Knee Surg Sports Traumatol Arthrosc (2018) 26:1319–1325
https://doi.org/10.1007/s00167-017-4684-6

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Female sex is associated with greater rotatory knee laxity in collegiate athletes

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Received: 22 June 2017 / Accepted: 16 August 2017 / Published online: 19 August 2017

Abstract

Purpose/hypothesis The purpose of this observational study was to determine which factors, including sex, are associated with increased rotatory knee laxity in collegiate athletes with no history of knee injuries. It was hypothesized that increased rotatory knee laxity, measured by a quantitative pivot shift test, would correlate with female sex, increased anterior translation during the Lachman test, generalized ligamentous laxity, and knee hyperextension.

Methods Ninety-eight collegiate athletes with a median age of 20 (range 18–25) years with no history of knee injuries were tested. IKDC and Marx activity scores were obtained and subjects underwent measurement of anterior translation during the Lachman test with a Rolimeter and measurement of knee hyperextension with a goniometer for both knees. A standardized pivot shift test was performed in both knees and quantified using image analysis technology. Generalized ligamentous laxity was assessed using the modified Beighton score.

Results The average anterior translation of the lateral compartment during the pivot shift test was 1.6 mm (range 0.1–7.1) with a mean side-to-side difference of 0.6 mm (range 0–2.7). The average anterior translation during the Lachman test was 9.0 (range 2–15). The anterior translation of the lateral compartment during the pivot shift test was significantly higher in females (median, 1.6; range 0.3–4.9) than in males (1.1, 0.1–7.1 mm) ($p < 0.05$). Anterior translation of the lateral compartment during the pivot shift test was significantly correlated with anterior translation during the Lachman test ($r = 0.34$; $p < 0.05$). There was no significant correlation between anterior translation of the lateral compartment during the pivot shift test and knee hyperextension or modified Beighton score (n.s).

Conclusion The data from this study show that female sex is associated with increased rotatory knee laxity measured during the pivot shift test and anterior translation during the Lachman test in collegiate athletes. In the future, these data may be helpful in diagnosing and managing ACL injuries in athletes and could be used in the clinic as a baseline by which to compare and identify patients who might exhibit increased rotatory laxity.

Level of evidence Diagnostic level II.

Keywords Knee · Rotatory knee laxity · Pivot shift · Knee instability

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Introduction

Non-contact anterior cruciate ligament (ACL) injuries are two to eight times more prevalent in females than in males [1, 3, 17, 21]. Given the increasing number of females participating in high level sports and the subsequent rise in the incidence of non-contact ACL injuries [19], an extensive amount of research has been devoted to elucidating the causes underlying this disparity [13, 17, 21, 22, 28, 32, 42, 43, 45]. This has led to the discovery of several anatomic risk factors including increased generalized ligamentous laxity [40] and increased knee laxity in response to anterior loading forces [40], i.e. anterior knee laxity. Generalized ligamentous laxity and anterior ligamentous laxity are believed to predispose to non-contact ACL injury [40] by altering knee joint stabilization and, consequently, gait and loading mechanics [30].

Similar to generalized and anterior ligamentous laxity, increased rotatory knee laxity may also be a risk factor for altered functional biomechanics and non-contact ACL injury. There is evidence that increased rotatory knee laxity, assessed by methods such as the pivot shift test [9], is associated with worsened patient-reported outcomes and increased long-term risk for osteoarthritis [5, 26, 29]. Females, compared to males, have been shown to exhibit increased generalized ligamentous laxity and anterior knee laxity [28, 34, 35, 41, 42]. Similarly, females may exhibit increased rotatory knee laxity, which could contribute to their increased risk for non-contact ACL injuries [1, 3, 17, 21]. An understanding of risk factors, including sex, that predispose individuals to rotatory knee laxity could assist in identifying individuals with elevated risk for non-contact ACL injuries and guide possible interventions and prevention programs. For example, individuals with increased rotatory knee laxity may potentially derive greater benefit from neuromuscular training programs that have been shown to reduce the incidence of ACL injury [19, 20]. Before it can be determined whether increased rotatory knee laxity is a risk factor for ACL injury, reference values must first be established for rotatory knee laxity in healthy individuals. Moreover, there has been little data reporting on the association between rotatory laxity and other factors including patient characteristics and clinical exam findings. Further understanding of risk factors for increased rotatory laxity is needed to help clinicians identify patients with increased rotatory laxity who may be at risk for subjective instability after ACL reconstruction.

The purpose of this observational study was, therefore, to determine whether sex, anterior translation during the Lachman test, generalized ligamentous laxity, and knee hyperextension, are associated with increased rotatory knee laxity in collegiate athletes. A secondary aim was to determine normative values for rotatory knee laxity in collegiate athletes. It was hypothesized that increased rotatory knee laxity would correlate with female sex, increased anterior translation during the Lachman test, knee hyperextension, and generalized ligamentous laxity.

Materials and method

From June 2015 to September 2016, 101 male and female collegiate athletes underwent testing at the University of Pittsburgh Medical Center during their pre-season physical exams. To reduce selection bias, subjects were randomly selected from among a larger pool of 360 individuals undergoing pre-season physical exams. Random selection was performed as follows: after subjects completed their pre-season physical exam, they were pulled aside and chosen for testing only if testers were available. If no testers were available, subjects were allowed to exit the testing area without being tested. As a result, only a subset of the total pool of collegiate athletes could be tested in order to minimize any logistical disruption to the athletes' annual physical exams. Inclusion criteria for subjects were defined as being between 18 and 25 years of age and having no history of previous knee injuries requiring surgical treatment. Exclusion criteria were defined as having any history of knee injuries which required surgical intervention or any functional limitation or injury that prevented complete evaluation during their examination. After first providing informed consent, subjects completed a questionnaire consisting of a demographics form, the Tegner Activity Scale, the Marx Activity Rating Scale, and the International Knee Documentation Committee Subjective Knee Form (IKDC).

Two examiners were previously trained on the testing device and performed all rotatory laxity tests (T.P. and A.K.) and were blinded to the results of testing of anterior translation during the Lachman test. The use of a computer tablet-based method (iPad; Apple Inc) for image capture and 2D image analysis of the pivot shift exam has been previously described [24] and validated [38] and is depicted in Fig. 1. Briefly, three round yellow markers, ¾ inch in diameter (Color Coding Labels, Avery Dennison Corporation, Pasadena, CA, USA), were attached to the skin over the lateral epicondyle, Gerdy's tubercle, and the fibular head. With the subject relaxed, a standardized pivot shift test was performed in both knees [23, 39]. Using specially designed computer tablet software, anterior translation of the lateral compartment was calculated. Previous studies have shown the accuracy of this technique to be greater than 92% (accuracy <0.1 mm) when the computer tablet is held at a distance of 50–175 cm from the subject and at a deviation from the perpendicular position of <45° [4]. This method has also been found to have acceptable reliability, with reported

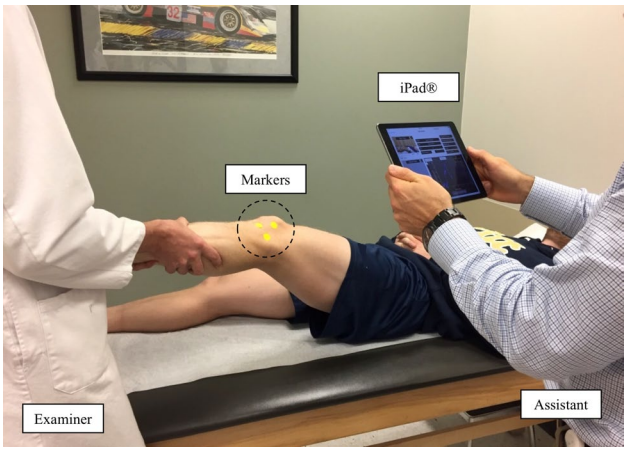

Fig. 1 Measurement of anterior translation of the lateral compartment during the pivot shift test (PIVOT technology). The examiner performs a standardized pivot test while an assistant holds the iPad in a fixed position to track the skin markers

intra-class correlation coefficients for intra- and inter-tester reliability of 0.75 and 0.73, respectively [4, 24, 37].

Subjects underwent a physical exam consisting of measurement of their anterior translation during the Lachman test using a Rolimeter (Aircast, Europe) and of the active and passive extension and flexion of each knee with a standard goniometer while the patient was in the supine position. These measurements have resolutions of 0.1 mm and 1°, respectively, and both have been shown to have excellent reliability with ICC's for inter-rater reliability >0.9 [8, 18]. All Lachman and ROM measurements were performed by one observer (EH) who was blinded to the results of rotatory laxity measurement. Subjects were assessed for general laxity using the modified Beighton criteria [6]. A modified Beighton score of 5 points or greater was defined as the cutoff for generalized ligamentous laxity. Prior to commencing the study, approval was obtained from the University of Pittsburgh Institutional Review Board (PRO15050261).

Statistical analysis

Statistical analyses were performed using SPSS software (v24; IBM Corp). Descriptive statistics were performed to determine the prevalence of patient demographics including sex and age. A median, range, and standard deviation were determined for ordinal variables, including the Tegner and Marx Activity Scores. A mean, standard deviation, and range were determined for continuous variables, i.e. IKDC scores, anterior translation of the lateral compartment as measured by the computer tablet application, anterior translation during the Lachman test as measured by the rolimeter, and the side-to-side difference between each knee's anterior translation of the lateral compartment. An independent *t* test or Mann–Whitney *U* test was used to compare the means of parametric and nonparametric variables, respectively, between males and females. An analysis of variance (ANOVA) was used to determine whether there was a significant difference in the anterior translation of the lateral compartment between any of the subgroups. Spearman's rank correlation coefficient was used to analyse correlations. To describe the strength of each correlation, the following scale was used for the absolute value of the correlation coefficient (r): strong relationship ($0.50 \leq r \leq 1.0$), moderate relationship ($0.3 \leq r < 0.5$), and weak relationship ($r < 0.3$). Statistical significance was set at a p value less than 0.05.

A post hoc power analysis was performed using G*Power 3.1.9.2 (Franz Paul, Kiel, Germany) to calculate the power of the present study. Based on the results of the Spearman's rank correlation coefficient regarding the correlation between anterior translation of the lateral compartment of the knee during a pivot shift test and mean anterior translation during the Lachman test, a power of 0.86 was calculated. Based on the results of the independent t test comparing the mean anterior translation of the lateral compartment of the knee during a pivot shift test between male and female subjects, an effect size of 0.29 ($\alpha = 0.05$), and a study group of 98 patients, a power of 0.4 was calculated.

Results

Three of 101 subjects were excluded for the following reasons: one subject had a prior distal femur fracture, one had a history of an ACL reconstruction, and one had a history of meniscal surgery. Subsequently, 98 subjects were successfully enrolled. Valid data sets were successfully obtained in all 98 subjects. Demographic characteristics of the included study participants are listed in Table 1. The median Tegner and Marx scores for the entire cohort were 10 (range 6–10) and 16 (range 4–16), respectively. The mean IKDC score was 98.8 ± 2.6 points and did not correlate significantly with quantitative pivot shift values (n.s.). Subgroup analysis revealed no significant differences in the anterior translation of the lateral compartment between collegiate athletes from each sport, suggesting that any potential selection bias in the distribution of athletes by sport did not affect final results (n.s.).

The results of laxity testing, including mean values for anterior translation of the lateral compartment during a pivot shift test and anterior translation during the Lachman test, are presented in Table 2. Anterior translation of the lateral compartment of the knee during the pivot shift test was significantly higher in female (median 1.6; range 0.3–4.9) than in male (1.1, 0.1–7.1 mm) subjects ($p < 0.05$) by 20%. In all subjects, there was a moderate correlation between anterior translation of the lateral compartment of the knee during

Table 1 Demographic data of the 98 included subjects

	Male	Female
N	48	50
Age (year)	20 (8)	20 (5)
Height (cm)	186 ± 5	168 ± 7
Weight (kg)	91 ± 8	64 ± 7
Sport		
American Football	36	0
Soccer	0	10
Basketball	3	3
Baseball/Softball	9	6
Track and Field	0	12
Lacrosse	0	10
Other	0	9
Marx (0–16)	16 (5)	16 (12)
Tegner (0–10)	10 (4)	8 (4)

Continuous variables are reported as a mean ± 1 standard deviation except for age which is reported as a median (range)

Ordinal variables are reported as a median ± 1 standard deviation except for Marx and Tegner scores which are reported as a median (range)

Sports and number of subjects in "Other" include bowling (1), golf (2), swimming (3), tennis (1), and rowing (3)

a pivot shift test and mean anterior translation during the Lachman test ($r = 0.34$, $p < 0.05$). A moderate correlation was observed between the anterior translation of the lateral compartment during the pivot shift test and the side-to-side difference in the anterior translation of the lateral compartment during the pivot shift test ($r = 0.4$ and 0.5 for right and left knees, respectively, $p < 0.05$). There was a moderate correlation between anterior translation during the Lachman test and the side-to-side difference in anterior translation of the lateral compartment of the knee during a pivot shift test ($r = 0.3$, $p < 0.05$). Results of the questionnaires, ligamentous laxity testing, and range of motion are shown in Table II. There was no correlation between average anterior translation of the lateral compartment and measurements of the range of motion of the knee (n.s.). The median modified Beighton score was found to be 0 (range 0–5), and there was only one individual with generalized ligamentous hyperlaxity. The modified Beighton score did not significantly correlate with anterior translation of the lateral compartment of the knee (n.s.)

Discussion

The most important finding of the present study was that, compared to their male peers, female collegiate athletes exhibit increased rotatory knee laxity as measured by an image analysis technology during the pivot shift test, proving the hypothesis under study. While there are inter-sex differences in rotatory laxity between females and not every female may exhibit greater rotatory laxity than every male, it is an important finding that females may, on average, display 20% more rotatory laxity than males. Moreover,

Table 2 Functional testing

	Total ($N = 98$)	Male ($N = 48$)	Female ($N = 50$)	*p* value
QPS (mm) Absolute value	1.6 ± 1.1	1.5 ± 1.1	1.8 ± 1.0	<0.05
QPS (mm) Side-to-side difference	0.6 ± 0.7	0.5 ± 0.6	0.8 ± 0.7	<0.05
Rolimeter (mm) Absolute value	9.0 ± 3.3	8.0 ± 3.5	9.9 ± 2.8	<0.05
Rolimeter (mm) Side-to-side difference	0.3 ± 0.6	0.2 ± 0.4	0.4 ± 0.8	NS
Extension (passive, deg) Absolute value	3.4 ± 2.5	2.8 ± 2.4	4.0 ± 2.5	<0.05
Extension (passive, deg) Side-to-side difference	1.4 ± 1.6	1.2 ± 1.4	1.5 ± 1.8	NS
Flexion (passive, deg) Absolute value	137.0 ± 6.8	135.2 ± 6.3	138.8 ± 6.9	NS
Flexion (passive, deg) side-to-side difference	0.3 ± 0.3	0.2 ± 0.3	0.4 ± 0.2	NS
Hyperextension >5°	15 (15.3%)	$N = 4$ (8.3%)	$N = 11$ (22%)	NS

QPS = quantitative pivot shift (Anterior translation of the lateral compartment of the knee during a pivot shift test measured by the PIVOT technology). Rolimeter = Anterior Translation during the Lachman test as measured by a Rolimeter (Aircast, Europe)). Extension = Passive extension measured by a universal goniometer in degrees. Flexion = Passive flexion measured by an universal goniometer in degrees. Values are given as mean ± 1 standard deviation. *p* values are reported as either a significant. Differences between males and females ($p < 0.05$) or not significant (NS, $p > 0.05$)

given the evidence that bony motion during the pivot shift may be greater than skin motion captured by the 2D image analysis method used in this study by a factor of 2.7–3.5 [4], it is possible that this observed difference in anterior translation of the lateral compartment of the knee may indicate a 0.81 mm to 1.05 mm difference between sexes. The relationship between female sex and rotatory knee laxity is important because female athletes are at an increased risk for ACL tear compared to their male counterparts and, given the increasing number of female athletes, constitute a sizeable population at high risk for primary ACL tear [1–3, 17, 21]. Increased rotatory knee laxity has been suggested as a risk factor for primary ACL injury and is associated with an increased risk of failure and post-traumatic arthritis after ACL reconstruction [5, 26, 29, 31]. As such, it is possible that the increased baseline rotatory knee laxity in female athletes may contribute to their increased risk of non-contact ACL injuries and may potentially predispose to poorer outcomes after ACL reconstruction.

This finding is of increased importance in this population of collegiate athletes given the increasing number of individuals participating in collegiate sports coupled with the increasing number of females participating in high level sports and subsequent rise incidence of ACL injuries in female athletes [19]. This is a high-risk population that may derive greater benefit from specific targeted interventions such as neuromuscular training programs or pre-season physical screening exams to identify individuals with greater rotatory laxity who may be at higher risk for ACL injuries or subjective instability after ACL reconstruction.

This observed difference in rotatory knee laxity between males and females is likely multifactorial. Potential contributors to increased rotatory laxity in females include sex differences in passive ligamentous constraints, active muscle constraints, bony morphology, lower extremity alignment, and neuromuscular activation patterns [7, 11–13, 16, 17, 46]. It has been well described that females exhibit increased incidence of generalized ligamentous laxity and anterior knee laxity compared to males [28, 34, 35, 41, 42]. This increased generalized ligamentous laxity may contribute to increased rotatory knee laxity in females. However, neither hyperlaxity nor knee hyperextension was correlated with increased rotatory knee laxity in this study population. This may be due to the high activity level and exclusively post-high school age of our population. Previous studies have suggested that athletes may have reduced ligamentous laxity as compared to non-athletes, and that training may even reduce ligamentous laxity [14, 15].

In addition to soft tissue restraints, there are also a number of unique differences between the bony morphology of females and males [10, 33, 44, 45] that may contribute to their increased rotatory knee laxity. For example, there is evidence that women have a more prominent posterior portion of the lateral condyle when compared to men [10]. It is possible that the increased size of the posterior portion of lateral femoral condyle in women could lead to higher moments being applied to the knee during the rotational component of the pivot shift manoeuvre, thus leading to increased translation of the lateral compartment.

In further support of the hypothesis under study, rotatory knee laxity was moderately correlated with anterior knee laxity. This correlates well with prior evidence that the ACL plays an important role in restraining anterior translation in response to the pivot shift [25, 27]. A previous cadaveric study found a strong correlation between anterior subluxation of the lateral compartment during a pivot shift test and anteroposterior laxity at 30 degrees in ACL-intact knees and a much weaker correlation in ACL-deficient knees [36]. The authors noted that only some, not all ACL-deficient patients with significant anteroposterior laxity display a high-grade pivot shift and posited that these conflicting findings are likely due to anatomic variation, including bony morphologic differences, among patients [36].

Collegiate athletes were observed to have a mean anterior translation of the lateral compartment during quantitative pivot shift testing 1.6 mm with a mean side-to-side difference of 0.6 mm. This correlates well with prior studies which reported a mean anterior translation of the lateral compartment of 1.3 ± 1.7 mm in healthy knees and 3.2 ± 1.0 mm in ACL-deficient knees with a mean side-to-to side difference of 1.9 ± 2.1 mm [24]. There may be soft tissue and bony factors contributing to the wide range of values for subjects' rotatory knee laxity, thus warranting future research.

The normative side-to-side data presented here may be helpful to distinguish physiologic from pathologic ligamentous laxity pre-operatively in patients with suspected ACL injuries. Ideally, clinicians would perform a quantitative pivot shift in high-risk athletes as part of their baseline testing prior to the start of their season. This data could then be used to assess for baseline comparison of possible ACL injuries at future time-points. This data could also be utilized for intra-operative confirmation of successful ACL reconstruction. The data could potentially be utilized post-operatively to monitor knee function and progress during the rehabilitation phase.

A limitation is that this study only enrolled collegiate athletes, which limits the generalizability of the normative data. Only collegiate athletes from selected sports, including football, soccer, track and field, and a few others were enrolled, which might induce selection bias. There was also a difference in the distribution of female and male athletes in each sport, with a predominance of females in sports such as track and field and predominance of males in sports such as football. This was due to the nature of the pre-season physical exams being performed for specific sports at universities

who were cared for by the reporting institution. It is possible that this disparity in the representation of sports could influence the findings here given that certain sports, such as golf, may self-select for patients with higher general ligamentous laxity. There was, however, no significant correlation between sport played and rotatory or anterior knee laxity, which suggests against the presence of selection bias. This also suggests that any differences in the distribution of female and male athletes in each sport did not introduce any bias. The collegiate athletes in this study were awake during the quantitative pivot shift test, so it is possible that healthy individuals under anaesthesia might exhibit different values for their rotatory knee laxity.

Conclusion

The data presented in this study show that the factors associated with increased rotatory laxity include female gender and increased anterior translation during the Lachman test. This data could be used in the clinical setting to identify individuals with increased rotatory laxity and who may benefit greater from targeted ACL intervention programs. This data may also serve as a reference by which values of rotatory laxity can be compared in patients.

Author contributions TP, AK, EH, KN, AA, and CM were involved in the acquisition of data. TP, AK, AP, and VM were involved in the interpretation and analysis of the data. AK and TP drafted the original manuscript. RD and VM conceived and designed the original project. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest All other authors declare that they have no conflict of interest related to this study.

Funding Funding for this project was generously provided by the Coulter Foundation at the University of Pittsburgh.

Ethical approval Approval was obtained from the University of Pittsburgh Institutional Review Board (PRO15050261).

Informed consent Informed consent was obtained from all individual participants included in the study.

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