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A Prospective Study of Overuse Knee Injuries Among Female Athletes With Muscle Imbalances and Structural Abnormalities

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Objective: To prospectively examine the influence of hamstring-to-quadriceps (H:Q) ratio and structural abnormalities on the prevalence of overuse knee injuries among female collegiate athletes.

Design and Setting: We used chi-square 2 × 2 contingency tables and the Fischer exact test to examine associations among H:Q ratios, structural abnormalities, and overuse knee injuries.

Subjects: Fifty-three apparently healthy women (age = 19.4 ± 1.3 years, height = 167.6 ± 10.1 cm, mass = 65.0 ± 10.0 kg) from National Collegiate Athletic Association Division I women's field hockey (n = 23), soccer (n = 20), and basketball teams (n = 10) volunteered.

Measurements: The H:Q ratio was determined from a preseason isokinetic test on a Biodex system at 60°/s and 300°/s. We measured athletes for genu recurvatum and Q-angles with a 14-in (35.56-cm) goniometer. Iliotibial band flexibility was assessed via the Ober test.

Results: Ten overuse knee injuries (iliotibial band friction syndromes = 5, patellar tendinitis = 3, patellofemoral syndrome = 1, pes anserine tendinitis = 1) occurred in 9 athletes. The H:Q ratio below the normal range at 300°/s ($P = 0.047$) was associated with overuse knee injuries, as was the presence of genu recurvatum ($P = 0.004$). In addition, athletes possessing lower H:Q ratios at 300°/s and genu recurvatum incurred more overuse knee injuries than athletes without these abnormalities ($P = 0.001$).

Conclusions: The presence of genu recurvatum and an H:Q ratio below normal range was associated with an increased prevalence of overuse knee injuries among female collegiate athletes. Further investigation is needed to clarify which preseason screening procedures may identify collegiate athletes who are susceptible to overuse knee injuries.

Key Words: genu recurvatum, isokinetic testing, hamstring-to-quadriceps ratio

According to data from the National Collegiate Athletic Association Injury Surveillance System, knee injuries have increased among female basketball and soccer players compared with their male counterparts.[1–3] The focus of this research has been the reason for sex disparities in anterior cruciate ligament tears. The greater prevalence of muscle imbalances among female than male athletes suggests that the hamstring-to-quadriceps (H:Q) ratio is a mitigating factor for anterior cruciate ligament tears.[4–6] The H:Q ratios and structural abnormalities have been investigated in anterior cruciate ligament tears because of the higher incidence of this injury in female versus male athletes. Because studies support sex differences among H:Q ratios and structural abnormalities, it is reasonable to examine if these differences play a role in other knee injuries. For instance, H:Q ratios have been examined as a possible risk factor for hamstring injuries in male athletes, although findings do not support H:Q ratios as a predictor of hamstring strains.[7] The influence of H:Q ratios on knee injuries other than anterior cruciate ligament tears or hamstring strains has not been thoroughly investigated as a potential risk factor for overuse knee injuries.

Whether female athletes are more prone to overuse knee injuries than their male peers is controversial. Sex differences in other types of knee injuries and their predisposing factors have received less attention from the sports medicine community. However, female athletes have decreased thigh musculature compared with male athletes, possibly altering kinematics during landing that may result in injury.[8] Women have decreased H:Q ratios and a shorter time to peak hamstring torque than men.[4–6] Excessive Q-angles and genu recurvatum are more common in women than men.[9–12] These structural and biomechanical differences may place added stress on the knee, increasing the likelihood of an overuse knee injury in female athletes compared with their male counterparts.

Retrospective examination of the possible mediating factors for overuse knee injuries may lead to misdiagnosis. In these studies, it is difficult to ascertain if hamstring or quadriceps

Table 1. Clinical Findings Used to Identify Overuse Knee Injuries

Injury	Subjective Findings	Palpation Findings	Objective Findings	Mechanism of Injury
Tendinitis	Athlete complains of pain or swelling in tendon	Point tenderness along tendon, crepitus	Pain along tendon of agonist muscle with active contraction against resistance; pain along tendon of agonist muscle with passive stretching	No specific mechanism of injury
Patellofemoral syndrome	Athlete complains of pain in or under patella while running, going up or down stairs	Pain is diffuse; unable to determine specific site	Cinema sign*; pain with activities involving flexion and extension of knee	No specific mechanism of injury
Iliotibial band friction syndrome	Athlete complains of pain along lateral aspect of knee while running, going up or down stairs	Pain over lateral femoral condyle, above lateral joint line	(+) Noble test†; pain at 30° of resistive knee extension-flexion over lateral femoral condyle	No specific mechanism of injury

*Cinema sign: increased pain along anterior aspect of knee on standing after sitting for long periods of time.[26]
†Noble compression test: Athlete lies supine on a table with examiner standing lateral to involved side. Examiner holds involved knee flexed with one hand, grasping above lateral joint line with thumb over lateral femoral condyle and the other hand supporting the lower leg. Leg is flexed and extended by examiner while pressure is applied to lateral femoral condyle. Test is positive if pain is elicited approaching 30° of flexion.[11] These 2 tests were used by the principal investigator in consultation with the team physician to make the final classification.

weakness or both resulted in knee injury or were merely a consequence of the injury. Prospective investigations on knee injury prevalence among female collegiate athletes are limited. Our purpose was to prospectively investigate the influence of H:Q muscle imbalances and structural abnormalities assessed in the preseason on overuse knee injuries that collegiate female athletes incurred during the subsequent competitive season. We hypothesized that female athletes with these muscle and structural abnormalities would be more predisposed to overuse knee injuries than athletes without these anomalies.

METHODS

Subjects

Volunteers were from National Collegiate Athletic Association Division I women's field hockey (n = 23), soccer (n = 20), and basketball (n = 10) teams during the 1999–2000 athletic season. Before participating, all women signed an informed consent form approved by the university's institutional review board, which also approved the study. The sports medicine staff excluded an athlete if she had a prior injury or was unable to perform a preseason isokinetic test, such as an athlete within 1 year of anterior cruciate ligament surgery or with a tibial stress fracture. The principal investigator (M.R.D.) conferred with the athlete's physician before making a final decision to exclude a participant from the study.

Procedures

Height and weight were recorded from preseason physical examinations by the athletic trainer for each team. To determine their H:Q ratios, athletes performed a preseason isokinetic test with an isokinetic Biodex system (Biodex Medical Systems, Shirley, NY) at the beginning of the preseason. The subject was strapped into a chair with a lever aligned at the distal tibia, using the lateral femoral condyle as an anatomical reference for the axis of rotation on the Biodex. The principal investigator instructed the athlete to extend and flex the knee at full force throughout the test. The athlete was allowed to flex and extend the knee a few times at each speed to acquaint herself with the test. The athlete completed 5 repetitions of flexion and extension of each knee at a speed of 60°/s to assess muscle strength.[13] Then, in order to assess muscle endurance, 15 repetitions at 300°/s were performed to determine the abilities of the muscle to maintain work.[14] Athletes were first tested at 60°/s in order to eliminate fatigue as a limiting factor for the muscle-strength determinations.[15] Total work (ft-lbs) for both flexion and extension were recorded for determining the H:Q ratios.[14] The Biodex Medical Systems absolute values for H:Q ratios were used for statistical analysis.[14]

All athletes (n = 53) were measured once with a 14-in (35.56-cm) goniometer (Graham-Field, Inc, Atlanta, GA) by the primary investigator for the presence of genu recurvatum (≥10°) and Q-angles greater than 18°.[11,12] Iliotibial band flexibility was assessed through the Ober test.[10–12] Structures were measured while the athlete was standing. Genu recurvatum was assessed by aligning the proximal arm of the goniometer at the greater trochanter, the axis at the lateral femoral epicondyle, and the distal arm of the goniometer at the lateral malleolus.[10–12] Q-angle was measured with the proximal arm of the goniometer aligned at the anterior superior iliac spine, the axis at the midpoint of the patella, and the distal arm aligned with the tibial tubercle.[10–12]

We assessed iliotibial band flexibility with the Ober test. The athlete was side lying on a table facing away from the examiner. The examiner stabilized the hip of the athlete with one hand while extending and lowering the top leg (in extension) with the other hand.[10–12] If the ankle did not fall below the edge of the table (ie, the hip remained abducted, parallel to the table), the test was considered positive for iliotibial band tightness.

Injuries sustained by an athlete during the season as a result of repetitive submaximal loading on the knee joint without any direct trauma to the knee joint were defined as ''overuse.'' These injuries, determined by clinical findings, included tendinitis, patellofemoral pain, and iliotibial band friction syndrome (Table 1). The athletic trainer for each sport monitored the occurrence of any overuse knee injuries and maintained records.

Table 2. Prevalence of Overuse Knee Injuries (n = 10) Among Athletes (n = 53) by Sport

Sport	Patellar Tendinitis	Pes Anserine Tendinitis	Patellofemoral Pain Syndrome	Iliotibial Band Friction Syndrome
Basketball (n = 10)	2	0	1	0
Field hockey (n = 23)	0	1	0	3
Soccer (n = 20)	1	0	0	2
Total	3	1	1	5

Table 3. Biodex and Goniometer Measurements of the Athletes (n = 53)

Measurement	Mean ± SD	Normal Range
Right leg H:Q* at 60°/s	62.2 ± 7.8%	60–69%
Left leg H:Q at 60°/s	63.5 ± 8.9%	60–69%
Right leg H:Q at 300°/s	73.6 ± 14.0%	80–95%
Left leg H:Q at 300°/s	74.7 ± 16.1%	80–95%
Right Q-angle	12.8 ± 3.7°	<18°
Left Q-angle	11.2 ± 2.9°	<18°
Right recurvatum	5.0 ± 3.4°	<10°
Left recurvatum	4.9 ± 3.7°	<10°

*H:Q indicates hamstring-to-quadriceps ratio.

Statistical Analysis

Independent variables were the presence of genu recurvatum, increased Q-angle, decreased iliotibial band flexibility, and abnormal H:Q ratio. Muscle imbalances were divided into 2 categories according to H:Q ratios: above the normal ranges (>69% at 60°/s and >95% at 300°/s) and below the normal ranges (<60% at 60°/s and <80% for 300°/s). The dependent variable was overuse knee injuries. We calculated a 2×2 chi-square contingency table to determine if there were associations among muscle imbalances, structural abnormalities, and overuse knee injuries. The Fisher exact test was used to determine statistical significance if the expected cell frequency in at least 1 cell was <10. All statistical analyses were computed with the Statistical Package for the Social Sciences (version 7.0; SPSS Inc, Chicago, IL). The P value for statistical significance was set at $< .05$, and results were reported as mean ± SD.

RESULTS

Subjects

Initially, 63 field hockey (n = 25), soccer (n = 26), and basketball (n = 12) Division I female athletes volunteered to participate. Of these, 10 athletes were excluded because they were unable to perform the preseason Biodex test due to preexisting musculoskeletal limitations or injuries (n = 9) or previous season-ending injuries (n = 1). The 53 athletes (height = 167.6 ± 10.1 cm, mass = 65.0 ± 10.0 kg) who completed the study were an average age of 19.4 ± 1.3 years old.

A total of 10 overuse knee injuries (in 9 athletes) that resulted from stress due to repetitive submaximal loading were recorded, with 8 of these affecting the right knee. One athlete experienced bilateral iliotibial band friction syndrome. The most common injury incurred by female athletes was iliotibial band friction syndrome (n = 5). The remaining injuries included patellar tendinitis (n = 3), pes anserine tendinitis (n = 1), and patellofemoral syndrome (n = 1). The occurrence of overuse knee injuries during the season did not differ among sports ($P = .47$) (Table 2).

Muscle Imbalances

The mean right and left H:Q ratios at 60°/s and 300°/s were similar among athletes (Table 3). The average right and left H:Q ratios at 60°/s were within the ''normal'' Biodex range of 60%–69%. However, at 300°/s, the mean right and left H:Q ratios were below the ''normal'' range of 80% to 95%. Most of the athletes (72%) manifested an H:Q ratio of less than 80% at 300°/s, indicating less hamstring endurance (H_e) relative to quadriceps endurance ($H_e < Q_e$). Of the 53 athletes, 24 (45%) had H:Q ratios of less than 60% at 60°/s, suggesting increased strength of the quadriceps compared with the hamstring ($Q_s > H_s$). A total of 9 athletes with H:Q ratios greater than 69% at 60°/s (n = 3) or at 300°/s (n = 6) showed increased hamstring strength ($H_s > Q_s$) and endurance ($H_e > Q_e$), respectively.

The number of athletes possessing H:Q ratios above, within, or below the normal ranges and the prevalence of structural abnormalities or injuries are displayed in Tables 4 and 5. All 10 overuse knee injuries occurred in athletes with H:Q ratios below the normal Biodex ranges. The H:Q ratios of less than 80% at 300°/s ($H_e < Q_e$) were linked with the occurrence of overuse knee injuries ($P = .047$). No associations were noted between H:Q ratios of less than 60% at 60°/s ($H_s < Q_s$), great-

Table 4. Hamstring-to-Quadriceps (H:Q) Ratios at 60°/s, Structural Abnormalities, and the Occurrence of Overuse Knee Injuries Among Athletes (n = 53)

	H:Q Ratio at 60°/s	Genu Recurvatum (≥10°)	Positive Ober Test	Excessive Q-Angle (>18°)	Overuse Knee Injury
Normal range	60–69% (n = 26)	2	7	3	1
Below normal range	<60% (n = 24)	5	5	3	8*
Above normal range	>69% (n = 3)	2	2	0	1

*One athlete had bilateral iliotibial band friction syndrome. The injury was recorded twice for a total of 10 overuse knee injuries, although 9 athletes suffered overuse knee injuries.

Table 5. Hamstring-to-Quadriceps (H:Q) Ratios at 300°/s, Structural Abnormalities, and the Occurrence of Overuse Knee Injuries Among Athletes (n = 53)

	H:Q Ratio at 300°/s	Genu Recurvatum (≥10°)	Positive Ober Test	Excessive Q-Angle (>18°)	Overuse Knee Injury
Normal range	80–95% (n = 9)	2	2	1	0
Below normal range	<80% (n = 38)	7	12	2	10*
Above normal range	>95% (n = 6)	0	0	3	0

*One athlete had bilateral iliotibial band friction syndrome. The injury was recorded twice for a total of 10 overuse knee injuries, although 9 athletes suffered overuse knee injuries.

er than 69% at 60°/s ($H_s > Q_s$), or greater than 95% at 300°/s ($H_e > Q_e$) and the occurrence of overuse knee injuries ($P > .05$). The prevalence of overuse knee injuries was greater for athletes possessing H:Q ratios below the normal range at both 60°/s ($H_s < Q_s$) and 300°/s ($H_e < Q_e$) than for athletes without these muscle imbalances ($P = .004$).

Structural Abnormalities

Genu recurvatum was present in 9 athletes, and 6 athletes had Q-angles greater than 17°. A positive Ober test for iliotibial band tightness was observed in 14 athletes. Genu recurvatum greater than or equal to 10° (present in 5 of the 9 athletes with overuse knee injuries) was more common among those sustaining overuse knee injuries than in those not sustaining an injury during the competitive season ($P = .004$). The prevalence of overuse knee injuries was similar between athletes with a positive Ober test ($P = .68$) or excessive Q-angles ($P = .57$) and those without these structural abnormalities.

Interactions Among Muscle Imbalances, Structural Abnormalities, and Overuse Knee Injuries

The presence of genu recurvatum was not associated with the occurrence of overuse knee injuries in athletes having H:Q ratios less than 80% at 300°/s ($H_e < Q_e$, $P > .05$) or less than 60% at 60°/s ($H_s < Q_s$, $P > .05$). Athletes with H:Q ratios less than 80% at 300°/s ($H_e < Q_e$) and genu recurvatum greater than or equal to 10° had a greater number of overuse knee injuries than athletes without these muscular and structural abnormalities ($P = .001$). In addition, female athletes with H:Q ratios less than 60% at 60°/s ($H_s < Q_s$) and genu recurvatum greater than or equal to 10° also incurred more overuse knee injuries than those not having these characteristics ($P = .013$).

Athletes possessing a positive Ober test and H:Q ratios less than 60% at 60°/s ($H_s < Q_s$) did incur more overuse knee injuries than athletes without these abnormalities ($P = .03$). However, overuse knee injuries did not occur more frequently in athletes with H:Q ratios less than 80% at 300°/s ($H_e < Q_e$) and a positive Ober test ($P = .67$). Also, no differences were found between athletes with H:Q ratios below the normal ranges at 60°/s or 300°/s ($H_s < Q_s$) and excessive Q angles among those with overuse knee injuries versus women without these aberrations ($P = .81$).

DISCUSSION

Grace et al[16] prospectively investigated the relationship between H:Q imbalances and knee joint injuries among 172 high school football players. They characterized an H:Q muscle imbalance as a discrepancy of 10% or more between the H:Q ratios of each athlete's legs. They found no relationship between H:Q imbalances and knee injuries. However, these authors made no distinction between overuse and acute knee joint injuries, nor did they use normative data to classify the H:Q ratios.

We prospectively examined the association among H:Q muscle imbalances and structural abnormalities and the prevalence of overuse knee injuries among Division I female athletes during a competitive season. The lack of prospective studies on female athletes incurring atraumatic knee injuries, despite the well-documented structural and muscular differences between the sexes, is noteworthy. Consistent with our hypothesis and contrary to the findings of Grace et al,[16] we found that athletes possessing H:Q ratios below the normal ranges at both 60°/s and 300°/s and genu recurvatum were more likely to sustain an overuse knee injury than athletes without these anomalies.

Athletes with genu recurvatum had H:Q ratios below the normal ranges at 60°/s and 300°/s ($H_e < Q_e$, $H_s < Q_s$), indicating increased quadriceps strength and endurance. Quadriceps weakness and/or pain with active quadriceps contraction accompanies patellofemoral pain.[11,12,17,18] Witvrouw et al[19] used isokinetic testing of peak torque at 60°/s, 180°/s, and 240°/s to identify intrinsic factors that preceded the development of anterior knee pain among male and female collegiate physical education students. These investigators reported a decrease in quadriceps strength in students who developed anterior knee pain versus those who were asymptomatic; however, H:Q ratios were not measured. Werner[20] retrospectively examined hamstring and quadriceps strength at isokinetic speeds of 60°/s and 180°/s in male and female subjects who had unilateral patellofemoral pain. Quadriceps strength in the involved leg was significantly less than the uninvolved leg, whereas hamstring strength was not different. Because H:Q ratios were not assessed before injury in this study, it remains possible that the weakened quadriceps muscle was a result of the injury rather than a predisposing factor to patellofemoral pain. In addition, the subjects in the investigations of Witvrouw et al[19] and Werner[20] were not elite female athletes, as they were in our study. Further investigation with a larger sample size and appropriately timed isokinetic testing is needed to clarify whether decreased hamstring strength and endurance in relation to quadriceps strength and endurance and the presence of genu recurvatum contribute to overuse knee injuries in elite female collegiate athletes.

When the hamstrings tire, the duration of the swing phase of gait increases, placing the hamstrings in this weakened po-

sition for a longer period of time.[21] Interestingly, the iliotibial band is most active during the swing phase of gait.[22] In our study, the most common overuse knee injury was iliotibial band friction syndrome. All recorded cases of this injury were from athletes with H:Q ratios less than 80% at 300°/s ($H_e < Q_e$). Our findings indicate that future researchers should investigate the roles of hamstring fatigue ($H_e < Q_e$) and iliotibial band friction syndrome in overuse knee injuries.

All the athletes with iliotibial band friction syndrome had a negative bilateral Ober test, whereas only 3 athletes who sustained an overuse knee injury had a positive Ober test. Although decreased iliotibial band flexibility has been linked to the occurrence of overuse knee injuries,[11,12,14,23,24] a positive Ober test was not associated with the occurrence of overuse knee injuries among female athletes. Of the 3 structural abnormalities observed in this study, excessive Q-angles have received the most attention as a predisposing factor for patellofemoral joint injuries in female athletes.[10–12,14,23–28] However, we found that none of the 9 athletes who sustained an overuse knee injury had an excessive Q-angle.

Our study focused on prospectively examining predisposing factors that may result in the occurrence of overuse knee injuries among Division I collegiate female athletes over a competitive season. The different footwear and training surfaces of the various sports may have influenced our findings, but we did not account for these factors in our statistical analyses. As previously stated, the occurrence of overuse knee injuries did not vary statistically among sports ($P = .47$), but a larger sample size may yield different results.

Most athletes ($n = 45$) had H:Q ratios of less than 80% at 300°/s, below the normal range (see Table 3). The Biodex Medical normative values used were not specific to an athletic population. The large number of female athletes with values outside the normative ranges in our study indicates that research is needed to establish whether the existing normative isokinetic data apply to elite female athletes.

In conclusion, we found that those athletes possessing ratios of less than 80% at 300°/s ($H_e < Q_e$) and genu recurvatum had a greater occurrence of overuse knee injuries than those not having these musculoskeletal abnormalities. Our results suggest that diminished hamstring muscle endurance (H_e) and hamstring strength (H_s) relative to quadriceps endurance (Q_e) and quadriceps strength (Q_s) are predisposing factors for the occurrence of overuse knee injuries during the competitive season. Identifying genu recurvatum before sport participation and correcting hamstring muscle imbalances through strength training and conditioning may be key to preventing overuse knee injuries among female athletes.

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