratio of ER:IR strength to be lower in the dominant than the nondominant limb (range, 4%–11%) secondary to gains in IR strength of the dominant limb in the absence of corresponding gains in ER strength. A proper balance between agonist and antagonist muscle groups is thought to provide dynamic stabilization to the inherently unstable shoulder joint.[28] The range of optimal ER:IR muscle strength in the overhead athlete has been defined as 66% to 75%.[28,34] However, the strength ratios we reported are markedly higher than these previously reported values. In the thrower's position, we measured ER:IR strength ratios of 96% and 105% in the dominant and nondominant limbs, respectively (Table 2). However, most researchers who have evaluated shoulder strength in baseball pitchers have used isokinetic testing modes to assess concentric muscle strength at speeds ranging from 90°/s to 300°/s.[13–16,20,35] In contrast, Donatelli et al,[10] Magnusson et al,[17] and Byram et al[9] used handheld dynamometers to assess isometric rotator cuff strength in professional baseball pitchers. Using similar methods, these authors described ratios of ER:IR strength (range, 72%–142%) that were comparable to the results we reported. The discrepancy in strength performance during isokinetic compared with isometric muscle contractions might be explained, at least in part, by the force-velocity relationship. The greatest force production occurs during eccentric muscle contractions followed by isometric contractions, and high-speed contractions typically elicit the lowest muscle force.[36] Strength assessed during an eccentric contraction is greatest secondary to internal muscle force production as the muscle is forcibly lengthened, which stresses the elastic components of the contractile structure.[36] Isometric testing conditions result in greater force production than isokinetic testing because more time exists for cross-bridge formation, which is one of the primary contributors to force production, to be completed. Positioning the limb in midrange during isometric testing also takes advantage of the force-length principle, which stipulates that maximal force production is possible when optimal actin and myosin overlap is present.[37] When the muscle is shortened or lengthened beyond the full resting length, the probability of actin and myosin interaction is less, and muscle tension decreases.[37]

Previous work supports this physiologic rationale as the basis for differences in the ER:IR strength ratios we identified. In isokinetic studies, researchers assessing eccentric muscle performance have reported higher eccentric ER to concentric IR strength ratios than researchers evaluating concentric performance of both muscle groups.[19] Furthermore, Knapik et al[38] reported that muscle torque production during strength testing was greater during isometric conditions than isotonic or isokinetic testing modes. It is possible that ER strength deficiencies elicited during isokinetic testing of the baseball athlete are a consequence of the testing mode and do not precisely capture the strength production capabilities of this muscle group. These results emphasize that differences exist in the type of information garnered based on the methods used for strength assessment. Thus, isometric assessment techniques might be more useful for identifying discrete strength deficits. Isokinetic strength assessment using high speeds and eccentric contractions might provide greater insight into functional performance in throwers, including muscle fatigability and speed of contraction. Information from both testing modes might be valuable in designing injury prevention and rehabilitation exercise programs.

The secondary purpose of our study was to identify chronologic factors that might affect dominant-limb strength in the uninjured high school baseball pitcher. Adaptations in shoulder strength associated with baseball participation have been described for athletes from high school to professional levels of play.[14,16,19] Expecting more pronounced adaptations in muscle strength to be associated with physical maturation and longevity of sport participation would be reasonable. However, none of the chronologic variables we evaluated had a meaningful effect on shoulder rotational strength. We did not identify differences in strength for the dominant limb by age, and although age at the time of testing predicted ER strength and the ER:IR strength ratio, the amount of variability accounted for by the athlete's age was quite small. The ranges of ages and pitching experiences of our participants possibly were not large enough to capture the influence of chronologic characteristics on rotator cuff strength in the baseball pitcher. Alternatively, other factors, including the volume of throwing activities, might have an effect on muscle strength adaptations. We were unable to assess the influence of the number of innings pitched or pitches thrown on strength because we did not believe that a retrospective collection of this information could be captured with a high level of accuracy. We advocate that future investigators assess strength across a spectrum of ages and prospectively capture the volume of throwing activities to identify factors that contribute to muscle strength adaptations in the baseball pitcher.

Our study had limitations. It is important for clinicians to replicate the methods in this investigation when using the normative population data. Alternative testing positions or methods might affect muscle force production and thereby influence the interpretation of the athlete's strength. Multiple testing positions, including supine, prone, seated with support, and seated without support, have been described for assessment of rotator cuff strength. We performed strength testing in an unsupported, seated position to approximate a position of function for the baseball athlete and to facilitate reproduction of the study's methods in almost any environment. However, this position introduces the potential for compensatory motions and the inability to control scapular position. Substitutions were limited with instruction, practice, and use of a second examiner, and the participant was allowed to stabilize (ie, grasp the table) with the nontesting limb. The methods we used have been described. Tyler et al[26] reported having a second examiner manually stabilize the limb of participants who were in a seated position. In addition, the seated position is often the position used during isokinetic testing.[13,16,20] Bak and Magnusson[39] described participants grasping the sitting surface with the nontesting limb during the strength assessment to increase stability. We acknowledge that the most functional assessment of muscle activity would be with the athlete standing and the muscles of interest working as a component of the whole-body kinetic chain. However, we believe the standing position would have introduced too much variability in the participant's ability to stabilize the trunk and upper extremity. Under these circumstances, the ability to accurately capture the force-producing capabilities of the rotator cuff musculature would be unacceptably compromised. Finally, our evaluation of the influence of age on strength adaptations included groups of unequal sizes. The 18-year-old age group included only 9 participants. Thus, associations between age and rotator cuff strength might have been masked in this investigation secondary to a small sample within this subgroup.

CONCLUSIONS

Isometric shoulder IR and ER strength was tested in 165 uninjured high school baseball pitchers. Strength data for these muscle groups and the ratio of ER:IR strength established a normative profile of rotational shoulder strength for the high school baseball pitcher. These data are important for clinicians to use when interpreting strength performance in athletes who are attempting to return to play after an injury and when individualizing training enhancement programs. These data also suggested that unilateral adaptations in dominant-limb strength are a normal finding in these young athletes.

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Performance After Rotator Cuff Tear and Operative Treatment: A Case-Control Study of Major League Baseball Pitchers

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Context: Little is known about pitching performance or lack of it among Major League Baseball (MLB) pitchers who undergo operative treatment of rotator cuff tears.

Objective: To assess pitching performance outcomes in MLB players who needed operative treatment of rotator cuff tears and to compare performance in these athletes with that in a control group of MLB players.

Design: Case-control study.

Setting: Publicly available player profiles, press releases, and team injury reports.

Patients or Other Participants: Thirty-three MLB pitchers with documented surgery to treat rotator cuff tears and 117 control pitchers who did not have documented rotator cuff tears were identified.

Main Outcome Measure(s): Major League Baseball pitching attrition and performance variables.

Results: Players who underwent rotator cuff surgery were no more likely not to play than control players. Performance variables of players who underwent surgery improved after surgery but never returned to baseline preoperative status. Players who needed rotator cuff surgery typically were more experienced and had better earned run averages than control players.

Conclusions: Pitchers who had symptomatic rotator cuff tears that necessitated operative treatment tended to decline gradually in performance leading up to their operations and to improve gradually over the next 3 seasons. In contrast to what we expected, they did not have a greater attrition rate than their control counterparts; however, their performances did not return to preoperative levels over the course of the study.

Key Words: pitching, clinical outcome, shoulder

Key Points

- Pitchers who had operative treatment of symptomatic rotator cuff tears tended to have a gradual decline in performance before surgery and to improve gradually over the 3 seasons after surgery.
- The attrition rate was not greater in pitchers who had operative treatment than in the control pitchers.
- Pitchers who had surgery for rotator cuffs tears did not return to their preoperative performance levels during the study period.

Rotator cuff tears (RCTs) can cause great pain and dysfunction in both work-related and non–work-related activities of daily living, as well as loss of shoulder motion and strength. Without treatment, full-thickness RCTs can be career-ending injuries for professional athletes. Although tears often occur in patients aged 40 years and older,[1,2] overhead athletes, particularly professional baseball pitchers, present a unique cohort of athletes at great risk for this type of overuse injury.

Professional baseball pitchers subject the rotator cuff to supraphysiologic loads that lead to rotator cuff tendinitis, partial-thickness RCTs, and, in advanced stages, full-thickness RCTs.[3–5] At one time, RCT was considered a career-ending injury for a Major League Baseball (MLB) pitcher. As the approach to the operative and nonoperative management of RCTs in athletes has evolved over the past 3 decades, the goal of operative treatment of partial-thickness and full-thickness tears in these elite-level athletes also has changed. Whereas pain relief and restoration of function are considered good outcomes in a general population, the goal for MLB pitchers is to return to athletic competition with the same preinjury performance ability.

Subjective patient-derived outcomes and physician-derived physical examination variables often are improved after rotator cuff surgery in elite pitchers; however, return of players to athletic performance at high levels has been variable.[4,6,7] Mazoué and Andrews[4] reviewed the results of 12 professional pitchers who underwent repair of full-thickness RCTs of the dominant shoulder and noted that only 1 player (8%) was able to return to a high competitive level of baseball without great shoulder dysfunction. Similarly, Reynolds et al[6] examined preoperative and intraoperative findings of 82 professional pitchers who had undergone debridement of partial-thickness RCTs and found that most athletes returned to competitive pitching; however, returning to their previous levels of competition remained a challenge for many players. Little is known about postoperative pitching performance among pitchers who return to MLB play. Performance outcomes have been described in MLB pitchers who have undergone repair of the ulnar collateral ligament[8] and repair of isolated glenoid labral injuries.[9] Therefore, the purpose of our study was to describe pitching performance outcomes in MLB players who needed surgery to treat RCTs and to compare performance variables and return to play between these athletes and a randomly selected cohort of MLB players. We hypothesized that players who had operative treatment of RCTs would be less likely to return to play in any given year than a randomly selected group of players. In addition, we hypothesized that rotator cuff surgery (RCS) would have a deleterious effect on athletic performance variables.

METHODS

Our main outcomes of interest were performance-based factors that were continuous measures; therefore, a power analysis was conducted based on the *t* test for independent samples. For an α level of .05 and a power of 0.8, a harmonic mean number of 50 players was necessary to detect a medium standardized difference (Cohen d = 0.5) for the outcomes of interest. Our study exceeded this number, with 33 affected players and 117 control players (harmonic mean = 51 players).[10]

Data were reviewed for 33 MLB pitchers who pitched in at least 1 MLB game before undergoing surgery to treat RCTs. All pitchers appeared in more than 1 game before surgery, and most pitchers appeared in several games during multiple seasons. Pitchers were identified from team injury reports, press releases, and player profiles indicating that they underwent surgery to treat RCTs in their pitching shoulders. We did not determine whether a patient had a partial-thickness or a full-thickness tear. Furthermore, we could not determine the surgical approach or technique. Data obtained were available via Article XIII, Section C of the Major League Baseball Players Association's collective bargaining agreement, which provides standards for injury reporting in MLB. It states, "Application by a Club to the Commissioner to place a Player on the Disabled List shall be accompanied by a Standard Form of Diagnosis" that "shall be completed by the Club physician."[11]

Surgery was performed between 1976 and 2003. Age and MLB pitching experience were determined at the time of surgery. Body mass index (BMI), throwing handedness, all-star status, and pitching role (starting or relief pitcher) were recorded for each pitcher (Table 1). Body mass index was calculated from height and mass data. The date of return to MLB play was recorded, and the duration from surgery to return was calculated. Mean innings pitched (IP) per season, earned run average (ERA), walks and hits per inning pitched (WHIP), and strikeouts per 9 innings (K/9) were compared for each MLB pitcher for 3 seasons before (preindex seasons 1, 2, and 3) and after (postindex seasons 1, 2, and 3) surgery. Preindex season 1 was defined as the season immediately before the operative year, and postindex season 1 was defined as the season immediately after the operative year. This resulted in a study duration of 7 consecutive seasons for each player. The ERA is the average number of earned runs allowed per 9 innings pitched. An earned run is any run scored by the opposing team for which the pitcher is held accountable. Walks and hits per inning are determined by dividing the sum of walks and hits by the total number of innings pitched. The K/9 is defined as the sum of strikeouts divided by 9 innings. These are standard measures of pitching performance in MLB.

A control group was selected to allow comparison of the treated players with a sample of players representing all MLB pitchers who did not undergo rotator cuff surgery. Every fifth name was selected from a complete alphabetical roster of MLB pitchers from the 2000 season for a total of 117 pitchers in the control group. For this cohort, the 2000 MLB season was defined as the index (equivalent to the operative year for the operatively treated pitchers) year for this cohort. Similarly, data were obtained for 3 seasons before (preindex seasons 1, 2, and 3) and after the index year (postindex seasons 1, 2, and 3). Players with a known history of rotator cuff surgery were excluded from this list before selection. Pitchers were not excluded from

Table 1. Demographics of Pitchers in the Rotator Cuff Surgery and Control Groups

Variable	Group: Rotator Cuff Surgery (n = 33)	Group: Control (n = 117)	t[a]	χ^2	*P*
Baseline earned run average[b,c]	3.93 ± 1.01	5.95 ± 2.41	4.71	NA	<.001[d]
Age, y[c]	30.87 ± 3.88	28.57 ± 4.17	2.82	NA	.005[d]
Preindex Major League Baseball seasons[c]	7.82 ± 3.32	5.43 ± 4.04	3.16	NA	.001[d]
Body mass index[c]	25.41 ± 2.10	26.92 ± 1.99	3.77	NA	.001[d]
Preindex all-star status[e]					
All-star	17 (51.5%)	17 (14.5%)	NA	18.0	<.001[d]
Not all-star	16 (48.5%)	100 (85.5%)			
Throwing handedness[e]					
Right	26 (78.8%)	88 (75.2%)	NA	0.03	.84
Left	7 (21.2%)	29 (24.8%)			
Pitching role[e]					
Starting pitcher	24 (72.7%)	48 (41%)	NA	9.13	.003[d]
Reliever	9 (27.3%)	69 (59%)			

Abbreviation: NA, not applicable.

[a] Indicates t_{148} except for baseline earned run average (t_{103}).

[b] Earned run average in first season in database.

[c] Compared with independent-samples *t* tests. Equal variances were not assumed.

[d] Indicates significant difference.

[e] Compared with χ^2 test with Yates correction for continuity.

the control group on the basis of any other reported injuries or operative procedures. Age and MLB pitching experience were determined using the 2000 season. The same demographic and performance variables noted earlier were obtained for the control group as for the RCS group.

Because our data were obtained from publicly available sources, they were exempt from institutional board review.

Statistical Analysis

Comparisons of demographic factors between these groups and differences between those who returned to play after the index season and those who did not were conducted with 2-sided t tests for independent samples (equal variances not assumed) when the data were continuous and with the χ^2 test with Yates correction when the data were categorical or binary. When the numbers in the categories were 5 or less, a Fisher exact test was used. Paired-samples t tests were used to compare IP, ERA, WHIP, and K/9 between the 3 seasons before surgery and the 3 seasons after surgery. A similar calculation was done for the control group. Independent-samples t tests were used to compare the change in performance between groups.

Binary logistic regression was performed in both a univariate and multivariate fashion to determine risk factors for attrition and to compare groups while adjusting for potentially confounding factors. Multivariate binary logistic regression was performed with the backward likelihood ratio method using greater than 0.10 as the criterion for removal of a variable at each iteration. Finally, postindex season games played was determined for each player, and a Kaplan-Meier survival analysis was performed to determine whether a difference was found in time to attrition between players who had RCS and those who had not. The log-rank test was used to compare the differences between survival curves for the RCS and control groups. The α level was set a priori at .05. All statistics were calculated using SPSS (version 15.0; SPSS Inc, Chicago, IL).

RESULTS

Pitchers who underwent RCS were more often older, were more experienced, were more often starters, had a lower BMI, and were more likely to be all-stars than control pitchers. Seventy-three percent (24/33) of pitchers returned to MLB play at a mean of 17 months after surgery. No pitchers in the RCS group returned to MLB play during the index year. Twenty (61%) pitchers in the RCS group returned to MLB play during postindex season 1. Three (9%) pitchers in this group returned to MLB play by postindex season 2. One (3%) pitcher in the RCS group returned to MLB play by postindex season 3.

When the RCS group performance was compared between preindex and postindex seasons, the greatest changes were observed between preindex season 2 and the postindex seasons (Table 2). When the differences between preindex season 3 and postindex seasons were examined, fewer postindex innings were played in postindex seasons 1 (67.9 fewer; $t_{20}=3.6$, $P=.002$) and 2 (65.1 fewer; $t_{16}=3.4$, $P=.004$). Because of attrition, fewer pitchers played in postindex season 3; therefore, although players played 57.8 fewer innings, this finding was not different ($t_{12}=2.1$, $P<.05$). We also noted a decline in WHIP ($t_{16}=-2.5$, $P=.03$) and K/9 ($t_{16}=2.3$, $P=.04$) between preindex season 3 and postindex season 2. We observed no other differences between preindex season 3 and any other postindex season. We found no changes between preindex season 1 and any postindex season.

Table 2. Important Performance Factors From Preindex Season 2 to Postindex Seasons 1, 2, and 3 in Players who Underwent Rotator Cuff Surgery[a]

Seasons	Innings Pitched	t^b	P	Games Played	t^b	P	Walks and Hits per Inning Pitched	t^b	P	Strikeouts per 9 Innings	t^b	P	Earned Run Average	t^b	P
Preindex 2–postindex 1 (n=21)	68.80	4.22	<.001[c]	14.57	3.32	.003[c]	−0.14	−1.92	.07	0.86	2.19	.04[c]	−1.03	−2.90	.009[c]
Preindex 2 – postindex 2 (n=17)	70.62	3.83	.001[c]	8.59	2.01	.06	−0.17	−2.53	.02[c]	1.15	3.60	.002[c]	−1.32	−3.25	.005[c]
Preindex 2–postindex 3 (n=13)	67.89	2.85	.02[c]	7.69	1.25	.24	−0.20	−1.92	.08	0.81	1.91	.08	−1.40	−2.02	.07

[a] Comparisons were made using paired-samples t tests.

[b] Indicates t_{20} for preindex season 2 to postindex season 1, t_{16} for preindex season 2 to postindex season 2, and t_{12} for preindex season 2 to postindex season 3.

[c] Indicates significant difference.

When the change in innings played from preindex to postindex seasons was compared between the RCS and control groups ([control group preindex – postindex] – [RCS group preindex – postindex]), we noted a greater change for the RCS group than the control group between preindex season 3 and postindex season 1 (63.7 fewer innings; $t_{36.6}=-2.9$, $P=.007$), between preindex season 3 and postindex season 2 (52.1 fewer innings; $t_{25.5}=-2.4$, $P=.03$), and between preindex season 2 and postindex seasons 1, 2, and 3 (57.9 [$t_{57.9}=-3.1$, $P=.004$], 60.1 [$t_{25.1}=-2.9$, $P=.008$], and 54.1 [$t_{53.9}=-3.4$, $P=.001$] fewer innings, respectively). We also observed a greater decline in ERA between preindex season 2 and postindex season 1 (1.45 lower ERA; $t_{81.7}=2.1$, $P=.04$). We found no other differences in the change in performance preindex to postindex between the RCS and control groups.

Figure 1 illustrates the dramatic decline in IP in preindex season 1 and a steady increase in IP over the 3 postindex seasons. Compared with the RCS group, the control group averaged fewer IP at baseline and demonstrated a more consistent performance pattern over the course of the study period. The RCS group pitchers had better baseline ERAs but demonstrated an upward trend in ERA throughout the postindex period (Figure 2). The control group demonstrated more dramatic fluctuations in ERA; however, these did not follow a distinct trend. Changes in WHIP and K/9 from preindex to postindex seasons were not different between groups during any seasons compared. Figures 3 and 4 show that the RCS group began with better performance in terms of WHIP and K/9, respectively, and demonstrated a slight trend toward poorer postindex WHIP and K/9 performance that was not significantly different.

Before other variables were accounted for, preindex experience, all-star status, and pitching role were each associated with lower odds of attrition ($P=.04$, .03, and .004, respectively; Table 3). We found no variables that, by themselves, conferred a higher risk of attrition. Specifically, RCS did not confer an increased risk of attrition in the period we studied ($P=.58$).

A multivariate binary logistic regression model for the probability of a player not returning was constructed, and the primary outcome of interest was a comparison of the RCS and control groups. In this model, age, BMI, preindex seasons, all-star status, starter status, throwing handedness, and baseline ERA were accounted for statistically as potential confounders. The backward likelihood ratio method was used for selection of variables with a probability of association with the outcome greater than 0.10 on the –2 log likelihood statistic as the criterion for removal at each iteration. Only the number of preindex MLB seasons ($P=.03$) and role as a starting pitcher ($P=.04$) were predictors (negative) for attrition. The BMI ($P=.1$) was a negative predictor of attrition, and age ($P=.09$) was a positive predictor; however, these variables were not significant predictors. Rotator cuff surgery was not a predictor of return to play. Age was a marginally significant positive predictor of attrition (Table 4). Post hoc analysis showed no multicollinearity and showed that the model fit the data well (Hosmer-Lemeshow statistic [df = 8] = 5.24, $P=.73$).

The Kaplan-Meier survival analysis showed that although the absolute number of games until attrition averaged 93.7 (median = 65 games) in the control group and 69.9 games (median = 31 games) in the RCS group, these findings were not different (log-rank statistic [Mantel-Cox] $\chi^2_{0.354}=1$, $P=.55$).

DISCUSSION

The purpose of our study was to describe pitching performance outcomes in MLB pitchers who had operative treatment of RCTs and to compare performance variables in these athletes with those of a randomly selected cohort of MLB players. We found that MLB pitchers who underwent surgery for RCT often were older, were more experienced, were more likely to be starting pitchers, and performed at higher preindex levels than the average MLB pitcher. More than one-fourth of pitchers who underwent RCS did not return to pitch at the MLB level. The pitchers in the RCS group who did return often missed at least 1 full season in recovery and did not return to their pre-

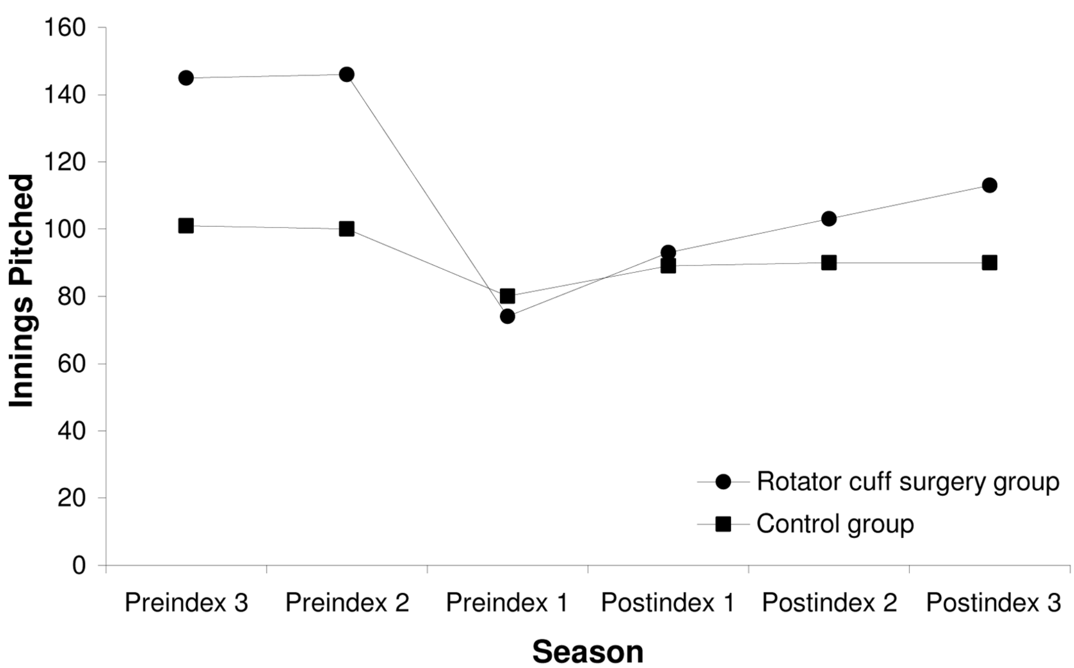

Figure 1. Innings pitched per season in the rotator cuff surgery and control groups over the study period.

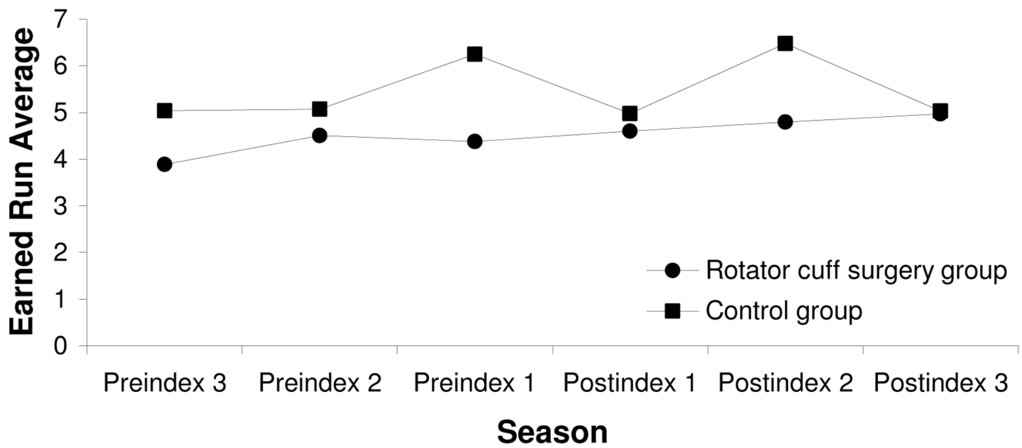

Figure 2. Earned run averages in the rotator cuff surgery and control groups over the study period.

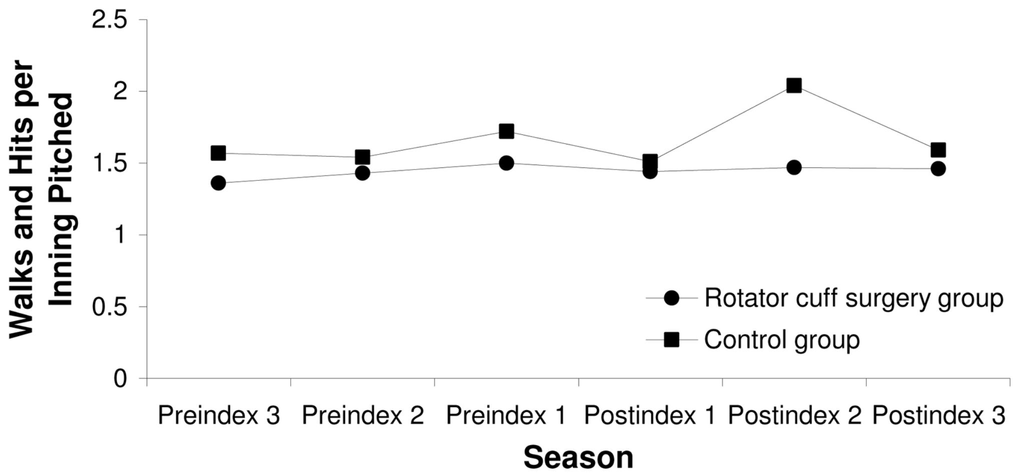

Figure 3. Walks and hits per inning pitched in the rotator cuff surgery and control groups over the study period.

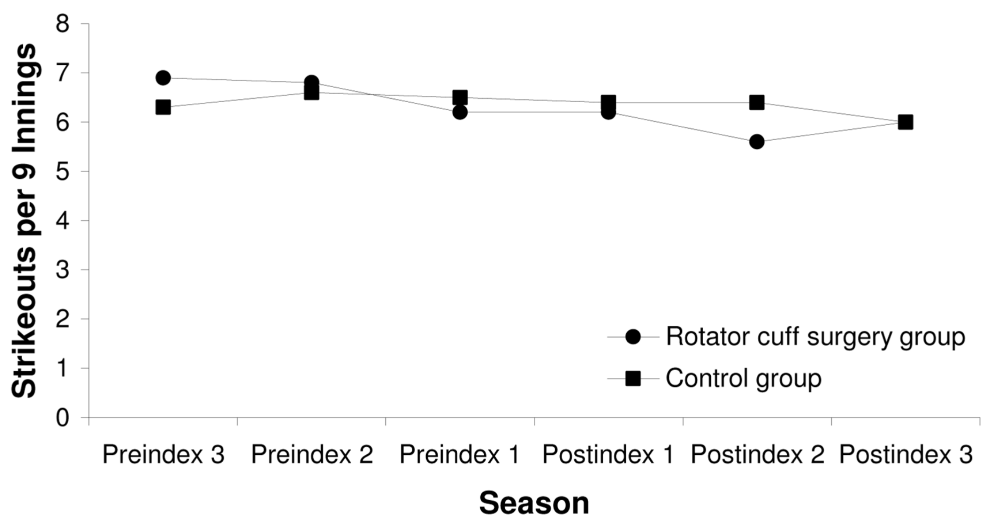

Figure 4. Strikeouts per 9 innings in the rotator cuff surgery and control groups over the study period.

Table 3. Univariate Binary Logistic Regression for Whether a Pitcher Leaves Major League Baseball in a 3-Year Period

Variable	Odds Ratio[a]	95% Confidence Interval	*P*
Rotator cuff surgery	0.80	0.36, 1.77	.58
Age	0.98	0.91, 1.06	.61
Body mass index	0.87	0.74, 1.02	.09
Experience (preindex seasons)	0.92	0.84, 0.99	.04[b]
Preindex all-star	0.42	0.19, 0.92	.03[b]
Starting pitcher	0.36	0.18, 0.72	.004[b]
Right-handed thrower	0.53	0.23, 1.23	.14
Baseline earned run average	1.10	0.97, 1.26	.14

[a] Higher odds ratios indicate higher probability of leaving Major League Baseball.
[b] Indicates significant difference.

Table 4. Multiple Binary Logistic Regression of Attrition From Play in Major League Baseball Pitchers

Variable	Odds Ratio[a]	95% Confidence Interval	*P*
Rotator cuff surgery	0.902	0.354, 2.299	.83
Age	1.149	0.977, 1.352	.09
Body mass index	0.857	0.713, 1.030	.10
Experience (preindex seasons)	0.824	0.691, 0.982	.03[b]
Starting pitcher	0.456	0.214, 0.971	.04[b]

[a] All variables were significant factors by –2 log likelihood in logistic regression, with the exception of rotator cuff repair, which was our primary outcome of interest.
[b] Indicates significant difference.

index levels of performance in the first 3 postindex seasons. Despite this decline, these pitchers demonstrated attrition rates that were similar to those of pitchers in the control group and continued to perform at levels that were higher than those of their peers. The most salient finding of our study was that players who developed RCTs and subsequently had surgery declined in performance, had surgery, and gradually improved, but they never reached their baseline levels of performance after surgery.

Rotator cuff tears are a common cause of pain, shoulder dysfunction, and loss of work in the general population.[12–14] In the elite athlete, symptomatic RCTs often prohibit competitive sport participation. The MLB pitchers place great demands on their shoulders, more specifically their rotator cuffs, and are at higher risk for overuse injury. However, few MLB pitchers actually undergo RCS, with only 33 players over 27 years identified in our study. Although pain relief continues to be an important treatment goal, MLB pitchers often seek treatment with the hope of rapid recovery, quick return to play, and high likelihood of regaining preoperative performance.

When comparing the demographics of MLB pitchers who underwent RCS with those who did not, we found that the pitchers in the former group were older, had pitched more preindex seasons, and were more likely to be starting pitchers. All these variables point to shoulder overuse as a factor that predisposes pitchers to RCTs and subsequent surgery. In fact, we found that players in the RCS group pitched an average of 45 more innings per season in the 3 preindex seasons than players in the control group. In addition to greater numbers of preindex IP, pitchers in the RCS group demonstrated higher preindex performance in other categories (lower ERA, lower WHIP, higher K/9) than pitchers in the control group. Wright et al[15] investigated plain radiographic findings in the shoulders of 57 MLB pitchers and noted that a greater number of IP was associated with increased degenerative changes of the dominant shoulder and elbow, such as osteophytes, cystic changes, joint space narrowing, and loose bodies. However, these radiographic findings were not predictive variables for a pitcher being placed on the disabled list.

In addition, although our survival analysis did not demonstrate a difference in the rate of attrition between groups, the control group included, on average, lower-functioning MLB pitchers and as a result might have been likely to demonstrate attrition irrespective of injury or retirement. On the other hand, the attrition demonstrated by the high-functioning RCS group was probably a direct result of injury or surgery. Logistic regression suggested that age, number of preindex seasons, and being a starting pitcher might play a greater role in attrition than rotator cuff surgery. This implies that the surgery itself might not be responsible but that this increased attrition might be an artifact of eventual burnout of these high-level athletes. The RCT and subsequent surgery might be part of this natural history. Pitchers who had RCS were older at the study's inception and therefore had already pitched more years in MLB than pitchers in the control group.

In terms of performance, the RCS group pitched fewer innings and exhibited higher ERAs, more WHIP, and a lower K/9 value in the postindex than the preindex seasons. Although changes in WHIP and K/9 were less substantial, pitchers did not return to their preindex levels of performance. In their review of 12 professional pitchers who underwent RCS of the dominant shoulder, Mazoué and Andrews[4] observed that many pitchers were able to return to pitching with good velocity and control but fatigued early, allowing them to pitch effectively for only a short period. In addition, several pitchers reported prolonged recovery times, meaning that they needed several days to weeks between outings to recover sufficient strength to pitch again.[4] We believe that these findings are consistent with the performance outcomes we observed. Yet we demonstrated that in the postindex period, the RCS group continued to function at a level that was generally higher than that of the average MLB pitcher. Over the postindex period, the pitchers in the RCS group showed a trend toward greater numbers of IP each year; however, their performance did not appear to improve in like form, and mean ERA increased in each postindex season. We cannot state definitively that performance decline is caused by rotator cuff tear or surgery and can assume only that injury and surgery played a large role in pitching performance. Payne et al[16] divided collegiate and professional overhead athletes into 2 groups (A and B) by history and mechanism of injury. Group A included 14 patients who had acute, traumatic injuries; 12 (86%) of these patients had satisfactory postoperative results, and 9 (64%) returned to preinjury sports after arthroscopic subacromial decompression and tear debridement. Group B included 29 overhead athletes who had insidious, atraumatic shoulder pain; 19 (66%) of these patients had satisfactory postoperative results, and 13 (45%) returned to preinjury sports after arthroscopic debridement.[16]

Our study had several other weaknesses, including a lack of preoperative imaging or intraoperative data regarding RCT size (eg, partial thickness, full thickness, tendons involved, retractions) and surgical technique (eg, single row, double row, arthroscopic, open, mini-open). Other researchers have been able to specifically evaluate these variables in their analyses. In addition, we lacked data on postoperative rehabilitation protocols and do not know how this variable influences performance outcome.[4,6] Mazoué and Andrews[4] evaluated full-thickness RCRs by a mini-open approach in 12 professional pitchers and noted that only 1 returned to pitch professionally over a 66.6-month follow-up. Reynolds et al[6] evaluated 82 professional pitchers who underwent debridement of small, partial-thickness RCTs and found that 76% were able to return to competitive pitching at the professional level and 55% were able to return to the same or higher level of competition. Tibone et al[7] looked specifically at the results of open repair of full-thickness RCTs in baseball players and included 5 professional baseball pitchers. Three (60%) of these pitchers were unable to play professional baseball after repair, and 2 (40%) players returned to professional pitching but had difficulties with throwing.[7] We do not know the chronicity, size, or character of the RCTs of the pitchers in our study and cannot comment on methods of surgical treatment, including debridement or repair. Although team injury reports, press releases, and player profiles were reviewed comprehensively, it is possible that some players who underwent surgery for an RCT were not identified or that these data sources were not accurate at times. We cannot comment on physical examination variables in the preoperative or postoperative setting, and our methods did not allow for assessment of satisfaction or patient-derived perceptions of outcomes. In addition, the treatment of RCTs changed much over the time of the study. Extensive changes have occurred in surgical procedures, and there have been some innovations in rehabilitation in the last decade. However, we believe that the findings are applicable in terms of the overall pathogenesis and course of this injury in high-level pitchers.

Despite these weaknesses, our study had notable strengths. We had a clearly defined study sample and outcome variables with adequate prestudy power to detect differences for the outcomes of interest. Each player was his own control during paired analyses, eliminating player-to-player variability; a separate control group was a sample of the entire cohort of MLB pitchers during the study period and represented the average MLB pitcher. Finally, we obtained data on pitchers for 3 preindex and 3 postindex seasons and were able to present performance trends over a substantial period.

CONCLUSIONS

Pitchers who had symptomatic RCTs that necessitated surgery tended to have a gradual decline in performance leading up to their surgery and to improve gradually over the next 3 seasons. In contrast to what we expected, they did not have a greater attrition rate than their control counterparts, but their performance did not return to preindex levels over the course of the study.

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original research

Perceptions of Clinical Athletic Trainers on the Spiritual Care of Injured Athletes

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Context: Treating both the body and the mind of an injured or ill patient is accepted as necessary for full healing to occur. However, treating the spiritual needs of the patient has less consensus.

Objective: To determine the perceptions and practices of certified athletic trainers (ATs) working in the college/university setting pertaining to spiritual care of the injured athlete.

Design: Cross-sectional study.

Setting: A survey instrument was e-mailed to a stratified random sample of 2000 ATs at 4-year colleges and universities.

Patients or Other Participants: Five hundred sixty-four participants (296 men, 234 women; 34 did not specify sex).

Main Outcome Measure(s): We measured the ATs' perceptions and practices related to spiritual care for athletes.

Results: We found that 82.4% of respondents agreed that addressing spiritual concerns could result in more positive therapeutic outcomes for athletes; however, 64.3% disagreed that ATs are responsible for providing the spiritual care. Positive correlations were found between personal spirituality and items favoring implementing spiritual care.

Conclusions: Athletic trainers have a conceptual appreciation of the importance of spiritual care for athletes, but the practicalities of how to define, acquire skills in, and practice spiritual care are unresolved.

Key Words: treatment, spirituality, holistic care

Key Points

- Athletic trainers agreed that addressing spiritual care of injured athletes could result in more positive therapeutic outcomes.
- Participants disagreed that providing spiritual care is their responsibility.
- Hesitancy by practitioners to incorporate spirituality into therapy might result from an inaccurate perception that providing spiritual care is synonymous with sharing personal spiritual beliefs.
- More research is needed to determine the scope and efficacy of practicing spiritual care with injured athletes.

Professionals who treat illness and injury have reached agreement on some of the components that must be addressed to bring individuals back to health. Most would agree that treating the body and mind results in a better recovery process. However, treatment that includes addressing the spiritual care of an ill or injured person has less consensus. The emerging premise from some fields is that, in addition to the body and mind, spirituality should be one of the dimensions that composes holistic care in the allied health care professions.[1,2] Ledger[1(p225)] claimed, "The patient has a right to receive holistic care, which includes cultural, religious and/or spiritual care." However, aspects of spiritual care are not identified easily because they emerge from the concept of spirituality, which has a myriad of interpretations. Reed[3] defined *spirituality* as follows: "In general, spirituality refers to an awareness of one's inner self and a sense of connection to a higher being, nature, others, or to some purpose greater than oneself." According to this definition, spirituality is neither religious expression, which is linked to the experience of external communal practices,[4] nor the psychology of healing, which concentrates more on the mind-body connection for addressing injury. Instead, spirituality and, more specifically, spiritual care places an emphasis on the injured person's phenomenologic or subjective experiences with a higher being.[4] We based our operational definition of *spirituality* for this study on the work of Reed.[3]

Studies in which researchers have evaluated health care workers' perceptions, attitudes, and beliefs concerning the provision of spiritual care are not as common as other types of research in spiritual care; however, they are available in nursing,[5–9] physical therapy (PT),[10–12] and occupational therapy (OT).[13] In nursing, "The Joint Commission has recognized that psychological, spiritual, and cultural values affect how patients respond to their care … [and] requires spiritual assessments and spiritual care for patients."[14(p33)] Most health care professionals have agreed that providing some type of spiritual care or support is an important part of their jobs;[6,10–13] however, they also have reported that their instruction in spiritual care was very limited and they would benefit from more.[7,11,13] Nurses have reported that personal characteristics are the most important factors in proving spiritual care[7] and have agreed that identifying spiritual needs is difficult (62%).[6] However, they have been divided on the difficulty of providing care (42% believe it is not too difficult, 47% believe it is difficult or very difficult).[6]

In addition to nursing, researchers in the fields of OT and

PT have started exploring attitudes about spirituality as part of a treatment plan. Although Engquist et al[13] stated that spiritual care should be added to the OT rehabilitation routine only if it is initiated by the patient, Coyne[10] argued that the move to include spiritual care in PT treatment was, in fact, patient driven. The PT student participants whom Highfield and Osterhues[11] studied suggested that simply listening to spiritual concerns, sharing research findings, and providing referrals to clergy were adequate spiritual interventions for PT patients. In Coyne's[10] interviews, the need to be supportive, positive, and present for patients, even if not always knowledgeable about the particular religion of the patient, also was stated as a necessity for physical therapists. The occupational therapists were not as sure, with most stating that they were "confused, undecided, or disagreed that spirituality holds a viable position in the scope of occupational therapy practice."[13(p176)]

Despite the emerging literature about spirituality in the referenced fields, no researchers to date have evaluated attitudes toward spirituality among athletic training professionals. Therefore, the purpose of our study was to determine the perceptions and practices of certified athletic trainers (ATs) working in the college/university setting pertaining to spiritual care of the injured athlete.

METHODS

Participants

A stratified random sample that was proportionate to the district membership distribution of the National Athletic Trainers' Association (NATA) was obtained through a request to the NATA for a random selection of 2000 e-mail addresses of certified members who currently were employed at 4-year colleges/universities and worked in the clinical setting. Of the 2000 surveys sent, 564 were returned. Although the return rate (28.20%) was less than ideal, the final sample matched within ±2% the same distribution by NATA district as the population, with the exception of District 8, which was overrepresented by 4.18% in our final sample (ie, the population representation for District 8 was 6.57% [n = 360] nationally and was 10.75% [n = 56] in the final sample).

The participants were somewhat evenly distributed across sex (52.5% men [n = 296], 41.5% women [n = 234]; 6.0% [n = 34] did not specify sex). However, they were not distributed evenly across race (86.87% white [n = 490]). Of the 5 age-group categories that were assessed, only ATs up to 24 years of age (representing 1.5% [n = 8] of the final sample) were not represented sufficiently; 24.4% (n = 129) of the sample was aged 25 to 29 years, 19.7% (n = 104) was aged 30 to 34 years, 17.0% (n = 90) was aged 35 to 39 years, and 37.4% (n = 198) was aged 40 years or more. In addition, 61.0% (n = 322) of the sample had 10 or more years of experience as an AT.

Most participants (51.88%, n = 275) were from public institutions. Participants at private, faith-based institutions accounted for 23.77% (n = 126) of the sample, and participants at private colleges accounted for 23.39% (n = 124) of all institutions. Five participants selected the "other" category (0.01%), and 34 participants (6.0%) did not select an institution type. Data were missing for 17 participants.

Participants provided informed consent when they clicked a button on the page that included the informed consent statement and were directed to the next page of the survey. The Institutional Review Board of Azusa Pacific University approved the study.

Instrument

We created a 50-item survey with multiple sections, all of which included a fixed-format item type. After informed consent was obtained, the survey began with the definition of spirituality from Reed.[3] Immediately after this definition, respondents were instructed to use a 4-point Likert scale (1 indicated *strongly disagree*, 4 indicated *strongly agree*) to rate their levels of agreement with 10 statements related to spirituality and athletic training approaches. The next section listed spiritually based clinical interventions (eg, "Praying for the athlete") and instructed participants to use a 3-point scale (1 indicated *not at all appropriate*, 3 indicated *very appropriate*) to rate how appropriate each intervention was for an AT to provide. The subsequent section repeated the list of interventions and instructed participants to identify which, if any, of those interventions they had used as part of the treatment process with an injured athlete. The next section listed 6 possible obstacles or challenges an AT could experience when attempting to provide spiritual care: "lack of knowledge concerning spiritual care," "lack of training in providing spiritual care," "lack of time to provide spiritual care," "discomfort with the subject of spirituality," "fear of imposing personal spiritual views on the athlete," and "difficulty identifying the injured athlete's need for spiritual care" (note: participants were not instructed to rate how much of an obstacle each factor was for them personally). Respondents were instructed to use a 4-point Likert scale (1 indicated *no obstacle*, 4 indicated *significant obstacle*) to rate how much of an obstacle each suggested challenge might be to an AT wanting to provide spiritual care to athletes. The final section of the survey was a reproduction of the Spiritual Perspective Scale (SPS), which originally was called the Religious Perspective Scale.[3] Using 6-point Likert scales, participants indicated how frequently they engaged in spiritual activities (1 signified *not at all*, 6 signified *about once a day*) and indicated their levels of agreement related to personal spirituality (1 signified *strongly disagree*, 6 signified *strongly agree*). The SPS scale has a reported reliability with a standardized α coefficient of 0.92.[13] Because the survey in our study was not conceptualized to measure a single construct and was not intended for further distribution after this study, it was not tested for reliability or validity.

Data Collection

To assess the coherence of the instrument, we piloted the survey with 20 ATs who were attending the Far West Athletic Trainers' Association Conference in 2008. We obtained both written and oral feedback, from which we altered the wording of some questions and revised the rating scale in a section. After final revisions, we obtained permission to use the SPS.

The survey and an informed consent statement were posted to a Web link that was e-mailed to the participants. We sent a follow-up e-mail 8 weeks later inviting ATs to complete the survey, giving participants 2 weeks more to provide their results.

Statistical Analysis

Various analyses were conducted to identify perceptions on the items measured by the instrument and to identify any group differences or meaningful patterns that emerged. Frequency analyses were calculated to determine the distribution of scores on all items. To test for group differences, analyses of covariance, *t* tests, and χ^2 analyses were calculated. We computed

Pearson product moment correlations and Spearman rank correlations to examine the relationships between summary scores from the SPS and the other outcome measures to determine if personal spirituality was associated with opinions about the spiritual treatment aspects of patient care.

RESULTS

Opinions About Spiritual Care for the Injured Athlete

General Opinions About Spiritual Care. Respondents rated their levels of agreement using a 4-point Likert scale, with 10 statements related to spirituality and athletic training approaches (Table 1). Based on a frequency analysis, 82.4% of the respondents (n = 761) agreed or strongly agreed that "Addressing the spiritual concerns of an athlete could result in a more positive outcome when treating an athletic injury (eg, faster return to play)," and 61.7% (n = 346) agreed or strongly agreed that "Research should be conducted to assess injured athletes' spiritual needs." Opinions about who is responsible for addressing the spiritual needs of athletes also were assessed. Participants to a large extent (63.9%, n = 357) disagreed or strongly disagreed that "Only spiritual experts should deal with spiritual issues of injured athletes," and 61.7% (n = 345) agreed or strongly agreed that "Athletic trainers should have some basic skills and knowledge necessary to support the spiritual needs of the injured athlete"; however, most respondents did not agree that spiritual support falls in the domain of an AT's scope of practice. Specifically, 64.3% (n = 362) of respondents disagreed or strongly disagreed with the statement, "If an athlete wishes it to be part of their [*sic*] recovery process, it is the athletic trainer's responsibility to provide spiritual care as part of treatment," and 66.6% (n = 373) agreed or strongly agreed that "Spiritual care is not in the athletic trainer's scope of practice." In addition, 59.3% (n = 334) of the sample disagreed or strongly disagreed that "Athletic Training Education Program curriculums should include the spiritual dimension as part of the comprehensive education curriculum."

Relationship Between Personal Spirituality and Opinions About Spiritual Care. Pearson product moment correlation coefficients were calculated to investigate the relationship between participants' SPS summary scores and their subsequent ratings of agreement on the Likert-scale items (Table 2). All 10 items produced significant correlation coefficients; specifically, positive correlations were found between SPS summary scores and items favorable to incorporating spiritual care as part of treatment. Conversely, negative correlations were found between SPS summary scores and responses on items discouraging spirituality as relevant for athletic training practice.

Sex Differences in Opinions About Spiritual Care. Independent-samples *t* tests were calculated to test for sex differences in the Likert-scale items, and we found differences in 2 of the 10 items. For the item "Athletic Training Education Program curriculums should include the spiritual dimension as part of the comprehensive education curriculum," mean scores were lower for men (2.24 ± 0.848) than for women (2.41 ± 0.689) (t_{527} = 2.528, *P* = .01). For the item "Addressing the spiritual concerns of an athlete could result in a more positive outcome when treating an athletic injury (eg, faster return to play)," scores were lower for men (2.88 ± 0.813) than for women (3.01 ± 0.606) (t_{525} = 2.675, *P* = .008). Although several other items approached statistical significance, no other items demonstrated sex differences.

Institutional Differences in Opinions About Spiritual Care. To test for institutional differences (public, private, faith based) on the 10 Likert-scale items, an analysis of covariance with sex and personal levels of spirituality (SPS score) examined as covariates was conducted for each item (Table 3). The

Table 1. Levels of Agreement With 4-Point Likert Scale Items (N = 564)[a]

	Level of Agreement, %			
Survey Item	Strongly Disagree	Disagree	Agree	Strongly Agree
If an athlete wishes it to be part of their [*sic*] recovery process, it is the athletic trainer's responsibility to provide spiritual care as part of treatment.	14.9	49.4	30.9	4.8
It is difficult to identify an injured athlete in need of spiritual care.	3.9	31.6	55.4	9.1
Athletic Training Education Program curriculums should include the spiritual dimension as part of the comprehensive education curriculum.	15.6	43.7	36.1	4.6
Research should be conducted to assess injured athletes' spiritual needs.	7.0	31.4	53.5	8.2
Athletic trainers should have some basic skills and knowledge necessary to support the spiritual needs of the injured athlete.	7.0	31.4	55.4	6.3
An injured athlete's spiritual perspective may affect his/her treatment progress.	1.6	7.3	64.3	26.8
Only spiritual experts should deal with spiritual issues of injured athletes.	11.8	52.1	25.8	10.4
Addressing the spiritual concerns of an athlete could result in a more positive outcome when treating an athletic injury (eg, faster return to play).	2.5	15.2	68.8	13.6
Knowledge about spirituality is not relevant to medical care.	15.6	63.9	16.5	3.9
Spiritual care is not in the athletic trainer's scope of practice.	4.8	28.6	49.1	17.5

[a] 1 indicated *strongly disagree*; 2, *disagree*; 3, *agree*; and 4, *strongly agree*.

Table 2. Correlations Between Total Spiritual Perspective Scale Score and Survey Items

Survey Item	Correlation with Spiritual Perspective Scale[3]	*P* Value
Spirituality and athletic training approaches[a]		
If an athlete wishes it to be part of their [sic] recovery process, it is the athletic trainer's responsibility to provide spiritual care as part of treatment.	0.354	<.001
It is difficult to identify an injured athlete in need of spiritual care.	−0.329	<.001
Athletic Training Education Program curriculums should include the spiritual dimension as part of the comprehensive education curriculum.	0.395	<.001
Research should be conducted to assess injured athletes' spiritual needs.	0.375	<.001
Athletic trainers should have some basic skills and knowledge necessary to support the spiritual needs of the injured athlete.	0.432	<.001
An injured athlete's spiritual perspective may affect his/her treatment progress.	0.408	<.001
Only spiritual experts should deal with spiritual issues of injured athletes.	−0.472	<.001
Addressing the spiritual concerns of an athlete could result in a more positive outcome when treating an athletic injury (eg, faster return to play).	0.483	<.001
Knowledge about spirituality is not relevant to medical care.	−0.423	<.001
Spiritual care is not in the athletic trainer's scope of practice.	−0.443	<.001
Spiritually based clinical interventions[b]		
Listening to the injured athlete's spiritual concerns	0.435	<.001
Referring the athlete to clergy or other spiritual advisor	0.259	<.001
Praying with the injured athlete	0.638	<.001
Praying for the injured athlete	0.672	<.001
Teaching meditation techniques	0.094	.02
Teaching general visualization techniques	0.096	.02
Teaching visualization techniques that use spiritual images	0.335	<.001
Talking with the injured athlete about spiritual matters	0.541	<.001
Having a respectful attitude toward the injured athlete's spiritual views	0.072	.05
Encouraging the expression of the injured athlete's spirituality	0.425	<.001
Encouraging the injured athlete's search for meaning and purpose	0.411	<.001
Sharing the athletic trainer's personal spiritual beliefs with the injured athlete	0.612	<.001
Sharing the athletic trainer's personal spiritual journey with the injured athlete	0.622	<.001
Sharing research findings on the relationship between spirituality and health with the athlete	0.437	<.001

[a] Indicates items scored on a 4-point Likert scale that rated level of agreement and included anchors of 1 (*strongly disagree*) and 4 (*strongly agree*). Pearson product moment correlations were calculated for these items.

[b] Indicates items scored on a 3-point Likert scale that rated appropriateness, with 1 indicating *not at all appropriate*, 2 indicating *somewhat appropriate*, and 3 indicating *very appropriate*. Spearman rank correlations were calculated for these items.

SPS score was a significant covariate for each Likert item, and sex was a significant covariate for items 3 ("Athletic Training Education Program curriculums should include the spiritual dimension as part of the comprehensive education curriculum") and 8 ("Addressing the spiritual concerns of an athlete could result in a more positive outcome when treating an athletic injury [eg, faster return to play]"). After controlling for the 2 covariates, institutional differences were found in 1 of the 10 items. Specifically, for item 5, "Athletic trainers should have some basic skills and knowledge necessary to support the spiritual needs of the injured athlete," mean scores were higher for participants at faith-based institutions (2.85 ± 0.601) than for participants at private (2.55 ± 0.730) or public (2.55 ± 0.706) institutions ($F_{2,501} = 4.31$, $\eta^2 = 0.017$).

Ratings of Appropriateness of Spiritual Practices for ATs

Participants used a 3-point scale to rate how appropriate certain spiritually based athletic training actions were to an athlete's treatment plan (assuming the consent of the athlete), and a frequency analysis demonstrated that the most typical response was *somewhat appropriate*, followed by *very appropriate* and *not at all appropriate*. However, exceptions to this pattern existed. The highest percentage of respondents rated the following actions as *very appropriate*: "Having a respectful attitude toward the injured athlete's spiritual views" (94.6%, n = 511), "Referring the athlete to clergy or other spiritual advisor" (65.8%, n = 362), and "Praying for the injured athlete" (50.4%, n = 275). Conversely, the highest percentage of respondents rated the following actions as *not at all appropriate*: "Sharing the athletic trainer's personal spiritual beliefs with the injured athlete" (44.6%, n = 243) and "Sharing the athletic trainer's personal spiritual journey with the injured athlete" (46.3%, n = 254; Table 4).

Relationship Between Personal Spirituality and Ratings of Appropriateness. Spearman rank order correlation coefficients were computed to compare participants' SPS summary scores with their subsequent ratings of the appropriateness of certain spiritually based athletic training actions (Table 2). Of the 14 items, positive correlations emerged for 13, indicating that higher SPS scores were correlated with higher ratings of appropriateness (eg, "Praying with the injured athlete" [r = 0.64, $P < .001$], "Praying for the injured athlete" [r = 0.67, $P < .001$], "Sharing the athletic trainer's personal spiritual beliefs with the injured athlete" [r = 0.61, $P < .001$], and "Sharing the athletic trainer's personal spiritual journey with the injured athlete" [r = 0.62, $P < .001$]) (Table 2).

Sex Differences in Ratings of Appropriateness. Chi-square analyses comparing responses by sex on the appropriateness of spiritually based athletic training actions yielded 2 items that were different and yielded a consistent pattern; women were

Table 3. Analysis of Covariance Investigating Institutional Differences After Controlling for Sex and Spirituality (Mean ± SD)

Survey Item	Institution Type[a]			Analysis of Covariance[b]	
	Faith-Based (n = 122)	Private (n = 121)	Public (n = 265)	$F_{2,501}$	η^2
If an athlete wishes it to be part of their [sic] recovery process, it is the athletic trainer's responsibility to provide spiritual care as part of treatment.	2.40 ± 0.736	2.22 ± 0.780	2.23 ± 0.755	0.593	0.002
It is difficult to identify an injured athlete in need of spiritual care.	2.55 ± 0.657	2.79 ± 0.718	2.69 ± 0.652	2.21	0.009
Athletic Training Education Program curriculums should include the spiritual dimension as part of the comprehensive education curriculum.	2.50 ± 0.763	2.24 ± 0.837	2.26 ± 0.745	1.88	0.007
Research should be conducted to assess injured athletes' spiritual needs.	2.84 ± 0.630	2.62 ± 0.722	2.60 ± 0.749	2.19	0.113
Athletic trainers should have some basic skills and knowledge necessary to support the spiritual needs of the injured athlete.	2.85 ± 0.601	2.55 ± 0.730	2.55 ± 0.706	4.31[c]	0.017
An injured athlete's spiritual perspective may affect his/her treatment progress.	3.30 ± 0.587	3.21 ± 0.503	3.12 ± 0.646	1.81	0.007
Only spiritual experts should deal with spiritual issues of injured athletes.	2.14 ± 0.897	2.37 ± 0.819	2.42 ± 0.775	1.72	0.180
Addressing the spiritual concerns of an athlete could result in a more positive outcome when treating an athletic injury (eg, faster return to play).	3.04 ± 0.566	2.96 ± 0.573	2.89 ± 0.634	0.704	0.003
Knowledge about spirituality is not relevant to medical care.	1.96 ± 0.673	2.05 ± 0.743	2.12 ± 0.645	0.665	0.003
Spiritual care is not in the athletic trainer's scope of practice.	2.60 ± 0.759	2.75 ± 0.822	2.87 ± 0.763	2.51	0.010

[a] Five participants selected the category *other*, 34 did not select an institution, and data were missing for 17.

[b] Sex and Spiritual Perspective Scale[3] score were examined as covariates for all analyses, but only Spiritual Perspective Scale was a significant covariate for each analysis.

[c] Indicates $P < .05$. Item was scored on a 4-point Likert scale, with 1 indicating *strongly disagree*; 2, *disagree*; 3, *agree*; and 4, *strongly agree*.

more likely than men to rate practices as *very appropriate*, whereas men were more likely than women to rate those same practices as *not at all appropriate* or *somewhat appropriate*. The χ^2 results indicated that 45.6% (n = 104) of women and 29.4% (n = 85) of men considered "Encouraging the expression of the injured athlete's spirituality" during the course of treatment to be *very appropriate*, whereas 56.1% (n = 162) of men and 44.3% (n = 101) of women considered it to be *somewhat appropriate* ($\chi^2_2 = 14.615$, $P = .001$). A similar trend was found for the appropriateness of "Encouraging the injured athlete's search for meaning and purpose" related to his or her injury ($\chi^2_2 = 8.693$, $P = .013$). It was considered *very appropriate* by 47.8% (n = 88) of men and 52.2% (n = 96) of women and was considered *somewhat appropriate* by 55.1% (n = 161) of men and 43.2% (n = 99) of women.

Institutional Differences in Ratings of Appropriateness. When comparing ratings of appropriateness from ATs at different types of institutions (faith based, private, public), a χ^2 analysis yielded findings that were different for 12 of the 14 items, indicating that the distribution of ratings did not follow a pattern based on chance factors but exemplified a pattern related to the type of institution (Table 5). In all cases, ATs working at faith-based institutions were more likely than expected to rate an action as *very appropriate*, whereas those working at public institutions were less likely than expected to rate an action as *very appropriate*. Conversely, ATs working at public institutions were more likely to rate an action as *not at all appropriate*, whereas those working at faith-based institutions were less likely to rate the same action as *not at all appropriate*. The ATs working at private institutions followed a pattern of response based on a typical, chance distribution.

Spirituality in Clinical Settings

From a structured list, participants identified all activities they had used in a clinical setting (Table 4). The activities matched the list of behaviors from the previous section in which ratings of appropriateness were obtained from participants. A frequency analysis was conducted on these items. Almost all participants (90.1%, n = 498) reported using the clinical intervention "Having a respectful attitude toward the injured athlete's spiritual views," and most (68.7%, n = 380) reported using the intervention "Listening to the injured athlete's spiritual concerns." Dichotomous responses occurred in the area of prayer, where 55.9% (n = 309) reported "Praying for the injured athlete" but 19.9% (n = 110) reported "Praying with the injured athlete." Similarly, 58.2% (n = 322) reported "Teaching general visualization techniques" to athletes, whereas only 4.0% (n = 22) reported "Teaching visualization techniques that use spiritual images." Activities reported with the least frequency included "Sharing the athletic trainer's personal spiritual beliefs with the injured athlete" (32.2%, n = 178), "Teaching meditation techniques" (25.0%, n = 138), "Sharing the athletic trainer's personal spiritual journey with the injured athlete" (23.3%, n = 129), "Praying with the injured athlete" (19.9%, n = 110), "Sharing research findings on the relationship between spirituality and health with the athlete" (13.5%, n = 76), and "Teaching visualization techniques that use spiritual images" (4.0%, n = 22).

Table 4. Ratings of Appropriateness and Reported Use of Spiritually Based Clinical Interventions (N = 564)[a]

Clinical Intervention	Level of Appropriateness, %			Used Clinically, %
	Not at All	Somewhat	Very	
Listening to the injured athlete's spiritual concerns	3.6	48.7	47.6	68.7
Referring the athlete to clergy or other spiritual advisor	4.2	30.0	65.8	32.9
Praying with the injured athlete	33.7	41.9	24.4	19.9
Praying for the injured athlete	11.2	38.5	50.4	55.9
Teaching meditation techniques	15.7	52.8	31.4	25.0
Teaching general visualization techniques	4.8	38.8	56.4	58.2
Teaching visualization techniques that use spiritual images	36.1	51.5	12.4	4.0
Talking with the injured athlete about spiritual matters	19.9	58.1	22.0	Missing[b]
Having a respectful attitude toward the injured athlete's spiritual views	0.0	5.4	94.6	90.1
Encouraging the expression of the injured athlete's spirituality	13.0	51.0	36.0	34.5
Encouraging the injured athlete's search for meaning and purpose	15.7	49.8	34.5	36.9
Sharing the athletic trainer's personal spiritual beliefs with the injured athlete	44.6	43.3	12.1	32.2
Sharing the athletic trainer's personal spiritual journey with the injured athlete	46.3	41.5	12.2	23.3
Sharing research findings on the relationship between spirituality and health with the athlete	12.4	53.2	34.4	13.5

[a] On the Likert scale, 1 indicated *strongly disagree;* 2, *disagree;* 3, *agree;* and 4, *strongly agree*.

[b] Indicates item was struck inadvertently from survey, so no data were collected.

Obstacles to Providing Spiritual Care to an Injured Athlete

In an attempt to identify the extent to which certain obstacles might exist to providing spiritual care to injured athletes, participants used a 4-point Likert scale to rate how much of an obstacle each of 6 factors might be for ATs. Results demonstrated that, across the 6 factors, 13.1% (n = 71) or less of respondents indicated a factor was *no obstacle* and more than 60% of respondents rated every factor as either a *moderate* or *significant obstacle* for ATs. The factors rated most frequently as a *significant obstacle* concerned "fear of imposing personal spiritual views on the athlete" (44.6% [n = 242] rated as *significant obstacle*; 72.8% [n = 395], either *moderate* or *significant obstacle*), "lack of training in providing spiritual care" (40.7% [n = 221] rated as *significant obstacle*; 67.4% [n = 366], either *moderate* or *significant obstacle*), and "lack of time to provide spiritual care" (32.3% [n = 173] rated as *significant obstacle*; 65.6% [n = 355], either *moderate* or *significant obstacle*). We did not find any notable group differences in the pattern of responses to these factors.

DISCUSSION

The purpose of our study was to determine the perceptions and practices of ATs working in the college/university setting pertaining to spiritual care of injured athletes. *Spirituality* was defined as "an awareness of one's inner self and a sense of connection to a higher being, nature, others, or to some purpose greater than oneself."[3] Elements of spirituality and spiritual care for injured athletes were further operationalized by the wording of the items on the survey. Although we hope that respondents operated from the framework of the definition provided, we cannot ensure that participants' personal experiences and cultural lenses did not influence the interpretation of the survey items. This is the difficulty of assessing a construct that has yet to achieve an agreed-upon definition in the academic and professional clinical communities. Most responses provided by the ATs illustrated the complexity of this issue. Participants indicated that addressing spiritual concerns could result in more positive therapeutic outcomes for athletes; that ATs should have some basic skills in spiritual care; and that spiritual care should not be left solely to experts, such as clergy. However, they also agreed that spiritual care should not be taught in the athletic training curriculum, that it is not in the scope of practice for athletic training, and that it is not their responsibility to provide spiritual care.

An investigation of the potential influence of personal and institutional variables on these responses produced both expected and unexpected results. Surprisingly, an exploration of sex differences resulted in few areas where opinions differed between men and women. When differences arose, women were less likely to disagree with statements about the importance of spiritual care for the athlete and were more likely to rate as *very appropriate* spiritually based clinical interventions that men rated as *somewhat appropriate*. For the most part, however, we found few sex differences.

Of little surprise was the relationship between an AT's personal spirituality and his or her subsequent responses to survey items. Pearson product moment and Spearman rank correlations highlighted the fact that ATs with high scores on the SPS were likely to respond more favorably to statements about the appropriateness and helpfulness of spiritual practices in athletic training (Table 2). The effect of personal spirituality also was highlighted in its role as a covariate when examining differential responses across institution types (private, public, faith based). Specifically, when SPS scores were controlled, institutional differences on the Likert items nearly disappeared, indicating that observed differences in perceptions across institutions more likely were a result of personal spirituality than of institution type. However, these results highlighted the logical connection among people's spirituality, the type of institution at which they choose to work, and the subsequent importance they place on integrating spiritual practice into athletic training care.

Although survey results indicated a pattern of responses that was more favorable for those who had higher reported levels of personal spirituality, who worked at a faith-based institution,

Table 5. Chi-Square Analysis Comparing Institution-Specific Ratings of Appropriateness of Spiritually Based Clinical Interventions[a]

Clinical Intervention	Level of Appropriateness, %				
	Not at All	Somewhat	Very	χ^2	*P* Value
Listening to the injured athlete's spiritual concerns				12.18	.02
Public university	3.3	54.0	42.7		
Private university	4.8	44.4	50.8		
Faith-based university	2.4	37.3	60.3		
Referring the athlete to clergy or other spiritual advisor				19.90	.001
Public university	5.8	34.3	59.9		
Private university	1.6	27.4	71.0		
Faith-based university	0.8	19.4	79.8		
Praying with the injured athlete				41.71	<.001
Public university	38.2	44.1	17.6		
Private university	31.5	47.6	21.0		
Faith-based university	19.2	34.4	46.4		
Praying for the injured athlete				22.61	<.001
Public university	13.3	41.9	44.8		
Private university	12.2	35.0	52.8		
Faith-based university	3.2	28.0	68.8		
Teaching meditation techniques				14.29	.006
Public university	17.3	51.8	30.9		
Private university	14.6	61.8	23.6		
Faith-based university	11.3	44.4	44.4		
Teaching general visualization techniques				7.35	.12
Public university	5.9	39.1	55.0		
Private university	4.1	42.6	53.3		
Faith-based university	2.4	31.0	66.7		
Teaching visualization techniques that use spiritual images				16.06	.003
Public university	39.2	51.1	9.7		
Private university	39.2	50.0	10.8		
Faith-based university	25.8	51.6	22.6		
Talking with the injured athlete about spiritual matters				20.35	<.001
Public university	21.6	61.3	17.1		
Private university	18.0	60.7	21.3		
Faith-based university	14.6	48.0	37.4		
Having a respectful attitude toward the injured athlete's spiritual views				4.86	.09
Public university	0.0	7.1	92.9		
Private university	0.0	3.3	96.7		
Faith-based university	0.0	2.4	97.6		
Encouraging the expression of the injured athlete's spirituality				17.08	.002
Public university	14.6	53.0	32.5		
Private university	14.0	54.5	31.4		
Faith-based university	5.7	43.1	51.2		
Encouraging the injured athlete's search for meaning and purpose				12.83	.01
Public university	15.8	51.8	32.4		
Private university	16.7	54.2	29.2		
Faith-based university	9.7	41.9	48.4		
Sharing the athletic trainer's personal spiritual beliefs with the injured athlete				20.62	<.001
Public university	48.5	40.0	11.5		
Private university	47.5	40.2	12.3		
Faith-based university	25.4	59.5	15.1		
Sharing the athletic trainer's personal spiritual journey with the injured athlete				20.36	<.001
Public university	50.2	39.9	9.9		
Private university	50.0	37.1	12.9		
Faith-based university	27.8	54.8	17.5		
Sharing research findings on the relationship between spirituality and health with the athlete				13.04	.01
Public university	13.2	56.0	30.8		
Private university	15.3	51.6	33.1		
Faith-based university	6.4	46.4	47.2		

[a]Ratings on the Likert scale were 1, *strongly disagree*; 2, *disagree*; 3, *agree*; and 4, *strongly agree*.

and who were women, these groups' scores did not overwhelmingly endorse the incorporation of spirituality into athletic training practice. The global pattern of data represented in Tables 1 and 4 captures the landscape of the participants' responses, and, whereas statistical anomalies worth noting exist, they do not change the predominant mindset of the ATs who completed the survey. Specifically, ATs agreed that research should be conducted to assess athletes' spiritual needs and that addressing their spiritual needs likely would result in a more positive outcome. They also agreed that ATs should have some basic skills in spiritual care and that listening to an athlete's spiritual concerns and respecting the spiritual views of their injured athletes are *very appropriate*. However, they disagreed that spirituality should be incorporated into the athletic training education program (ATEP) curriculum or that performing spiritual care is within the AT's scope of practice, and they indicated that sharing their own spiritual perspectives with an injured athlete is *not at all appropriate*.

The consensus about the presumed benefit of spiritual care but the general reluctance to embrace it as part of athletic training practice raises some important questions. Is there an adequate understanding of what is meant by *spiritual care* as it relates to professional practice? Who is responsible for providing the spiritual care to the athletes so they gain more positive therapeutic outcomes? If having some basic spiritual care skills is important for the AT, how will those skills be obtained if they are not presented in the athletic training education curriculum?

Interestingly, our findings do not match those of other researchers who asked similar questions. Udermann et al[15] reported that 69.1% of ATEP program directors believed that the topic of spirituality should be addressed in a course within the ATEP. Similarly, researchers studying registered nurses working in Scotland indicated that 58% of nurses reported that providing spiritual support was either very important or essential and 69% reported that the responsibility for providing spiritual care primarily was that of the nurse (primary care provider).[6] In our study, 59.3% of the clinicians disagreed or strongly disagreed that the spiritual dimension should be addressed in the ATEP curriculum, and 66.6% agreed or strongly agreed that spiritual care is not within the AT's scope of practice (primary care provider).

The data we obtained did not provide explanations of or insights into the reasoning behind participants' responses. Based on our anecdotal experience as professionals in the field, one explanation for the reluctance to accept the provision of spiritual care as part of their clinical responsibilities could be that ATs cannot conceptualize how to incorporate spirituality into their scope of practice because they have not seen it modeled and have not been trained on how to do this, as evidenced in the survey by the identification of "lack of training in providing spiritual care" as an obstacle. As support for this supposition, occupational therapists in Canada, where spiritual practice is a required part of the curriculum, faced a similar dilemma, recognizing that spirituality is an important part of occupation and OT practice; however, they admitted feelings of inadequacy and a lack of educational preparation regarding implementing spiritual care into their practices.[13,16,17] Nurses and physical therapists have reported the same frustration of limited education in spiritual care.[7,11,18] Sargeant[12] found that physical therapists felt strongly that awareness of spirituality was important to PT care and concluded that spirituality should be included in the PT curriculum but that they felt overwhelmed about how to teach it. This lack of training, which nurses, occupational therapists, and physical therapists recognize consistently and we identified as one of the primary obstacles in providing spiritual care, might be part of the reason why ATs see benefit to spiritual care but are reluctant to claim it as part of athletic training practice. Education could clarify what spiritual care should be and alleviate fears about what it is not, thereby addressing the top obstacle in our study, "fear of imposing personal spiritual views on the athlete." If spiritual care is perceived as synonymous with sharing one's personal spiritual beliefs, this certainly could produce the observed reluctance among professionally trained clinicians, especially those who might not claim a strong personal spirituality. For example, the data from our study indicated that those who work in faith-based institutions and those who have a strong personal spirituality were more likely to answer in ways that favored inclusion of spirituality into athletic training practice. Udermann et al[15] found similar results in their survey of ATEP program directors, reporting that program directors

> who believed there was a connection between health and healing, … that addressing spirituality with clients could lead to faster recovery times, … or believed that addressing spirituality with clients could result in a better mental status … were significantly more likely to endorse the inclusion of spirituality into the curriculum of ATEPs.[15(p23)]

These findings also were consistent with those of Soeken and Carson,[8] who reported that spiritual well-being and an optimistic attitude toward providing spiritual care were positively correlated. In addition, Speck[2] discussed an unpublished thesis by Dukes (1999), who found that nurses with weak religious or spiritual beliefs were less likely to recognize patients' religious and/or spiritual needs than were nurses with strong religious beliefs. All these data suggest that the religious or spiritual background (or both) of the clinician could make a difference in the comfort level surrounding practices related to providing spiritual care to the patient. Given the willingness of ATs to be receptive and listen to issues of spirituality, the reluctance of the ATs to agree that spiritual care falls within their scope of practice might stem from a legitimate aversion to the practice of overt personal religious expression.

However, we would be remiss to conclude from our study that spiritual people endorse spiritual practice and vice versa. The predominant trend in the data was still toward a nondirective approach with spiritual issues in athletic training practice. When we examined what the participants deemed appropriate spiritual practices for ATs and what they have used in their own clinical settings, the top practice for both was "Having a respectful attitude toward the injured athlete's spiritual views." Participants also believed "Listening to the injured athlete's spiritual concerns"; "Teaching general visualization techniques"; and "Praying for the injured athlete" were appropriate, and those who believed that such actions were appropriate were more were likely to have actually practiced these interventions. Those spiritual interventions rated most frequently as *not at all appropriate* in our study were "Sharing the athletic trainer's personal spiritual beliefs with the injured athlete," "Sharing the athletic trainer's personal spiritual journey with the injured athlete," and "Teaching visualization techniques that use spiritual images." Our results are similar to those in the nursing literature. Conveying a caring or accepting attitude was also the top spiritual intervention reported by Louis and Alpert[5] in their study of parish and nonparish nurses. This intervention was followed by providing support, encouragement, and respect; listening actively; providing presence; and praying privately for the patient. Listening and providing respect, along with simply being present, seem to be the essence of spiritual care.[9,10,19] In addition, Treloar[20] stated that the ultimate purpose of spiritual care (in nursing) is not to solve the patient's spiritual problems but to create an environment and provide resources conducive to spiritual expression and healing by the patient and his or her family. As such, a better understanding of the practice of spirituality as it relates to patient care might avert some of the apparent reluctance by ATs to agree that they should do it.

As with any survey research, our study had limitations that might have affected the accuracy of our results. The lower-than-preferred response rate, along with the potential for self-selection bias, might have produced skewed data. However, because the final sample maintained a proportionate representation by NATA district and because group differences in survey responses were lacking, we concluded that their results are not likely to deviate greatly from the population to which we would generalize our results in the future. Although we had hoped to reach a more ethnically diverse sample to ensure that all opinions were represented, ethnic diversity was lacking in our sample, reflecting the lack of diversity in the AT population nationally.

As with all first attempts at survey construction, we identified some limitations with the wording of the survey that need to be remedied for better accuracy. For example, instructing participants to identify how regularly certain techniques were used in the clinical setting would be better than instructing them to identify if they had ever used a clinical technique with their injured athletes (resulting in dichotomous data). This would enable us to better determine which spiritually based techniques were used regularly rather than occasionally. In addition, when instructing participants to rate the obstacles associated with providing spiritual care, it would be more accurate to instruct them to identify how much of an obstacle each item represented to them personally rather than generally. We also would have preferred to acquire other potential obstacles to include in the survey for more robust data collection. The scaling of some survey items limited the complexity of statistical analysis that could be performed and the accuracy of our conclusions. Although these limitations did not prevent us from drawing meaningful conclusions, they identified avenues to produce more accurate results. If we continue to use this instrument to obtain ATs' perceptions, we necessarily will perform a reliability and validity analysis.

Perhaps the greatest limitation of our study was also the most illustrative because the term *spirituality* is subject to personal interpretation by any person involved in the study, from researcher to participant and to reader. Although attempts were made to operationally define *spirituality* at the beginning of the survey, the very words used to construct survey items conveyed a subjective interpretation of the elements of spirituality that were worth assessing. Although the subjective nature of the topic does not preclude a researcher from studying it, the difficulties involved in measuring an abstract construct should be acknowledged.

CONCLUSIONS

We are among the first researchers to critically examine clinical ATs' perceptions of providing spiritual care to athletes; therefore, our research serves as a starting point for an important conversation. According to our data, ATs agreed that addressing spiritual care could result in more positive therapeutic outcomes but disagreed that they are responsible for providing that care. The reluctance might stem from any number of circumstances, ranging from lack of time or space in the curriculum to lack of understanding of what spiritual care would entail and to lack of skills training in the area. Because spiritual care is not an NATA competency, those teaching it or providing it need to continue research in the area to determine the scope and efficacy of the practice of spiritual care, so that results can be communicated to athletic trainers.

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National Collegiate Athletic Association Division and Primary Job Title of Athletic Trainers and Their Job Satisfaction or Intention to Leave Athletic Training

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Context: Membership in the National Athletic Trainers' Association (NATA) has declined in recent years, generating much debate about professional commitment.

Objective: To compare the contributing factors of job satisfaction and intention to leave athletic training of certified athletic trainers (ATs) employed in National Collegiate Athletic Association (NCAA) institutions.

Design: Cross-sectional study.

Setting: A link to a Web-based questionnaire containing the Spector Job Satisfaction Survey (JSS) and an original Intention to Leave Survey (ITLS) was distributed by e-mail to 1003 certified members of the National Athletic Trainers' Association.

Patients or Other Participants: A total of 191 certified members of the NATA employed in a college or university setting in a primarily clinical capacity; representing all NCAA divisions; and having the job title of head athletic trainer, associate/assistant athletic trainer, or graduate assistant/intern athletic trainer.

Main Outcome Measure(s): We used separate 3 × 3 factorial analyses of variance to compare the mean scores of each JSS subscale and of the ITLS with NCAA division and job title. A stepwise multiple regression was used to determine the strength of the relationships between the JSS subscales and the ITLS.

Results: We found differences for job title in the subscales of Fringe Benefits ($F_{2,182}$ = 7.82, P = .001) and Operating Conditions ($F_{2,182}$ = 12.01, P < .001). The JSS subscale Nature of Work was the greatest indicator of intention to leave ($\beta = -0.45$).

Conclusions: We found a strong negative correlation between various facets of job satisfaction and intention to leave athletic training. The NCAA division seemed to have no effect on an individual's job satisfaction or intention to leave the profession. In addition, only Fringe Benefits and Operating Conditions seemed to be affected by job title. The ATs had similar levels of job satisfaction regardless of NCAA division, and their job titles were not a major factor in job satisfaction.

Key Words: collegiate athletic trainers, membership retention, professional commitment

Key Points

- National Collegiate Athletic Association division and job title had a minimal effect on the levels of job satisfaction and intention to leave athletic training.
- The 8 subscales of the Job Satisfaction Survey were negatively correlated with total intention to leave.
- Of the Job Satisfaction Survey subscales, Nature of Work was the best predictor of total intention to leave.

Membership in the National Athletic Trainers' Association (NATA) has declined in recent years, generating much debate about the professional commitment of athletic trainers. Although it increased steadily starting in the mid-1970s and continuing to 2005,[1] membership declined for the first time in history in 2006.[2] Data from the NATA have indicated an approximate attrition of 19990 members between 2001 and 2006.[1] Examination of membership categories indicated a comparatively low (2.1%) increase in total certified membership compared with a 23% increase in total student membership from 2007 to 2008.[1] This suggests new membership from students is driving membership numbers.

Clearly, NATA membership numbers are declining, but whether individuals simply are not renewing their memberships in the organization or if they actually are abandoning the athletic training profession is unclear. Therefore, speculating whether a decline in NATA membership also could indicate a decline in job satisfaction and ultimately affect a person's decision to leave the profession entirely is reasonable. Although attrition in athletic training was examined in the early 1990s,[3] the issue has resurfaced as the constructs of *job satisfaction* and *intention to leave* have gained attention in the athletic training literature.[4–6]

Whereas many factors might influence a person's longevity in a career, job satisfaction has been seen as the main predictor of intention to leave a profession or organization.[7,8] A person with greater job satisfaction is less likely to leave a profession, whereas a person with lower job satisfaction is more likely to leave.[8] *Job satisfaction* has been defined as the degree to which people like their jobs[9] and consists of an affective component that comprises an individual's feeling of satisfaction regarding his or her job and a perceptual component that evaluates whether one's job is meeting one's needs.[10] Issues surrounding job satisfaction exist in every profession, and the nature of each profession might greatly influence the degree of satisfaction.

Job satisfaction within health professions has been a major concern since studies of nurses in the 1940s.[11] Job satisfaction has been studied since then in various health fields, including medicine,[12] nursing,[7,13–17] occupational therapy,[18–21] physiotherapy,[22] and physical therapy.[23,24] Research of job satisfaction in athletic training did not begin until the 1980s with a study of burnout syndrome[25] and has since focused mainly on athletic trainers (ATs) in the collegiate or university setting.[26–29] Through examination of job satisfaction in the various disciplines, these researchers have determined that certain factors greatly influence overall job satisfaction.

Many factors, including pay,[15] job stress,[30] work–family conflict,[31] and organizational constraints,[32] might positively and negatively affect an individual's overall job satisfaction. Increased pay and increased professional recognition have been found to have direct positive relationships with increased job satisfaction.[33,34] In contrast, increased job stress and work–family conflict have direct negative effects on job satisfaction.[35]

The potential consequences of job satisfaction have been well established.[8,15,36] The worst potential consequences of low job satisfaction are the intention to leave and ultimate departure from a profession. Research[15] in nursing has illustrated the relationship between lower job satisfaction and increased intention to leave a profession. To date, few authors[4–6] have examined job satisfaction and intention to leave the athletic training profession.

Approximately 20% of ATs are employed in the college or university setting, which is the second highest employment setting next to employment in clinics (23%).[1] Therefore, understanding job satisfaction in this setting is important. The various divisions of the National Collegiate Athletic Association (NCAA) provide different work environments for ATs that might affect their degrees of job satisfaction. By definition, major differences exist among NCAA divisions relative to the number of athletic teams sponsored, financial aid for student–athletes, and the size of athletic venues.[37] Anecdotally, this often translates into larger and more well-equipped athletic training facilities in the Division I setting. One might expect that working in a job setting that has abundant resources would lead to greater job satisfaction. However, this might be juxtaposed with ATs in the Division I setting feeling indirect pressure to contribute to the success of the athletic department. In contrast, although Division II or III settings might not have exceptional athletic training facilities, the pressure to succeed athletically also is lower at these levels. Most studies[38–41] in which researchers have examined the differences in job satisfaction among NCAA divisions have centered on coaches and have produced conflicting results. Although researchers[4,26–28] have discussed job satisfaction of ATs in colleges and universities, to our knowledge, no one has described differences in job satisfaction among ATs in different NCAA divisions.

Therefore, the purpose of our study was to compare the contributing factors of job satisfaction and intention to leave athletic training of ATs employed in NCAA institutions. The following research questions and associated hypotheses guided our investigation. (1) Does a difference exist in the subscales of job satisfaction of ATs based on NCAA division or primary job title? We hypothesized that ATs in Division I would have higher job satisfaction in all subscales than ATs in other divisions and that graduate assistant/intern athletic trainers (GAs) would have the lowest. (2) Does a difference exist in intention to leave the profession of athletic training based on NCAA division or primary job title? We hypothesized that ATs in Division II and GAs would have the greatest intention to leave the profession of athletic training. (3) Which of the job-satisfaction subscales was associated with intention to leave? We hypothesized that the items on all the subscales would influence intention to leave. (4) Which of the job-satisfaction subscales predict intention to leave the profession? We hypothesized that the subscales of Promotion and Coworkers would be the best predictors of an AT's intention to leave the profession of athletic training.

METHODS

Participants

Initially, the entire available population of NATA District 3 (n = 463) was solicited to participate in this study. Eligible participants met the following inclusion criteria: AT, employed in an NCAA college or university, and member of the NATA. The initial decision to solicit only NATA District 3 was based on convenience and our desire to understand the job satisfaction of ATs in the mid-Atlantic region. Because only 463 individuals in District 3 met the inclusion criteria, 540 additional individuals were selected randomly from the remaining 9 districts in an effort to increase the sample pool, resulting in a total of 1003 individuals selected for participation.

Of these 1003 individuals, 27 contacted us and indicated they were not eligible for the study. A total of 286 responses were collected from the 976 eligible units for a response rate of 29%. However, after further exclusion criteria were applied based on primary job title, failure to complete all sections of the Web-based survey instrument, and lack of clinical employment, 191 individuals met all inclusion criteria and participated in our study. The participants represented all 10 NATA districts and all 3 NCAA divisions and included head athletic trainers (HATs), associate/assistant athletic trainers (AATs), and GAs (Table 1). Completion of the survey instrument served as passive informed consent for all participants. The institutional review board approved the study.

Table 1. Participant Demographics (N = 191)

Category	n	Cohort, %
National Collegiate Athletic Association division		
I	106	55.5
II	37	19.4
III	48	25.1
Primary job title		
Head athletic trainer	63	33
Associate/assistant athletic trainer	103	53.9
Graduate assistant/intern athletic trainer	25	13.1
National Athletic Trainers' Association district[a]		
1	6	3.1
2	6	3.1
3	96	50.3
4	3	1.6
5	6	3.1
6	7	3.7
7	6	3.1
8	4	2.1
9	5	2.6
10	8	4.2

[a] An error in the instrument caused district demographic information not to be collected when the survey was first distributed. When the error was remedied, the remaining respondents (n = 147) answered the demographic question.

Instrumentation

We used a Web-based survey instrument housed on Survey Monkey (http://www.surveymonkey.com). The survey had 3 sections designed to collect demographic information and information regarding job satisfaction and intention to leave the athletic training profession. The first section of the survey consisted of various demographics; for our purposes, however, the main demographics of concern were NCAA division (I, II, III) and primary job title (HAT, AAT, GA).

The second section of the survey was a modified version of the Spector Job Satisfaction Survey (JSS),[9] consisting of 36 items. The JSS originally was designed to produce 10 scores (9 subscale scores and 1 total score). To ensure the 9 subscales were accurate, a principal components analysis (PCA) was calculated for all 36 items. The PCA of the JSS revealed only 8 separate subscales of the JSS. Of the original 9 subscales, 7 were left unchanged; however, the subscales of Pay and Contingent Rewards were combined into 1 subscale of Pay & Rewards based on the PCA. In addition, the original JSS instrument included 4 items per subscale; however, our modified subscales included an uneven number of items per subscale. For instance, the subscales of Supervision and Pay & Rewards each had 7 items, whereas the subscale of Operating Conditions had only 2 items. The resultant 8 subscales that we analyzed are described in Table 2.

To score the JSS, we used a 6-point Likert scale with the anchors of 1 (*disagree very much*) and 6 (*agree very much*). Some responses were scored in a positive and some in a negative direction. Agreement with a positively worded item indicated job satisfaction (eg, “I feel I am being paid a fair amount for the work I do”). Agreement with a negatively worded item indicated job dissatisfaction (eg, “There is really too little chance for promotion on my job”). Negatively worded items were reverse scored during data entry.

The third section of the survey was the self-developed Intention to Leave Survey (ITLS), which comprised 7 questions to determine a respondent’s intention to leave the profession of athletic training. The responses were presented in a 4-point Likert scale. Three items were intended to determine how often a participant had considered leaving the profession of athletic training, with possible responses of 1 (*never*), 2 (*a little*), 3 (*a lot*), or 4 (*constantly*). One item was intended to determine how actively an individual had pursued leaving the profession of athletic training, with possible responses of 1 (*I have done nothing*), 2 (*I have made inquiries into jobs outside of athletic training*), 3 (*I have applied to jobs outside of athletic training*), and 4 (*I have accepted jobs outside of athletic training*). The remaining items were intended to judge the probability of staying in the profession of athletic training, with possible responses of 1 (*excellent*, 75%–100% probability), 2 (*good*, 50%–74%), 3 (*fair*, 25%–49%), and 4 (*poor*, 0%–24%). For 5 items of the ITLS, a value of 1 corresponded with less intention to leave the profession of athletic training, and a 4 corresponded with more intention to leave. The remaining 2 items were reverse scored to remain consistent with a higher value equaling a greater intention to leave the profession. Reliability was assessed using the Cronbach α, and the overall reliability for all 7 items of the ITLS was very good (0.86).

Pilot testing was conducted to test the feasibility of using a Web-based survey protocol to calculate the interitem reliabilities of both the JSS and ITLS. Fifteen ATs were solicited by e-mail based on convenience and included those employed in NCAA Divisions I, II, and III outside of NATA District 3. They reviewed the instruments for overall clarity, purpose, and relevance and made revisions accordingly. In addition, 2 ATs with extensive research experience and a statistician reviewed the instrument to establish face and content validity.

An item analysis of the JSS pilot data was calculated using the Cronbach coefficient α. For pilot testing, no PCA was conducted, and reliability was based on the original 9 subscales. None of the subscales had a correlation of 0.80 or greater with another, ensuring that each subscale was measuring a separate construct. The Cronbach coefficient α for the 9 subscales ranged from 0.63 to 0.93, ensuring that each of the subscales demonstrated acceptable internal consistency. Cronbach coefficient α pilot data for the ITLS demonstrated internal consistency for all items of 0.85.

Procedures

We contacted the NATA to request a membership list rental with the criteria of “certified” and “certified student” members working in the “university & college” setting. The NATA contacted 1003 ATs via an initial e-mail solicitation, asking for their participation. The e-mail included the purpose of the study, a brief description of the survey, and a description of how consent was obtained. Participants were directed to a Web-site URL, where they were invited to complete an online survey.

Two weeks after the initial solicitation, a second e-mail solicitation was sent to all potential participants. Due to the solicitation method used by the NATA, a disclaimer was added to the second e-mail requesting that those who had already completed the survey ignore the follow-up solicitation. The investigation consisted of 3 weeks of data collection with 2 solicitations.

Statistical Analysis

All scores for the JSS and ITLS were collected automatically by Survey Monkey and were downloaded into an Excel 2003 (version 11; Microsoft Corporation, Redmond, WA) spreadsheet. Separate scores for each subscale of the JSS and

Table 2. Description and Reliability Analysis for the Subscales of the Job Satisfaction Survey

Subscale	Description: Satisfaction With . . .	Cronbach	No. of Items
Supervision	Supervisor	0.89	7
Pay & Rewards	Pay, appreciation, recognition, and rewards	0.87	7
Fringe Benefits	Extra benefits of monetary or nonmonetary value	0.83	4
Promotion	Opportunity for advancement or promotion	0.75	4
Nature of Work	The activities involved in the job	0.76	4
Coworkers	People with whom one works	0.78	3
Operating Conditions	Policies, procedures, and conditions of the workplace	0.69	2
Communication	Communication with personnel within the workplace	0.75	3

a composite score for the sum of the responses on the ITLS were calculated for each respondent. Descriptive statistics of central tendency and frequency distributions were collected for demographic information. Separate 3 (Division I, II, III) × 3 (HAT, AAT, GA) factorial analyses of variance (ANOVAs) were used to examine whether NCAA division or primary job title affected any of the subscales of job satisfaction or the total intention-to-leave score. The α level was set a priori at .05. A multiple regression was used to determine which subscales of job satisfaction predicted the total intention-to-leave score. An entry level of $P = .49$ and a removal level of $P = .51$ were preset to determine which subscale provided the best model. When a significant F test was identified, a post hoc Tukey honestly significant difference (HSD) analysis was conducted to determine group differences. We analyzed the data using SPSS (version 15.0; SPSS Inc, Chicago, IL).

RESULTS

With our first research question, we examined the relationship of the JSS subscales and primary job title and NCAA division. Separate 3 × 3 factorial ANOVAs were completed for each of the 8 JSS subscales with fixed factors of NCAA division and primary job title. We found no differences in any job-satisfaction subscale among NCAA divisions. We found differences in primary job title with the subscales of Fringe Benefits ($F_{2,182} = 7.82$, $P = .001$) and Operating Conditions ($F_{2,182} = 12.01$, $P < .001$). The post hoc Tukey HSD analysis for the Fringe Benefits subscale revealed lower mean scores for GAs than for HATs and AATs. In addition, the post hoc analysis revealed higher mean job satisfaction for both GAs and AATs than for HATs in the Operating Conditions subscale (Table 3).

Through our second research question, we examined intention to leave across NCAA division and primary job title. Factorial analyses of variance showed no difference in either total intention to leave based on NCAA division ($F_{2,191} = 1.27$, $P = .28$) or primary job title ($F_{2,191} = 1.33$, $P = .27$). We also found no interaction between NCAA division and primary job title ($F_{4,191} = 2.05$, $P = .09$).

With our third research question, we wanted to determine the relationship between the various subscales of job satisfaction and the total intention-to-leave score. A stepwise multiple regression analysis showed all 8 subscales of the JSS demonstrated negative correlations with total intention to leave (Table 4).

Through our final research question, we examined which subscales of the JSS were the main predictors of total intention to leave. Because all zero-order correlations between the JSS subscale scores and the ITLS score were significant, stepwise linear regression analysis was used to determine the aggregate relationship between the 8 subscales of the JSS and the total intention-to-leave score. At the preset entry level of $P = .49$ and removal level of $P = .51$, the JSS subscales of Nature of Work, Pay & Rewards, and Promotion provided the best model (Table 4). Examination of R^2 change revealed a significant F value change for this model and suggested that roughly 30% of the variance was explained by the subscales. Examination of standardized coefficient β weights suggested Nature of Work was the best predicting subscale of total intention to leave ($\beta = -0.45$).

DISCUSSION

The declining membership of the NATA and the potential loss of experienced clinicians in the profession has become an issue at the forefront of athletic training. Although many factors might be associated with these recent trends, we speculated that the interactions of poor job satisfaction and high intentions to leave the profession of athletic training are major contributors. It is possible to speculate from the statistics that the younger professionals, such as students, are driving membership numbers. Further examination showed a similar trend in the subcategories of "certified student" and "certified," with increases of 78.6% and only 12.6%, respectively.[1]

Our primary findings indicated NCAA division and primary job title minimally affected the levels of job satisfaction or intention to leave the profession for ATs. In addition, although all the subscales of job satisfaction had a negative correlation with intention to leave, the subscales of Pay & Rewards, Nature of Work, and Promotion were particularly good predictors, accounting for roughly 30% of the variance.

Research[5,26–29] on job satisfaction in athletic training has been focused mainly on ATs in the collegiatee or university setting. No investigators have examined how NCAA division affects job satisfaction in ATs; however, some authors[40] have examined division and satisfaction in coaching and have demonstrated higher job-satisfaction scores in Division I coaches than in Division III coaches. In terms of athletic training, researchers have shown greater levels of organizational commitment in Division

Table 3. Post Hoc Testing of the Job Satisfaction Survey and Primary Job Title

	Job Title			
Subscale	(A)	(B)	Mean Difference (A–B)	P Value
Fringe Benefits	Head athletic trainer	Assistant athletic trainer	−0.09	.99
	Head athletic trainer	Graduate assistant/intern athletic trainer	4.63[a]	<.001
	Assistant athletic trainer	Head athletic trainer	0.09	.99
	Assistant athletic trainer	Graduate assistant/intern athletic trainer	4.73[a]	<.001
	Graduate assistant/intern athletic trainer	Head athletic trainer	−4.63[a]	<.001
	Graduate assistant/intern athletic trainer	Assistant athletic trainer	−4.73[a]	<.001
Operating Conditions	Head athletic trainer	Assistant athletic trainer	−1.89[a]	<.001
	Head athletic trainer	Graduate assistant/intern athletic trainer	−1.37[a]	.03
	Assistant athletic trainer	Head athletic trainer	1.89[a]	<.001
	Assistant athletic trainer	Graduate assistant/intern athletic trainer	0.52	.55
	Graduate assistant/intern athletic trainer	Head athletic trainer	1.37[a]	.03
	Graduate assistant/intern athletic trainer	Assistant athletic trainer	−0.52	.55

[a] Indicates difference ($P \leq .05$).

Table 4. Correlation of Spector Job Satisfaction Survey Subscales and Total Intention to Leave

Subscale	*r*	*P* Value
Supervision	−0.23	.001
Pay & Rewards	−0.43[a]	<.001
Fringe Benefits	−0.23	.002
Promotion	−0.41[a]	<.001
Nature of Work	−0.45[a]	<.001
Coworkers	−0.25	<.001
Operating Conditions	−0.21	.003
Communication	−0.24	.001

[a] Indicates greatest predictors of intention to leave.

I than in Division III HATs[42] and a direct positive relationship between organizational commitment and job satisfaction.[43] Therefore, if Division I ATs have a greater commitment, they also should have greater job satisfaction. Our results did not support this, and we only found differences in job satisfaction based on NCAA division and the Nature of Work subscale.

A potential reason for the lack of differences in the other subscales might have been that the responsibilities of being an AT were similar regardless of the NCAA division in which participants were employed. In addition, investigators[44] have shown that interesting work environments and skill variety lead to increased job satisfaction. Each NCAA division can provide a unique work environment that is interesting and stimulating enough and includes a variety of skills for an AT. This might suggest that as long as the job is interesting to the AT, the division in which he or she is working is irrelevant.

When examining job satisfaction as it relates to primary job title, we hypothesized that GAs would show the lowest satisfaction scores. Our results surprisingly indicated that GAs did not have lower job satisfaction than full-time ATs overall and, in particular, in the subscale of Pay & Rewards. Researchers have shown that GAs experience more economic difficulties than full-time ATs[26] and that financial concerns are a major factor in job satisfaction. One possible reason for this could be that GAs have determined fair pay is based on the job title. For example, GAs would not expect to be paid $30000 for a part-time position; therefore, they might be satisfied with a $10000 stipend because they believe it is reasonable for an assistantship. This could have led GAs to answer the survey according to a preconceived notion of pay fairness.

Although our original research question and hypothesis focused on which job title had the lowest level of job satisfaction, we also assumed HATs would have the highest level of job satisfaction in each subscale based on the respect and authority offered by the position.[3,29] However, our results indicated differences only in the subscale of Operating Conditions, which revealed that HATs had the lowest satisfaction score in this area. This is possibly due to the typical HATs being most heavily involved in addressing policies, procedures, and work conditions of the facility and, therefore, likely having the highest levels of stress.

Regarding an AT's intention to leave the profession, our results indicated the subscales of Nature of Work, Pay & Rewards, and Promotion were the best predictors. Such topics, including increased pay and rewards[45,46] and flexible scheduling[47] have been discussed in the athletic training literature as ways to address intention to leave the profession. Our results are consistent with the model of Irvine and Evans[15] in which economics and structure of the work environment influenced nurses' intention to leave. This suggests similar factors affect various health professions, and understanding the effect of these factors might provide solutions for athletic training.

We did not find differences in intention to leave the athletic training profession based on NCAA division. We originally speculated that ATs employed in the Division II setting would have a greater intention to leave the profession than ATs employed in Divisions I or III. Our results did not support this notion; visual inspection actually associated Division II ATs with the least intention to leave.

When examining GAs, researchers recently have suggested that the new generation of health care professionals is more willing than ever to leave a job within the first few years if it does not meet their immediate goals[48] and that younger employees, especially those with less than 10 years of experience, have greater intentions to leave.[49] Our results were contrary to this literature because GAs did not show an increased intention to leave; they seemed more consistent with the results of researchers who have suggested the typical GA is eager to start his or her career and is willing to experience some setbacks in the first few years.[26]

The results of the JSS and ITLS can only be generalized to ATs working in the collegiate or university setting. Although we studied a national sample, the low response rate from 9 of the 10 NATA districts makes it difficult to generalize the results to these districts. And even though the 50% response rate of respondents in NATA District 3 makes the results extremely applicable to this district, we believe the results would have been similar in all NATA districts. In addition, the reliability analysis seemed adequate for all JSS subscales and the ITLS, with the exception of Operating Conditions.

Another primary limitation was response bias. The design of our survey did not allow us to track nonrespondents. Therefore, we could not determine whether the demographics, JSS scores, and ITLS scores of the respondents were similar to the nonrespondents. In addition, no effort was made to control for the number of responses per institution, especially in NATA District 3, where all eligible individuals were solicited. This allowed for institutional or organizational characteristics to possibly overshadow the job satisfaction and intention to leave at the occupational or professional level. This factor might be a particular concern with the ITLS because respondents might have based their answers more on their reactions to the institution than to the profession. Finally, the JSS subscale of Operating Conditions showed HATs had lower scores than the AATs and GAs; however, it consisted of only 2 items. A better-defined construct with more items might be needed in future research to determine how meaningful these results actually are.

CONCLUSIONS

We explored job satisfaction and intention to leave the profession of athletic training in clinically oriented ATs employed in various NCAA institutions. Our findings indicated NCAA division and job title minimally affected the levels of job satisfaction and intention to leave the athletic training profession. Although some individuals might consider NCAA Division I to be the highest level of athletic training in collegiate athletics, our data did not suggest ATs in this division have greater job satisfaction than ATs in other divisions. In addition, GAs did not seem to have less job satisfaction than full-time ATs, such as HATs or AATs. On the contrary, our results suggested handling policies, procedures, and work conditions by HATs led to lower job satisfaction in the area of Operating Conditions.

Our results indicated job satisfaction was not a simple construct but instead was multidimensional. Although no differences were found among job titles and NCAA divisions, the results did suggest job satisfaction had some variation based on these demographics. In addition, the hypothesis that certain levels of competition or job titles provided more satisfying work environments did not seem to be accurate.

Possible solutions to decreasing intention to leave should address the subscales that most greatly predict it. Increasing pay and rewards is a current topic in athletic training and has been receiving more support from various institutions.[45,46] Being compensated for working 60-hour weeks might provide enough job satisfaction to keep an AT in the profession longer. In addition, programs such as flexible scheduling are potential ways to positively reward ATs for their hard work and to retain them in the field.[47]

Methods to increase the professional recognition of being an AT also can help decrease overall intention to leave. Continuing to promote the profession of athletic training in a positive manner should be a major public relations focus, both to other allied health fields and to the general public. The continued efforts of the NATA to legislate for ATs on issues such as the right to fair practice provide professional credibility and respect not only to the AT as an individual but to the profession as a whole. Athletic trainers should support continued efforts at both the national and grassroots levels, regardless of their work settings or job titles.

In the future, researchers should continue to examine job-satisfaction differences not only in NCAA divisions but also in the many other work settings in which ATs are employed. Our results suggested job satisfaction appears not to be affected as long as a work environment is stimulating and interesting. Further study is needed to determine which aspects of each NCAA division make it interesting and stimulating for ATs and how to incorporate such characteristics at all NCAA levels.

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Transient Global Amnesia in a Collegiate Baseball Player with Type I Diabetes Mellitus: A Case Report

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Objective: To present the case of a collegiate pitcher with type I diabetes mellitus who developed transient global amnesia and to characterize the acute onset of symptoms and clinical diagnosis of this rarely reported neurologic condition in the student–athlete population.

Background: A 21-year-old collegiate pitcher with type I diabetes mellitus was found by his roommate to have acute-onset memory loss. The athletic trainer identified normal blood glucose levels and normal vital signs but profound amnesia. The patient was evaluated by his team physician and referred to the local emergency department for acute-onset memory disturbance.

Differential Diagnosis: Hypoglycemia, ketoacidosis, adverse drug reaction, infectious disease, transient epileptic amnesia, transient ischemic attack, acute confusional state, complex partial seizure, psychogenic amnesia, migraine, intracerebral hemorrhage, traumatic brain injury, tumor, and transient global amnesia.

Treatment: Diagnostic studies included computed tomography of the head, urine and serum toxicology, urinalysis, blood glucose level, electrolytes, blood urea nitrogen level, creatinine level, complete blood count, and electroencephalography. The patient was admitted overnight to the neurology service. The next morning, electroencephalography was repeated, and magnetic resonance imaging of the head with contrast was performed. The patient was discharged with the diagnosis of transient global amnesia.

Uniqueness: Transient global amnesia is considered a benign condition characterized by an acute episode of memory disturbance involving the inability to form new memories and recall recent events. It is rare in young people, with only 3 case reports involving young athletes published in the literature.

Conclusions: Transient global amnesia is a rarely diagnosed neurologic disturbance that may present acutely in student–athletes, although most reported cases affect older adults. Unfamiliarity with the symptoms may cause anxiety for the athlete and bystanders. Transient global amnesia does not result in long-term neurologic deficit, and neurologic function will return to baseline.

Key Words: memory loss, neurologic conditions, athletes

Features of transient memory loss were first described independently by Bender[1] and Guyotat and Courjon[2] in 1956 and formally named *transient global amnesia* (TGA) by Fisher and Adams[3] in 1958. Few cases of TGA have been documented in children and young adults.[4–7] We present the case of a collegiate baseball player with diabetes who experienced transient global amnesia.

CASE REPORT

A 21-year-old collegiate baseball player with type I diabetes mellitus diagnosed at age 9 years was brought to the athletic training room by his roommate on a Sunday morning at approximately 10 AM during the fall practice season because of memory loss. The roommate reported that the patient kept asking questions such as "When is practice?" and "What is my blood sugar?" Upon questioning by the athletic trainer, the patient was unable to recall any events of the previous day and whether he had eaten, checked his blood sugar, or given himself any insulin. His roommate reported that they had spent the prior evening watching football and baseball on television. The roommate and the patient both denied alcohol or drug use, and the roommate reported that the patient was his usual self before going to bed at about 1 AM. According to the log on his insulin pump, the patient had given himself a bolus of 5 units of Novolog (Novo Nordisk, Inc, Princeton, NJ) at about midnight and inferred that he must have had a light snack; he stated that he never gave himself insulin boluses unless he was about to eat. He was unable to recall what he ate, but his roommate confirmed that he had eaten a snack. The insulin pump showed no record of any other insulin boluses after midnight. The patient denied headache, visual changes, nausea or vomiting, numbness, tingling or weakness in the extremities, or slurred speech. He had no history of migraines, recent illness, or head trauma. Current medications included Novolog at a basal rate of 1.1 to 1.5 units per hour in addition to 1 unit per 12 grams of carbohydrates before each meal.

Upon examination in the athletic training room by the team physician and athletic trainer, the patient was alert but somewhat anxious. He asked the athletic trainer several times whether he had checked his blood sugar. His vital signs were as follows: temperature, 98.2ºF (36.7ºC); blood pressure, 143/90 mm Hg; heart rate, 82 beats/min; respiratory rate, 18 breaths/min. His speech was fluid. He was oriented to person, place, and time, except that he reported the date as 1 day earlier. He performed serial 7s correctly and missed 1 month when stating the calendar months backward. He was able to recall 3/3 words immediately and 0/3 after distraction. He was unable to recall the words with prompting. Abstract thinking was intact. He was able to give only 7 words that started with the letter "A" or "F." There was no agnosia or apraxia. He was able to recall the names and ages of his family members, which high school he attended, and the classes he was enrolled in. Cranial nerves II through XII were intact. Muscle strength was 5/5 in all major muscle groups of the upper and lower extremities bilaterally. Cerebellar functioning was intact; reflexes were 1+ in the Achilles tendon bilaterally and could not be elicited in the biceps or triceps muscle or patella bilaterally. Gait was normal. Cardiac examination revealed a regular rate and rhythm, and his lungs were clear to auscultation bilaterally. Fingerstick blood glucose level was 5.33 mmol/L (96 mg/dL). Dipstick urinalysis was negative for ketones.

The patient was referred to the local emergency department for further evaluation of his persistent amnesia. He still showed deficits in short-term memory recall; otherwise, his neurologic examination remained normal. Reflexes in the emergency department were 2+ at the brachial and patellar tendons. While in the emergency department, he developed a dull headache; computed tomography scan of the head was normal. Toxicology screens were negative for benzodiazepines, barbiturates, cocaine, opiates, cannabinoids, and amphetamines (urine screen) and acetaminophen, salicylate, and ethanol (blood screen). Urinalysis was negative. Blood glucose was 7.5 mmol/L (135 mg/dL); electrolyte, blood urea nitrogen, and creatinine levels and complete blood count were all normal. The patient was admitted overnight to the neurology service. On admission, reflexes were documented as 2/4 at all sites. His ability to form new memories started to improve about 6 hours after his initial presentation in the athletic training room, but he remained unable to recall any events from the night before or the morning of presentation. Additional diagnostic studies included electroencephalography, which initially showed mild bitemporal lobe slowing. By the next morning, the patient's headache had resolved and he had complete return of anterograde memory. He still lacked memory for events that occurred the night before and the morning of presentation, but his memory for events after hospital admission returned before discharge. Repeat electroencephalography was normal. Magnetic resonance imaging of the head with contrast was also normal. The patient was discharged with the diagnosis of transient global amnesia. The neurologist was puzzled by the patient's lack of ability to name at least 10 words per minute starting with the letters "A" or "F." Therefore, the patient was asked to follow up in 3 weeks for further evaluation.

At his 3-week and 6-month follow-ups, the patient was still able to give only 7 words beginning with the letters "A" or "F." This deficit remains unexplainable. We have no baseline for comparison and so are unable to interpret these results. His neurologic examination otherwise remained normal except for an amnestic gap for the duration of the attack. He performed well in school and on the field the remainder of the year.

Consideration was given to the possibility that the transient global amnesia might have resulted from a hypoglycemic event leading to hypoxia, but hypoglycemia was never found, and he never showed any altered level of consciousness throughout the episode. We believe that the initial absence of reflexes was not pathologic but examiner dependent. The team physician still has difficulty obtaining the patient's reflexes bilaterally, and the patient later reported that many physicians have had difficulty eliciting his reflexes in the past. The fact that the neurologist could elicit reflexes on admission lessens the likelihood that the initial absence of reflexes was a pathologic finding.

DISCUSSION

Transient global amnesia is considered a benign condition involving the inability to form new memories (anterograde amnesia) for several hours, along with the inability to recall recent events (retrograde amnesia). Remote memory is not disrupted. The incidence is reported to be 0.005% to 0.010% per year.[4,8] The condition is seen more commonly in those 50 to 80 years of age; most patients are in their 60s.[9]

Diagnostic criteria[10] (Table 1) include the acute onset of a witnessed anterograde amnesia that is usually discovered after the patient is found to ask the same questions repeatedly despite just having been given an answer. Cognition and consciousness are not affected, and no focal neurologic deficits exist. Attacks typically last from 1 to 8 hours[8,9] but not more than 24 hours.[10] There is no history of head trauma or seizures. Occasionally headache, nausea, or vomiting accompanies TGA. Patients return to baseline but have a gap in their memories for the duration of the attacks.[10]

The differential diagnosis of transient global amnesia is listed in Table 2. Temporal lobe epilepsy has been dismissed as a cause because epileptic symptoms usually last less than 1 hour, and the condition has a high recurrence rate.[4,8] Transient ischemic attacks are usually associated with motor and sensory deficits and not with anterograde amnesia by itself. Also, transient ischemic attacks can recur. An acute confusional state commonly occurs over a longer period of time (hours to days) and includes disorientation, impaired cognition, and hallucinations.[11] Inattention is a key difference between TGA and acute confusional state.[8] Complex partial seizures most often begin with an aura or tunnel vision, followed by impaired consciousness and automatisms.[11] Psychogenic amnesia involves loss of autobiographical memories and self-identity, usually triggered by stress. Retrograde amnesia is evident, but new learning is not disrupted; therefore, repetitive questioning by the patient does not occur.

In our patient's case, hypoglycemia was also entertained as the underlying problem because of his history of type I diabetes mellitus. However, the patient had lived with diabetes for 12 years and reported that his symptoms were not similar to those of previous hypoglycemic episodes. In addition, he was never found to be hypoglycemic. His blood sugar at initial presentation was 5.33 mmol/L (96 mg/dL). It is possible that the patient suffered a hypoglycemic event while sleeping but recovered by morning. This could have happened if low glucose led to the release of stress hormones such as epinephrine, cortisol, and growth hormone, which raise glucose levels. Two case reports[12,13] of prolonged amnesia after hypoglycemia have been published. However, both cases involved a severe hypoglycemic coma, changes on magnetic resonance imaging, and amnesia (including working and short-term memory) that resolved within months rather than hours of presentation.

Table 1. Diagnostic Criteria for Transient Global Amnesia[10]

Acute onset of anterograde amnesia
Witnessed attack
No change in cognition or level of consciousness (except for amnesia)
No loss of personal identity
No focal neurologic deficits on examination
Symptoms clear within 24 hours
No history of head trauma
No epileptic features or history of seizures

Table 2. Differential Diagnosis of Transient Global Amnesia

	Impaired Cognition	Impaired Consciousness	Focal Neurologic Deficits	Duration of Symptoms	Rate of Recurrence	Anterograde Amnesia	Inattention	Automatisms
Transient global amnesia	No	No	No	<24 h	Low	Yes	No	No
Transient epileptic amnesia	No	No	No	<1 h	High	Yes	No	Yes
Transient ischemic attack	No	No	Yes	<24 h	High	No	No	No
Acute confusional state	Yes	Yes	No	Hours to days	High[a]	No	Yes	No
Complex partial seizure	Yes	Yes	No	Minutes	High	No	Yes	Yes
Psychogenic amnesia	No	No	No	Hours to days to years	Low to high	No	No	No

[a] If underlying cause is not found.

In their review of the literature, Quinette et al[9] found that the 3 most common precipitators of an attack were emotional stress, physical effort, and extreme temperature change, such as immersion in cold water. Our patient lacked any of these precipitators. He had served as umpire for a baseball scrimmage the day before the onset of amnesia but otherwise had not engaged in any intense physical activity. No emotional stressors were identified, and he had no recent history of experiencing extreme temperature changes.

The areas of the brain involved in TGA are known: the mediobasal temporal region, hippocampus, and parahippocampus.[8] Yet the mechanism for TGA remains controversial. Various hypotheses have been put forth to explain the cause of TGA, including spreading depression of cortical electrical activity (from migraine headache) and venous congestion with ischemia in areas involving memory. Based on their literature review and study of 142 patients with TGA, Quinette et al[9] postulated that TGA may have at least 3 different causes: a neurotoxic effect on hippocampal function occurring after emotional or physical stress, venous congestion due to insufficient jugular vein valves precipitated by a Valsalva maneuver, and spreading depression of cortical activity in younger patients with a history of migraine. Cortical depression involves a wave of cellular depolarization that causes a brief period of cortical excitation followed by prolonged nerve depression and can be seen during a migraine attack. Quinette et al[9] questioned this last hypothesis because the risk of experiencing a migraine is higher in younger than in older patients. Therefore, coexistence of migraine and TGA cannot be ruled out. They found that patients with TGA were no more likely than a control group to have vascular risk factors or a history of migraines.

Very few cases of TGA have been reported in athletes. Tosi and Righetti[4] documented 2 cases of TGA, one in a 13-year-old female volleyball player and another in a 16-year-old male soccer player. Both occurred during athletic participation and were associated with migraine headache. The only other published case report[5] of TGA in an athlete involves a 13-year-old male soccer player who developed symptoms consistent with TGA after an evening practice. Although he did not have a history of migraines, he complained of a headache on admission.

CONCLUSIONS

Although TGA can bring much anxiety to the patient and witnesses of the attack, it is considered a benign condition and is not thought to be a precursor for stroke. Transient global amnesia rarely recurs, and the only lasting deficit is an amnestic gap for the duration of the attack. Health care providers should be aware of the signs and symptoms to address this condition promptly and appropriately.

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position statement

National Athletic Trainers' Association Position Statement: Safe Weight Loss and Maintenance Practices in Sport and Exercise

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Objective: To present athletic trainers with recommendations for safe weight loss and weight maintenance practices for athletes and active clients and to provide athletes, clients, coaches, and parents with safe guidelines that will allow athletes and clients to achieve and maintain weight and body composition goals.

Background: Unsafe weight management practices can compromise athletic performance and negatively affect health. Athletes and clients often attempt to lose weight by not eating, limiting caloric or specific nutrients from the diet, engaging in pathogenic weight control behaviors, and restricting fluids. These people often respond to pressures of the sport or activity, coaches, peers, or parents by adopting negative body images and unsafe practices to maintain an ideal body composition for the activity. We provide athletic trainers with recommendations for safe weight loss and weight maintenance in sport and exercise. Although safe weight gain is also a concern for athletic trainers and their athletes and clients, that topic is outside the scope of this position statement.

Recommendations: Athletic trainers are often the source of nutrition information for athletes and clients; therefore, they must have knowledge of proper nutrition, weight management practices, and methods to change body composition. Body composition assessments should be done in the most scientifically appropriate manner possible. Reasonable and individualized weight and body composition goals should be identified by appropriately trained health care personnel (eg, athletic trainers, registered dietitians, physicians). In keeping with the American Dietetics Association (ADA) preferred nomenclature, this document uses the terms *registered dietitian* or *dietician* when referring to a food and nutrition expert who has met the academic and professional requirements specified by the ADA's Commission on Accreditation for Dietetics Education. In some cases, a *registered nutritionist* may have equivalent credentials and be the commonly used term. All weight management and exercise protocols used to achieve these goals should be safe and based on the most current evidence. Athletes, clients, parents, and coaches should be educated on how to determine safe weight and body composition so that athletes and clients more safely achieve competitive weights that will meet sport and activity requirements while also allowing them to meet their energy and nutritional needs for optimal health and performance.

Key Words: body composition, body fat, diet, hydration, metabolism, sport performance

Weight classifications in sport (eg, youth football, wrestling, rowing, boxing) were designed to ensure healthy, safe, and equitable participation[1]; however, not all sports or activities in which weight might play a role in performance use a weight classification system. In activities such as dance, distance running, gymnastics, and cycling, weight and body composition are believed to influence physical performance and the aesthetics of performance. Yet the governing organizations of these activities have no mandated weight control practices. In 2005, the American Academy of Pediatrics[2] published a general weight control practice guide for children and adolescents involved in all sports.

In addition to the potential performance benefits of lean body mass and lower levels of body fat, long-term health benefits include decreased cardiovascular risk factors, reduced triglyceride concentration, possible increases in cardioprotective high-density lipoprotein cholesterol concentration, increased fibrinolysis, reduced resting blood pressure, reduced resting glucose and insulin, and increased insulin sensitivity.[3] In females, lower body fat may also protect against breast and other reproductive cancers.[4] Although lean body mass has been associated with positive health benefits, negative health outcomes are associated with excessive loss or gain of body mass.[5]

RECOMMENDATIONS

Based on the current research and literature, the National Athletic Trainers' Association (NATA) suggests the following safe weight loss and weight maintenance strategies for participants in all sports and physical activities. These recommendations are built on the premise that scientific evidence supports safe and effective weight loss and weight management practices and techniques, regardless of the activity or performance goals. The recommendations are categorized using the Strength of Recommendation Taxonomy criterion scale proposed by the American Academy of Family Physicians[6] on the basis of the level of scientific data found in the literature. Each recommendation is followed by a letter describing the level of evidence found in the literature supporting the recommendation: *A* means there are well-designed experimental, clinical, or epidemiologic studies to support the recommendation; *B* means there are experimental, clinical, or epidemiologic studies that provide a strong theoretical rationale for the recommendation; and *C* means the recommendation is based largely on anecdotal evidence at this time.

Assessing Body Composition and Weight

1. Body composition assessments should be used to determine safe body weight and body composition goals. *Evidence Category: B*
2. Body composition data should be collected, managed, and used in the same manner as other personal and confidential medical information. *Evidence Category: C*
3. The body composition assessor should be appropriately trained and should use a valid and reliable body composition assessment technique (Table 1). *Evidence Category: C*
4. Body weight should be determined in a hydrated state. *Evidence Category: B*
5. When determining goal weight, body weight should be assessed relative to body composition. This assessment should occur twice annually for most people, with no less than 2 to 3 months between measurements (Tables 2, 3). *Evidence Category: C*
6. To track a person's progress toward a weight or body composition goal, private weigh-ins and body composition assessments should be scheduled at intervals that provide information to guide and refine progress, as well as to establish reinforcement and reassessment periods. *Evidence Category: C*

Table 1. Body Composition Assessment Techniques[7]

Model	Assessment Technique	Standard Error of Estimate, %
2 Compartment	Hydrodensitometry	±2.5
	Air displacement plethysmography	±2.2–3.7[a]
	Skinfold measurements	±3.5[b]
	Near-infrared interactance	±5[b]
3 Compartment	Bioelectric impedance	±3.5–5[b]
	Dual-energy x-ray absorptiometry	±1.8[a]
Multiple compartment	Computed tomography or magnetic resonance imaging	Not fully developed[a]

[a] More research is needed.

[b] Differs with each equation.

Table 2. Body Fat Standards (%) by Sex and Age

Body Fat Standard	Males	Females
Lowest reference body fat (adults)[5,8–11]	5	12
Lowest reference body fat (adolescents)[2,12]	7	14
Healthy body fat ranges[13]	10–22	20–32

Table 3. Determining Goal Weight from Body Composition

Current % body fat – Desired % body fat = Nonessential body fat, %

________ – ________ = ________

Current body weight × Nonessential body fat, % (in decimal format) = Nonessential fat, lb

________ × ________ = ________

Current body weight – Nonessential fat, lb = Ideal body weight, lb

________ – ________ = ________

7. When hydration is a concern, regular or more frequent (or both) assessments of body weight are indicated. *Evidence Category: C*
8. Active clients and athletes in weight classification sports should not gain or lose excessive amounts of body weight at any point in their training cycles. *Evidence Category: C*
9. Management of body composition should include both diet and exercise. *Evidence Category: B*
10. Total caloric intake should be determined by calculating the basal metabolic rate (BMR) and the energy needs for activity. *Evidence Category: B*
11. Caloric intake should be based on the body weight goal (Table 4). *Evidence Category: C*
12. A safe and healthy dietary plan that supplies sufficient energy and nutrients should be maintained throughout the year (Table 5). *Evidence Category: B*
13. The U.S. Department of Agriculture's Food Pyramid Guide is one of the methods that can be used to ensure adequate nutrient intake. *Evidence Category: C*
14. The metabolic qualities of the activity should be considered when calculating the need for each energy-producing nutrient in the diet (Tables 6–8). *Evidence Category: B*
15. Safe and appropriate aerobic exercise will facilitate weight and body fat loss. *Evidence Category: C*
16. Body composition adjustments should be gradual, with no excessive restrictions or use of unsafe behaviors or products. *Evidence Category: C*
17. Combining weight management and body composition goals with physical conditioning periodization goals will assist athletes or clients in reaching weight goals. *Evidence Category: C*
18. Education on safe dietary and weight management practices should be communicated on a regular and planned basis. *Evidence Category: C*
19. Individual body composition or dietary needs should be discussed privately with appropriately trained nutrition and weight management experts. *Evidence Category: C*
20. Ergogenic and dietary aids should be ingested cautiously and under the advisement of those knowledgeable of the requirements of sports and other governing organizations. *Evidence Category: C*

Background and Literature Review

Weight management and nutrition is a multibillion-dollar industry that has become pervasive in almost every aspect of modern life. Diet and exercise have always affected sports and physical activity, but with the intensity of competition increasing at all levels has come a renewed interest in controlling the factors that influence performance and health. Diet, exercise, body composition, and weight management now play larger roles in an active person's life and performance. Because ath-

Table 4. Determining Total Caloric Needs

Harris-Benedict[14]
- Female basal metabolic rate = 655.1 + (9.6 × weight [kg]) + (1.9 × height [cm]) − (4.7 × age [y]) + Activity needs
- Male basal metabolic rate = 66.5 + (13.8 × wt [kg]) + (5 × ht [cm]) − (6.8 × age [y]) + Activity needs

Activity needs
- Sedentary (mostly sitting): add 20%–40% of basal metabolic rate
- Light activity (sitting, standing, some walking): add 55%–65% of basal metabolic rate
- Moderate activity (standing and some exercise): add 70%–75% of basal metabolic rate
- Heavy activity: add 80%–100% of basal metabolic rate

Mifflin-St. Jeor[15]
- Female basal metabolic rate = (10 × wt [kg]) + (6.25 × ht [cm]) − (5 × age [y]) − 161
- Male basal metabolic rate = (10 × wt [kg]) + (6.25 × ht [cm]) − (5 × age [y]) + 5

Table 5. Determining Energy-Producing Nutrient Intake

Protein intake

a. Calculation of protein needs based on activity levels:
BW, kg × g/kg BW = g of protein/kg BW
___________ × __________ = _________

b. Convert the g of protein into kcal needed:
_____ g protein × 4 = _________ kcal from protein

c. % Protein needed of total caloric intake:
______ kcal from protein ÷ ______ total kcal = _____%

Carbohydrate intake

a. Calculation of CHO needs based on activity levels:
BW in kg × grams/kg BW = g of CHO/kg BW
___________ × __________ = _________

b. Convert the g of CHO into kcal needed:
_____ g CHO × 4 = _________ kcal from CHO

c. Convert % kcal into actual number of calories:
______ kcal from CHO divided by ______ total kcal = _____%

Fat intake

a. Based on the remaining number of calories needed, calculate the fat intake needed:
CHO, kcal + protein, kcal = kcal from CHO and protein
________ + ________ = (A) _____

b. Total caloric need − value A = fat needed, kcal
_________ − ________ = (B) _____

c. Value B ÷ 9 = fat, g
_________ ÷ 9 = ___________

Abbreviations: BW, body weight; CHO, carbohydrate

Table 6. Energy-Producing Nutrients

Nutrient	General Population Requirement
Carbohydrates	5–7 g/kg of body weight per d
Proteins	0.8–1 g/kg of body weight per d
Fats	15%–35% of total caloric intake per d

letic trainers (ATs) and other members of the health care team have regular contact and ongoing relationships with athletes and clients engaged in active lifestyles, they are frequently asked for assistance in achieving personal and performance goals. These goals often include diet, exercise, and weight management. Some AT-client relationships and their shared body composition goals are formalized, as with weight-class sport athletes; others are not.

Weight Management in Weight-Class Sports

Many safe and effective methods are available to achieve and maintain goal weight and body composition. However, although published and widely accepted weight and body composition standards exist,[9] there are few published or mandated weight or body composition management requirements. Even within sports with weight-class systems (eg, boxing, lightweight crew, sprint football, wrestling), only wrestling and sprint football consider the components of an athlete's weight and body composition, as well as the safety considerations for achieving and maintaining that body size.[19,20]

Since 1997, specific rules and guidelines have been implemented to ensure that weight control practices in wrestling are safe, applied early in the competitive season, and conducted on a regular and planned schedule around competitions and do not include dehydration as a means of weight loss.[1] These weight management and dehydration prevention regulations are effective in reducing unhealthy "weight-cutting" behaviors and promoting equitable competition.[21]

In 2006, the National Federation of State High School Associations adopted similar standards (ie, body composition, weigh-in procedures, and hydration status) for determining minimum body weights in high school wrestlers, but the body fat minimums were higher (≥7% in males, ≥12% in females) than the levels for collegiate athletes determined by the National Collegiate Athletic Association (NCAA).[21] These differences were implemented to address growth needs in adolescents and sex differences. The National Federation of State High School

Table 7. Carbohydrate Intake[5,16]

Activity Type	Recommendation
Optimal glycogen storage for single term or single event	7–10 g/kg of body weight per d
Carbohydrate for moderate-intensity or intermittent exercise >1 h	0.5–1 g/kg of body weight per h (30–60 g/h)
Daily recovery and fuel for aerobic athlete (1–3 h moderate-intensity to high-intensity exercise)	7–10 g/kg of body weight per d
Daily recovery and fuel for extreme exercise program (>4–5 h moderate-intensity to high-intensity exercise)	10–12+ g/kg of body weight per d

Table 8. Protein Intake[5,8,14,17,18]

Athlete Type	Recommendation
Strength athletes	1.7–1.8 g/kg of body weight (maximum = 2 g)
Endurance athletes	1.2–1.4 g/kg of body weight
General population	0.8–1 g/kg of body weight
Vegetarians	0.9–1 g/kg of body weight

Associations standards have not been accepted or enforced universally in the United States. Therefore, universally safe or effective weight management practices in high school wrestling are not assured.

Sprint football is a collegiate sport sponsored by 6 teams in the Collegiate Sprint Football League: Cornell University, Mansfield University, Princeton University, University of Pennsylvania, U.S. Military Academy at West Point (Army), and U.S. Naval Academy (Navy). Sprint football has the same rules as NCAA football but also has a weight limit for players of 172.0 lb (78 kg), which is far lower than the weights typically seen in NCAA football players.[20] To the previously required minimum body composition of 5% body fat, sprint football in 2008 added compulsory assessment of body composition and playing weight in a hydrated state with a urine specific gravity of <1.020.[20]

In 1997, collegiate lightweight crew and rowing athletes began using U.S. Rowing weight classifications and a 5% minimum body fat guideline to determine a safe rowing weight. Unlike wrestling, the revised 2007 crew weight requirements did not take into account the athlete's body composition or hydration status in determining minimum body weight. Although some institutions have adopted weight certification guidelines similar to those in wrestling, no formal rules are in place. Today's standards stipulate that male lightweight rowers must not exceed 160 lb (73 kg), and female lightweight rowers must not exceed 130 lb (59 kg). Minimum weights are in place only for coxswains. All crew members must be weighed once a day, between 1 and 2 hours before the scheduled time of the first race, each day that the athlete competes.[22]

Sport Performance and Aesthetics

Practices of weight manipulation and body fat control are not exclusive to sports with weight-class requirements. Participants in other activities requiring speed and aesthetics also use weight manipulation to improve performance. Leaner athletes in sports such as middle-distance and long-distance running, cycling, and speed skating are often perceived by coaches and peers to perform better.[10]

Although body fat contributes to weight, it does not always contribute to energy in the muscular contractions needed for exercise and sport. A disproportionately greater amount of muscle mass and smaller amount of body fat are needed by participants in activities that may be influenced by body size. In sports such as the broad jump or vertical jump, in which the body must be propelled through space, generating power is essential. More power can be achieved by a body with a higher ratio of muscle to fat than one of the same mass with a lower ratio of muscle to fat. In swimming, although body fat allows for greater buoyancy in water, which reduces drag, athletes with a greater proportion of muscle mass to fat can produce more speed.

Similarly, in sports such as ski jumping, a lean, slight build was once thought desirable to reduce air resistance and to allow the athlete to stay airborne as long as possible and to cover a greater distance before landing.[10] This performance standard also holds true for activities such as dance, figure skating, gymnastics, and diving. The aesthetic aspect of performance is also a consideration for weight management practices in these activities. Leaner participants are viewed as more attractive and successful[23,24] and perceived to demonstrate better body symmetry, position, and fluidity of motion.

Because no scientific or health principles support weight management for the purpose of aesthetics in performance, we will address this topic only in its association with body composition and weight management. Many considerations for aesthetic performance activities are related to the body composition of female participants, but research[25,26] also recognizes the effect of similar social pressures on male body images.

Pressures on participants to control weight stem from various sources, including society, family,[25,27–29] peers,[3] and coaches,[30–33] as well as the judging criteria used in some activities.[34] These pressures may place participants at higher risk for developing unrealistic weight goals and problematic weight control behaviors. Most aesthetic performance activities require fit body types for success, and these requirements may trigger an unhealthy preoccupation with weight.[35] Generally, participants in competitive activities that emphasize leanness for the sake of performance or aesthetic enhancement are at the highest risk for developing dysmorphia, eating disorders, and disordered eating.[36–40]

Because of the need to control all factors that may affect performance, perfectionism is a common psychological trait among athletes. Along with the desire to look thin and the belief that decreased weight enhances performance, perfectionism increases the risk of developing an eating disorder.[41–43] Perfectionism is typically associated with setting high goals and working hard to attain them, which enables athletes to succeed.[40,44] People who are aware of concerns about their weight from coaches, parents, teammates, friends, or significant others are more likely to develop subclinical eating disorders.[45]

In general, women in non–weight-class activities identify their ideal body sizes and shapes as smaller than their actual bodies, whereas men tend to want to be larger (ie, more muscular) and are more concerned with shape than with weight.[46–49] The demands of a male's activity determine whether desirable body size or weight (or both) is smaller (eg, gymnastics) or larger (eg, football). Because the topic of dysmorphia has been addressed more comprehensively in the NATA's position statement on preventing, detecting, and managing disordered eating in athletes,[50] it is addressed here only in the context of weight management practices.

Regardless of the rationale to support weight management practices, goal weights and body compositions for athletes and active clients must be determined and maintained in a safe and effective manner. The purposes of this position statement are to identify safe methods by which goal weight can be determined and maintained and to discuss unsafe weight management practices and the effects of those practices on performance and overall health.

Body Composition

To fully understand the topic of body composition, it is essential to understand how body composition is assessed. Using the most common description of body composition, the 2-compartment (2-C) model is a quantifiable measure that can be divided into 2 structural components: fat and fat-free mass (FFM). Fat-free mass consists primarily of muscle, bone, water, and remainder elements.[9] In the general population, excess body fat is associated with adverse health consequences, which include cardiovascular disease,[51] diabetes,[52] gallstones,[53] orthopaedic problems,[54] and certain types of cancer.[55] Although active people have a lower incidence of these conditions, excess body fat combined with a family history of cardiovascular or metabolic diseases and inactivity can reverse the benefits of acquired health associated with an active, healthy lifestyle.

To develop a method for determining the risks associated with excess body fat, the body mass index (BMI) assessment was created. The original purpose of the BMI assessment was to predict the potential for developing the chronic diseases associated with obesity.[9] Body mass index may be an appropriate method for determining body size in the general population, but this technique does not assess fat mass and FFM. Therefore, BMI assessment is less accurate for athletes and active clients who have higher levels of FFM.[14] Even though a sedentary person and an active person may have the same height and weight, their fat to FFM ratios may be very different. When applied to the BMI formula, the active person's additional FFM skews the assessment of body composition, resulting in a BMI evaluation that is inaccurate as a predictor of increased risk for chronic diseases. More individualized body weight and body composition assessments are needed for active people with high levels of lean body mass to accurately evaluate the effect of body weight on the risk of developing chronic diseases (Table 9).

Body Weight, Fat, and FFM

Fat mass can be categorized as essential fat, sex-specific fat, and storage fat.[9] Essential fat, which averages 3% of total fat, makes up the bone marrow, heart, lungs, liver, spleen, kidneys, intestines, muscles, and lipid-rich tissues of the central nervous system.[9] In women, essential fat also may include sex-specific fat (eg, breasts, hips, pelvis) and averages 12%.[5,8–11] Storage fat, which averages 12% in men and 12% to 15% in women, is layered subcutaneously; it is stored by the body to provide an energy substrate for metabolism.[9] When essential fat is added to storage fat, men average 15% total body fat, whereas women average 20% to 27% total body fat. Low-reference body fat composition is 5% in men and 12% in women.[5,8–11] Low-reference body fat composition, which is necessary to maintain normal reproductive health and hormone function, is 7% in adolescent males and 14% in adolescent females.[2,12] Lower levels of fat have been associated with good health and normal body function.[5,8–11] Although no maximum body fat requirements exist, the highest safe weights should not exceed the body fat ranges considered satisfactory for health: 10% to 22% and 20% to 32% in physically mature adolescent males and females, respectively.[13]

Body fat is distributed in sex-specific patterns. Typically, women distribute more body fat in the gluteofemoral region in a gynoid fat distribution pattern, sometimes referred to as "pear shaped." Women also store more fat in the extremities than men. In contrast, men distribute more fat in the abdominal region in an android or "apple" pattern and have greater subscapular to triceps skinfold thickness than do women.[56] The android fat distribution has been related to more significant health consequences associated with cardiovascular disease, including diabetes, hypertension, and hyperlipidemia,[7,57] and may contribute more to increased disease risk than does obesity alone.[58]

Table 9. Body Mass Index (BMI)[a] Classifications[7]

BMI	Classification
<18.5	Underweight
18.5–24.99	Average (normal)
25.0–29.9	Overweight
30.0–34.9	Grade I obesity
35.0–39.9	Grade II obesity
≥40	Grade III extreme obesity

[a] BMI = weight, kg/height^2, m.

Assessment of Body Composition

Several methods are available to measure body composition, but most research on assessment in athletes has focused on densitometry, indirect measurement of body density using a 2-C model consisting of fat mass and FFM. Body density is the ratio of body weight to body volume (Table 1).

Total body volume is typically measured by hydrostatic (underwater) weighing[59] with a correction for pulmonary residual lung volume.[60] Most other body composition techniques have been validated in comparison with hydrostatic weighing because of its lower standard error of the estimate. Similar to hydrostatic weighing, air displacement plethysmography is a newer densitometric method that measures mass and volume to calculate body density.[61]

Multicompartment models, in which FFM is divided into 2 or more components, have been validated with hydrostatic weighing methods in athletes.[59–65] Some authors[66–68] suggested that these multicompartment models may be more appropriate for the athletic population; however, these findings are not widely accepted. Two-compartment models demonstrated a significant overestimation for air displacement plethysmography in collegiate football players[69] but close agreement between hydrostatic weighing and air displacement plethysmography in collegiate wrestlers.[70]

Some concerns have been raised about selecting the appropriate conversion formula when using the 2-C model to assess body composition in active people. The Schutte equation[71] is commonly used to estimate fat and FFM from body density in black males, but with multicompartment models, recent researchers[72–74] found that using race-specific equations to estimate percentage of fat from bone density was inappropriate. For adolescent and high school athletes, the adult conversion formulas of Siri[75] and Brozek et al[76] are generally accepted.

Dual-energy x-ray absorptiometry (DXA) has been reported[63,64] to slightly underestimate body fat in some athletic populations when compared with multicompartment models. Other authors[54,56] have noted strong agreement between DXA and multicompartment models in various athletic groups. Athletes generally have greater bone mineral content, bone mineral density, and FFM and a lower percentage of body fat than nonathletes.[77] Considering that DXA also measures bone mineral composition and density, it may be preferable to either hydrostatic or air displacement plethysmography 2-C models as a reference method for assessing body composition in athletes and active people.[78]

Clinical Methods Used to Assess Body Composition

Skinfold thickness, which has been validated with hydrostatic weighing, is the most frequently used and easily accessible clinical method to estimate body composition. Although skinfold measures are easy to obtain, the importance of developing a skillful measuring technique cannot be overstated. Standardized skinfold sites and measurement techniques are described in the *Anthropometric Standardization Reference Manual*.[79] An extensive number of prediction equations are available for estimating bone density from skinfold measures in different athletic populations (Durnin and Womersley, Katch and McArdle, Jackson-Pollock), but selected equations have been recognized for broad applicability to both male and female athletic populations. In addition to these equations, the generalized Lohman equation[80] is recommended for both high school and collegiate wrestlers.[78] Based on the referenced validity studies, ready availability of equipment, and ease of use, skinfold prediction is highly recommended as a body composition assessment technique for athletes and active clients.

The accuracy of bioelectric impedance analysis (BIA), another method used to assess body composition, is highly dependent on testing under controlled conditions. Skin temperature, strenuous exercise, dehydration, and glycogen depletion significantly affect impedance values.[81,82] Population-specific and generalized BIA equations, developed for the average population, do not accurately estimate the FFM of athletic men and women.[83–86] Some researchers[65,87,88] reported that the skinfold method is a better predictor of body fat percentage in athletes than the BIA method, which is a more effective tool for obtaining group data on athletes than for detecting small changes in individual athletes' body fat.[89]

Another body fat measuring technique, near-infrared interactance (NIR), provides optical density values for estimating body fat. The manufacturer's prediction equation systematically underestimated body fat in both active men and collegiate football players.[83,90,91] Limited research is available on the validity of NIR among female athletes in various sports. A few authors[92,93] used optical density values to develop prediction equations in athletic populations. The NIR prediction equations were slightly better than the skinfold method in estimating body composition and minimal wrestling weight in high school–aged wrestlers.[94]

Fat and FFM should be assessed by an AT or other trained body-composition assessor using one of the validated methods available (eg, hydrostatic weighing, air displacement plethysmography, skinfold measures). All manual measurement techniques (eg, skinfold calipers) should follow standardized protocols and be performed at least 3 times by the same assessor to ensure reliability.[79] The body size needs of the activity and the typical body composition of the participants in that activity should be considered, as well as the minimum body composition standards when available.

Body Composition and Hydration Assessment

Body composition and weight assessments should always be conducted on hydrated people. Criterion (ie, total body water and plasma markers) and field methods (ie, acute body mass change, urine and saliva markers, bioelectric impedance) can be used to assess hydration status. The gold standard for determining hydration status is measurement of total body water. Repeated measurements of water content before and after rapid weight reduction reflect the absolute change in fluid content. The FFM of adult bodies contains approximately 72% water,[94] a value slightly less than in children (75%) and adolescents (73%).[94,95]

Plasma markers, or a comparison of blood indices of hydration status with laboratory standards, also may be used to determine hydration status. Plasma osmolality of the blood, sodium content, and hemoglobin and hematocrit levels are typically elevated when the plasma volume is reduced because of dehydration. The plasma osmolality of a hydrated person ranges between 260 and 280 mOsm/kg. A plasma osmolality above 290 mOsm/kg indicates dehydration.[96] Hemoglobin and hematocrit levels can also be used to assess relative changes in plasma volume based on loss of fluid from the vascular space. However, this technique has many limitations and does not always reflect changes in hydration.[97,98]

The acute body-mass change field method is one of the simplest ways to assess changes in hydration. Assessing body weight before and after a period of exercise or heat exposure can provide data reflecting hydration. Immediate weight loss after exercise results from dehydration and should be addressed using the guidelines described in the NATA position statement on hydration.[99] Using weight-tracking charts to evaluate these changes during exercise can help to determine the hydration status of an active person.

Urine markers are another noninvasive method to determine the hydration status of the blood.[100–104] When the body has a fluid deficit, urine production decreases, and the urine becomes more concentrated. The total volume of urine produced during a specified period is lower than expected (normal is approximately 100 mL/h).[96] Simultaneously, urine specific gravity, osmolality, and conductivity increase due to a greater number of solids in the urine and the conservation of body fluid. Urine color also may serve as a gross predictor of hydration state.[102]

Urine specific gravity and osmolality respond to acute changes in hydration status. However, changes in these markers may be delayed or insensitive to low levels of acute dehydration (1% to 3% of body weight).[100] In addition, these markers may be no more effective in detecting dehydration than assessing urine protein content via the dipstick method.[105] Ease of collection and measurement, at least for urine specific gravity and color, make the dipstick method practical for self-assessment of hydration status in most settings.[99]

Similar to those of urine, characteristics of saliva change as the hydration level changes.[106] Because the salivary glands produce saliva using plasma, a decrease in plasma volume due to dehydration affects the concentration of substances found in saliva. Although a saliva sample is easy to obtain, the analysis for osmolality and total protein content requires instrumentation beyond the scope of most practice settings. Saliva flow rate is collected with a dental swab but requires an analytical balance for precise measurement of the change in swab weight after saliva collection.

Recently, BIA and bioelectric impedance spectroscopy have been proposed[104,107] for measuring total body water and the compartments within the total body water, respectively. These methods provide reasonable measurements of body composition and total body water for groups of individuals, but whether they can track changes in hydration status and an individual's hydration level is unknown. Several investigators[108,109] found that bioelectric impedance analysis and bioelectric impedance spectroscopy failed to accurately predict reductions in total body water after rapid dehydration. Some of this inaccuracy may result from other factors (eg, increased core temperature and skin blood flow) that may influence the reactance and resistance measurements on which these techniques rely.

To ensure adequate hydration, an average adult's water intake should be 3.7 L/d for men and 2.7 L/d for women.

Athletes, active clients, and those who are exposed to hot environments need higher intakes of total water.[110] To maintain adequate hydration, a person should drink 200 to 300 mL of fluid every 10 to 20 minutes during exercise. Pre-exercise and postexercise fluid intake should be consistent with the recommendations provided in the NATA position statement on fluid replacement.[99]

As noted previously, body weight and body composition should be assessed with the person in a hydrated state. Those who fail to meet the minimum hydration levels (urine specific gravity of less than 1.020 or urine color less than or equal to 4)[111] should not be assessed until hydration standards are met and no sooner than 24 hours after the first hydration status failure.

Body Composition and Determining Body Weight

No single source offers normative body composition data for athletes. Therefore, ATs and other health care personnel involved in body composition assessment should become familiar with data sources specific to their athlete or client populations. They should take into consideration the safe ranges and the body composition needs of the sport and then individualize weight and body composition goals.

The lowest safe weight should be calculated at no lower than the weight determined by the low-reference body fat composition delineated by sex and age. The *lowest safe weight* can be defined operationally as the lowest weight, sanctioned by the governing body, at which a competitor may compete. When no standard exists, participants should be required to remain above a certain minimum body fat. Highest safe weight should be calculated using a value no higher than the highest end of the range considered satisfactory for health: 10% to 22% body fat in males and 20% to 32% in females (Table 2).[13]

The AT should work closely with the team physician or medical supervisor to develop a plan for the collection and management of body composition data and related information.[112] This information should be restricted to those who need it to provide care for the athlete or client. The AT should fully disclose to the athlete or client who will have access to personal body composition information.[113] If the body composition or other nutritional and weight management findings indicate a potentially harmful or high-risk behavior, the AT is responsible for informing the athlete or client of the risk[113] and the team physician or medical supervisor of the medical concern.[114]

Body composition measurements to determine goal weights should be assessed twice annually,[115] with no less than 2 to 3 months between measurements[50] for most people. These regular measurements will allow ATs and other health professionals to alter weight goals based on decreases in body fat and increases in lean muscle mass. Caution should always be taken to ensure that an athlete's or client's body composition never falls below the lowest or rises above the highest safe weight or body fat level. To track an athlete's or client's progress toward a weight or body composition goal, private weight and body composition assessments should be scheduled at more frequent intervals to guide and refine progress and to establish reinforcement and reassessment periods.

Measurement intervals should be identified in consultation with the physician and other members of the health care team involved in the athlete's or client's care. This team should include an AT, licensed mental health care provider, physician, and registered dietitian.[116] If weight control practices are a concern, collaboration and education should occur early and frequently in the process.

Monitoring Body Weight

During preseason activities that involve equipment that could increase sweat loss or prevent adequate cooling in warmer and more humid climates, body weight should be reassessed at least daily because of the increased risk of dehydration and heat-related illness. Daily weigh-ins, before and after exercise, can help identify excessive weight loss due to dehydration.

Active clients and athletes in weight classification sports should not gain or lose excessive amounts of body weight at any point in their training cycles. Athletes and clients should attempt to maintain levels that are close to their weight and body composition goal when not competing and maintain their goal weight and body composition during competition. Excessive fluctuations in body weight or body composition (or both) can negatively affect the body, including but not limited to changes in metabolic activity, fluctuations in blood glucose levels, and muscle wasting.[14] Athletes in weight classification sports should have individual monitoring plans, such as assessments at least once per month in the off-season and at regular intervals, not to exceed once per week, to monitor for weight fluctuations.[115]

Body Composition and Dietary Intake

Caloric and nutrient intake should be based on lean body mass, desired body composition, goal weight, and sport or activity requirements. Intake that is too high or too low to support the desired lean body mass will negatively affect metabolic function and body composition. Metabolic function is more efficient in those with greater amounts of lean body mass. Metabolic function and oxygen utilization can be measured or estimated with predictive equations that take into consideration body size, fat mass, FFM, age, sex, and the expenditure of energy for activity.[12,117] The Harris-Benedict[14] and Mifflin-St. Jeor[15] estimation formulas, which account for height, weight, age, and sex to determine the BMR, are commonly recommended methods for indirectly estimating total caloric need; however, other methods are also appropriate. One drawback to the use of estimation formulas is that muscular tissue uses more energy than does nonmuscular tissue. Therefore, estimation formulas may underestimate the daily caloric needs of athletes or clients who are very muscular (Table 4).

A healthy diet or meal plan should provide adequate calories to achieve body weight goals, supply essential nutrients, and maintain hydration. To ensure effective performance, energy intake must come from an appropriate balance of the 3 essential energy-producing nutrients (ie, protein, carbohydrates, and fats). In addition, appropriate intake of non–energy-producing essential nutrients (eg, vitamins, minerals, water) is needed to facilitate energy creation and maintain other body processes.[8] Carbohydrates should provide 55% to 70% of the total caloric need of athletes and active people and may be as high as 12 g or more per kilogram of body weight.[5,10,16] Muscle glycogen (stored glucose) and blood glucose, derived from carbohydrates, are the primary energy substrates for working muscle.[17,18,118] Therefore, the more aerobic the activity, the greater the carbohydrate need (Tables 6, 7).

To determine needed protein intake, it is important to identify the type of exercise and the intensity level of that exercise.[5,10,17,18] Protein assists with many bodily functions, but most athletes and clients are interested in building and repairing muscle contractile and connective tissue. Protein provides 8% to 10% of the body's total energy needs. In events lasting longer than 60 to 70 minutes, amino acid oxidation increases, thereby increasing the use of protein to support the greater energy demands. Strength athletes and those whose goals are to build FFM need the most protein in the diet. For those who are not interested in developing a great deal of FFM but want to meet the needs of an aerobic activity, more moderate amounts of protein are desirable. Protein intake in excess of the body's physical requirements increases hydration needs, overburdens the liver and kidneys, and interferes with calcium absorption; in addition, excess protein can be broken down and used as components of other molecules, including stored fat (Table 6).[14]

Finally, dietary fats are essential to a healthy diet because they provide energy, assist in the transport and use of fat-soluble vitamins, and protect the essential elements of cells.[12] Fat metabolism provides a portion of the energy needed for low- to moderate-intensity exercise, and the use of fat for energy metabolism increases as aerobic metabolism increases. Fats can be used to spare both readily available glucose and stored muscle glycogen. Although the average intake of fat in athletes is approximately 30% of total caloric intake,[10,14] the commonly held consensus is that 20% to 25% of total caloric intake should come from fats.[12] To maximize performance, athletes should take in no less than 15% of total caloric intake from dietary fats.[12,17] Fat intake should minimize partially hydrogenated, unsaturated (trans) fats and saturated fats[17]; total fat intake should be equally divided among polyunsaturated, monounsaturated, and trans or saturated fats.

Maintaining Body Composition and Weight with Diet and Exercise

Diet. Management of body composition should include both diet and exercise. To maintain good health and stave off disease, a regular exercise program should be combined with a dietary plan. The dietary plan should be developed to address the athlete's or client's specific body composition, body weight, and activity goals. Individual body composition and dietary needs should be discussed privately with appropriately trained nutrition and weight management experts. Athletic trainers and other health professionals, such as registered dietitians, should provide nutritional information to athletes and clients. A Board-Certified Sports Dietitian (CSSD) is a registered dietitian who has earned the premier professional sports nutrition credential from the American Dietetic Association. Coaches, peers, and family members should not provide information on diet, body composition, weight, or weight management practices and should refrain from making comments on or participating in the monitoring of body composition and weight.[50]

Total caloric intake should be determined by calculating BMR and the energy needs for activity. Many methods are available to determine total caloric need, including assessments of metabolic function and oxygen utilization, but equations that estimate metabolic function are more plausible options for clinicians. These metabolic estimation equations take into consideration body size, fat mass and FFM, age, sex, and the expenditure of energy for activity.[12,117] One drawback to the use of estimation formulas is that muscular tissue uses more energy than does nonmuscular tissue; therefore, estimation formulas that are not adjusted for lean muscle mass may underestimate the daily caloric needs for athletes or clients who are very muscular.

Caloric intake should be based on the body weight goal. A person should consume a total number of calories based on body composition and weight goals. Caloric intake that is too high or too low to support the desired lean body mass will negatively affect metabolic function and body composition. Metabolic function is more efficient in those with greater amounts of lean body mass. When BMR is calculated based on the body composition and weight goals, this formula provides an important estimate of the energy needed to meet activity requirements.

A safe and healthy dietary plan that supplies sufficient energy and nutrients should be maintained throughout the year. A healthy diet or meal plan provides adequate calories to achieve body weight goals, supply essential nutrients, and maintain hydration. The U.S. Department of Agriculture's Food Pyramid Guide is one method that can be used to ensure adequate nutrient intake. Athletes and clients should identify the appropriate Food Guide Pyramid (www.mypyramid.gov)[119] that describes food groups and the recommended number of daily servings per group adults and children need to consume for essential nutrients. The AT or other trained health care professional can also use the appropriate Food Guide Pyramid to calculate the recommended caloric intake level based on the individual's goal weight. The guidelines at www.mypyramid.gov are consistent with recommendations by organizations such as the American Heart Association and the American Cancer Society to control diabetes, heart disease, cancer, and other chronic and debilitating diseases.[120] Even though this method may underestimate the protein and carbohydrate needs of athletes or clients, it can be used to correctly guide a person's eating needs for vitamin and mineral intake and overall caloric intake.

The metabolic qualities of the activity should be used to calculate the need for each energy-producing nutrient in the diet. To determine specific dietary needs and adjustments, an analysis of the metabolic characteristics (eg, anaerobic or aerobic) with consideration for the performance, body composition, weight, and personal goals of the athlete or client (eg, build muscle mass, lose fat) must be performed.

Ergogenic and dietary aids should be ingested with caution and under the advice of those knowledgeable about the requirements of sports and other governing organizations. The NCAA, U.S. Olympic Committee, and International Olympic Committee regulate supplements approved for use by athletes. By-law 16.52 g of the NCAA states that an institution may provide only non–muscle-building nutritional supplements to a student-athlete at any time for the purpose of providing additional calories and electrolytes, as long as the supplements do not contain any substances banned by the NCAA.[19] Athletes and clients should be educated against taking any dietary or other nutritional supplements without first checking with the AT or another health care provider who is familiar with the competitive regulations.

Exercise. The exercise program should not only train the person for his or her activity but should also help the person maintain overall physical fitness and wellness. Body weight and composition may be maintained by pursuing an exercise regimen that matches a person's needs. The American College of Sports Medicine recommends 30 minutes of exercise, 5 days per week to remain healthy[7]; however, if the goals are to facilitate weight and body fat loss, a safe and appropriate aerobic exercise program will facilitate that loss. To maximize the metabolism of excess fat, one must participate in continuous, rhythmic aerobic exercise for a minimum of 30 minutes per exercise bout but no longer than 60 to 90 minutes, for at least 150 minutes per week.[118,119,121] Although interval exercise for 30 minutes burns the same number of calories, the metabolism of fat is less. If the person is unfit or has not exercised at this level previously, a graded-progression approach should be used to achieve the exercise goals.[14] Target heart rate for this aerobic activity must be above 50% $\dot{V}O_2$max to initiate lipolysis, with the most efficient fat metabolism occurring between 60% and 70% $\dot{V}O_2$max (approximately 55% to 69% of maximum heart rate).[5,118] Caution should be used in those with orthopaedic or other health conditions that may warrant changes in exercise protocols. Non–weight-bearing or limited–weight-bearing aerobic exercises are recommended for those with orthopaedic conditions.

Body composition adjustments should be gradual, with no excessive restrictions or unsafe behaviors or products. On average, weight loss goals should be approximately 1 to 2 lb (0.5 to 0.9 kg) per week but should not exceed 1.5% of body weight loss per week.[1,122] A higher rate of weight loss indicates dehydration or other restrictive or unsafe behaviors that will negatively affect performance and health. One pound (0.5 kg) of fat is equal to 3500 kilocalories of energy; therefore, increases or decreases in calories to the level needed to maintain ideal lean mass will help to achieve body fat goals. Few authors have studied plans for weight gain goals in active people, but a process similar to that for weight loss may be used. The AT should work closely with the other members of the health care team to assist in this determination.

Combining weight management and body composition goals with physical conditioning periodization goals will assist athletes and clients in reaching weight goals. Periodization involves manipulating training intensity and volume to yield specific performance outcomes. The best time for adjustments in weight and body composition is during the preparatory period, which occurs outside competition.[115] The main emphasis of the competitive period should be on performing the sport or activity with the body nearing its highest level of physical fitness. During the competitive period, less time is available for physical conditioning and more time is spent on strength, power, and increased training intensity specifically related to sport performance. During the different phases of the preparatory period, physical conditioning goals can be used to achieve body composition goals. During the hypertrophy or endurance phase, the emphasis is on developing lean body mass, aerobic capacity, and muscular endurance, which can provide a physiologic environment to assist in decreasing body fat. During the basic strength and strength-power phases, the emphasis is on developing strength and speed and involves increasing levels of anaerobic activity.[123] An AT or other trained health care professional should be consulted for assistance in manipulating these phases of the periodization plan to meet training goals.

Education on safe dietary and weight management practices should be conducted on a regular and planned basis. The AT and other health care professionals should be involved in educating athletes or clients and monitoring their diets. The initial team meeting or client interview is an opportune time to communicate information on healthy eating habits and the effect of proper nutrition and hydration on performance.

Common Unsafe Weight Management Practices

Athletes and active people regularly seek methods to maximize performance, and many of the common methods involve managing diet, weight, or body composition (or a combination of these). Although many safe methods exist to achieve goal weight or the lowest safe weight, unsafe practices involve self-deprivation techniques that lead to dehydration, self-starvation, and disordered eating. In field studies and experimental research on weight-class athletes, the most common unsafe methods are a mixture of dehydration and other methods, including food restriction or improper dieting to reduce body fat. Therefore, the results of studies examining the physiologic and performance effects of rapid weight reduction may not reflect only dehydration. Studies selected for this summary are those that focused primarily on dehydration techniques and involved short-term, rapid weight reduction.

Dehydration and Weight Management

Since the late 1930s and as recently as 2003, authors[124,125] have reported that athletes used voluntary dehydration as a method of rapid weight loss to reach a lower body weight for competition. Several rapid weight loss methods involve rapid fluid loss; these methods use active, passive, diet-induced, pharmacologic-induced, and blood reinfusion techniques to achieve a desired weight. The active method involves increasing metabolic rate through exercise to increase the rate of heat production in active skeletal muscle.[126] At least 1 L of fluid may be lost through sweat evaporation during exercise[127] when an active person abstains from drinking fluid during activity. To ensure continued sweating, exercise is often combined with excessive clothing, which diminishes the evaporative effects of sweating and increases insulation and core temperature.[128,129] At one time, dehydration was a common method used by wrestlers,[130–132] but a survey[127] indicated that this method has become less popular because of changes in the weigh-in procedures (ie, assessments of hydration status) of sport governing bodies. These active methods may be enhanced by combining the active technique with environmental changes that increase the passive sweat rate, resulting in higher levels of dehydration, or the training facility may be artificially heated to ensure a higher passive sweat rate with less physical effort.[130–134] Recent changes in sport guidelines appear to have reduced the extent to which collegiate wrestlers use passive dehydration.[125]

Athletes who use passive dehydration methods also may restrict food intake for weight loss or may purposefully consume foods that promote diuresis for fluid loss. A combined high-protein, low-carbohydrate diet may promote dehydration through several mechanisms. Meals high in protein and devoid of carbohydrate may modestly stimulate urine production. As the body is deprived of carbohydrates, fat oxidation is increased, promoting additional fluid loss in the urine. With a high protein intake, the person may further induce diuresis from the increased nitrogen metabolism and urea excreted via the kidneys.[14]

Some researchers[135] suggested that total body water is elevated with the consumption of a high-carbohydrate diet, forcing muscle glycogen to be stored along with water, which can increase body weight. As dietary carbohydrate intake is restricted, glycogen resynthesis may be limited, thereby avoiding the increase in body weight caused by water storage.[135] However, this dietary strategy does not provide optimal energy stores for a competitive athlete,[136,137] and performance may suffer.[98,138,139]

Ingesting medications that stimulate urine production (eg, diuretics) may have a greater influence on body weight than does altering the diet. Diuretics appropriately prescribed for hypertensive therapy or to reduce edema have been misused by athletes seeking rapid weight loss for competition. Fortunately, the misapplication of pharmacologic agents was uncommon in weight-class athletes who were surveyed[23,132]; however, this practice has not been fully eradicated.

Finally, one report[140] and other anecdotal stories from athletes indicate that some athletes at international competitions have had blood removed intravenously before the required weigh-in. The blood is then reinfused after the athlete "makes weight" for competition. Other than the lone report, no formal information is available about this method or the extent to which it has been practiced or is currently used.

Effects of Dehydration on Performance

Dehydration results in suboptimal performance when the dehydration is ≥1% in children and ≥2% in adults.[140,141] In children, 1% dehydration causes a reduction in aerobic performance[142] and an increase in core temperature.[143] In adults, 2% to 3% dehydration causes decreased reflex activity, maximum oxygen consumption, physical work capacity, muscle strength, and muscle endurance and impairs temperature regulation.[144,145] At 4% to 6% dehydration, further deterioration occurs in maximum oxygen consumption, physical work capacity, muscle strength, and endurance time; temperature regulation is severely impaired.[111] These physiologic effects of dehydration are discussed in depth in 2 NATA position statements[99,111] and will not be discussed further here.

Most athletes who participate in weight-class sports need short-duration, high-intensity efforts that demand rates of energy production at or above the peak oxygen uptake. For single efforts, whether performance is affected by dehydration before performance is unclear. Dehydration does not appear to reduce phosphagen energy stores (adenosine triphosphate, creatine phosphate),[137] although some of the weight reduction found in this study occurred with diet manipulation and not dehydration alone. People involved in activities that use weight manipulation to improve performance appear to be more profoundly affected by hydration status. Efforts that are sustained at intensities below peak oxygen uptake are notably affected by prior dehydration. Dehydration induced with the use of pharmacologic diuretics increases frequency of muscle twitches, a potential risk factor for muscle cramps, more so than does exercise- or sauna-induced dehydration.[132]

Dietary Caloric Restriction and Weight Management

Dietary restriction is another common method used to maintain weight. Very low-calorie diets affect the cardiovascular system and can produce myofibrillar damage, orthostatic hypotension, bradycardia, low QRS voltage, QT-interval prolongation, ventricular arrhythmias, and sudden cardiac death.[146–149] Sudden death may be caused by the ventricular arrhythmias or hypokalemia associated with caloric restriction.[14] Very low-calorie diets can also result in a marked blunting of the normal heart rate increase and blood pressure response to exercise.[149] In addition to these physiologic changes, dietary restrictions cause deficits in recall, understanding visuospatial information,[150] working-memory capacity, recall on the phonologic loop task, and simple reaction time.[151] They also affect planning time.[152]

Low-calorie diets also affect the endocrine system. Levels of growth hormone and insulin-like growth factor (IGF) binding protein 2 are increased. The growth hormone response to growth hormone–releasing hormone is increased; however, levels of IGF I and IGF binding protein 3 are decreased.[153–155] The decrease in IGF I, an anabolic factor, limits growth and muscle development.[153] With improved nutrition, growth "catchup" occurs but is inadequate; children, in particular, will never achieve their potential genetic height.[156,157] Also, lower levels of IGF I are associated with poor muscle development, and thus potential maximum strength is never realized.[153] Lower levels of IGF I are associated with lower bone mineral densities.[153] Urinary excretion of cross-links, a marker of bone absorption, is increased, and serum osteocalcin, a marker for bone formation, is lower than normal in patients with low BMIs.[154] These findings indicate that more bone is being absorbed and less bone is being produced than normal, potentially leading to osteoporosis[154] and stress fractures.

Changes in thyroid function also occur as a result of low-calorie diets. Total thyroxine (T_4) and triiodothyronine (free T_3) decrease and reverse triiodothyronine (rT_3) increases.[155] The response of thyroid-stimulating hormone (TSH) to thyrotropin-releasing hormone (TRH) is diminished,[155] and the BMR is lowered. The adrenal glands produce an increased amount of free cortisol, and serum cortisol levels are elevated, without associated changes in adrenocorticotropic hormone.[155] Gonadotropin-releasing hormone (GnRH) from the hypothalamus is reduced,[158] leading to decreased levels of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) from the anterior pituitary.[159] Estrogen production is low, contributing significantly to osteoporosis[159] and menstrual dysfunction.[15]

Dietary restrictions affect the immune system by significantly impairing cell-mediated immunity, phagocyte function, the complement system, secretory immunoglobulin A levels, cytokinase production,[160–163] haptoglobin production, orosomucoid production,[164] T-lymphocyte response, and production of Th_2 cytokine; Th_1 cytokinase production increases.[162] These immunologic abnormalities may lead to an increased number of infections during the period of inadequate dietary intake.[165]

Eating Disorders, Disordered Eating, and Weight Management

Disordered eating behaviors have been identified in both male and female athletes.[131,166] A total of 10% to 15% of boys who participate in weight-sensitive sports practice unhealthy weight loss behaviors.[131,166] Eleven percent of wrestlers have been found to have eating disorders or disordered eating,[166] and up to 45% of wrestlers were at risk of developing an eating disorder.[129,167,168] Several studies[169–171] revealed a high prevalence of eating disorders in female athletes involved in weight-sensitive sports. Sixty percent of average-weight girls and 18% of underweight girls involved in swimming were attempting to lose weight.[172] Thus, both males and females may develop dysmorphia, disordered eating, and eating disorders as a consequence of their efforts to lose weight for their activities. The female athlete triad is a relationship among disordered eating, altered menstrual function, and abnormal bone mineralization.[160,173,174] Amenorrhea occurs as a result of decreased pulsatile release of GnRH from the hypothalamus,[157] which leads to fewer LH and FSH pulses from the anterior pituitary.[175] Osteoporosis can result from decreased estrogen or IGF I[153,154] and from excess cortisol production.[155]

Athletes competing in aesthetic sports had the highest indicators of eating disorders.[176] Those who participated in weight-matched sports also showed higher levels of disordered eating than did athletes in non–weight-restricted sports.[175–177] Athletes whose bodies differ from the "ideal" physique of the sport may also be at higher risk for developing disordered eating.[20] Some experts have surmised that the demands of the athletic subculture may involve inherent risk for the development of unhealthy weight control behaviors. Subclinical eating disorders in athletes have been associated with dieting to enhance appearance or improve health or dieting because someone (eg, coach, peer) recommended it.[45]

The spectrum of disordered eating behaviors ranges from the very benign and mild to the very severe.[50] In athletes, disordered eating may affect up to 62% of the population and is reportedly highest in weight-class events, such as boxing and wrestling, and aesthetic activities, such as dance and gymnastics, in which low body weight and leanness are emphasized.[178,179]

Disordered eating in the mild and earliest stages may start simply as a dietary plan to achieve a better aesthetic appearance or better performance. A common "diet" involves caloric restrictions, but when these restrictions are taken to the extreme, there is reason for concern. Often, athletes seek weight loss or dieting advice from friends or teammates or simply follow the suggestions of others without fully understanding the importance of maintaining an adequate energy balance. Other times, athletes may adhere to the recommendations made by coaches without understanding the nutritional requirements of the sport.[50] The health care team should be in place to help athletes and active clients address disordered eating behaviors and to assist in providing accurate and appropriate advice. The topics of disordered eating, eating disorders, and dysmorphia are addressed more comprehensively in the NATA position statement on disordered eating.[50]

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