Multiplanar Knee Laxity and Perceived Function During Activities of Daily Living and Sport

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Abstract:

Context: Greater knee-joint laxity may lead to a higher risk of knee injury, yet it is unknown whether results of self-reported outcome measures are associated with distinct knee-laxity profiles.

Objective: To identify the extent to which multiplanar knee laxity is associated with patient-reported outcomes of knee function in healthy individuals during activities of daily living and sport.

Design: Descriptive laboratory study.

Setting: University research laboratory.

Patients or Other Participants: Forty healthy individuals (20 men, 20 women; age = 18–31 years).

Main Outcome Measure(s): All participants were given the Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL) and Sports Activities Scale (KOS-SAS) and subsequently measured for knee laxity in the sagittal, frontal, and transverse planes. Separate backward stepwise regression analyses were performed to determine the extent to which multiplanar knee-laxity values predicted KOS-ADL and KOS-SAS scores within each sex.

Results: Women had higher magnitudes of anterior, posterior ($POST_{LAX}$), varus (VAR_{LAX}), valgus (VAL_{LAX}), and internal-rotation laxity than men and trended toward greater external rotation (ER_{LAX}) laxity. Greater $POST_{LAX}$, less VAL_{LAX}, and greater VAR_{LAX} was associated with lower KOS-ADL scores (KOS-ADL = −4.8 [$POST_{LAX}$], + 3.3 [VAL_{LAX}] − 2.2 [VAR_{LAX}] + 100.4, $R^2 = 0.74$, $P < .001$) and greater $POST_{LAX}$ and less VAL_{LAX} was associated with lower

KOS-SAS scores (KOS-SAS = −8.2 [POST$_{LAX}$], + 3.6 [VAL$_{LAX}$] + 96.4, $R^2 = 0.67$, $P < .001$) in women. In men, greater POST$_{LAX}$ and less ER$_{LAX}$ was associated with lower KOS-SAS scores (KOS-ADL = −4.7 [POST$_{LAX}$], + 0.9 [ER$_{LAX}$] + 96.4, $R^2 = 0.49$, $P < .001$).

Conclusions: The combination of POST$_{LAX}$ with less relative VAL$_{LAX}$ (women) or less relative ER$_{LAX}$ (men) was a strong predictor of KOS scores, suggesting that a self-reported outcome measure may be beneficial as part of a preparticipation screening battery to identify those with perceived functional deficits associated with their knee laxity.

Keywords: functional deficits | knee injury | Knee Outcome Survey

Article:

Key Points

- Consistent with the results of previous studies, women exhibited higher levels of multiplanar knee-joint laxity than men.
- In women, the combination of greater posterior laxity with less valgus laxity was a strong predictor of perceived function when measured by the Knee Outcome Survey.
- In men, the combination of greater posterior laxity with less external-rotation laxity was a strong predictor of Knee Outcome Survey scores.

In asymptomatic, physically active males and females, the magnitude of knee laxity varies widely[1–4] and can differ in relative magnitude across anatomical planes.[1] Females generally have greater laxity than males, particularly in the transverse and frontal planes.[3–8] This evidence is noteworthy because greater knee-joint laxity has been associated with a greater risk of knee injury, especially anterior cruciate ligament (ACL) rupture.[9–13] Biomechanically, individuals with greater knee laxity are more likely to demonstrate high-risk movement strategies and out-of-plane joint motions (eg, dynamic knee valgus) during weight-bearing activities such as jump landings, despite generating increased muscle activation.[2,14–16] Greater knee laxity is thought to contribute to aberrant joint motion and instability, which have implications for long-term joint injury or degeneration,[17] such as knee osteoarthritis.[7,18]Collectively, this research suggests that individuals with higher magnitudes of knee laxity may have more difficulty stabilizing their knees during functional activity. However, the threshold at which higher magnitudes of knee laxity begin to compromise function and the extent to which this instability may be perceived by the individual are unknown.

To that end, self-reported outcome measures, including the Knee Outcome Survey (KOS),[19] Knee Injury and Osteoarthritis Outcome Score (KOOS),[20] and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[21] are commonly used in rehabilitation settings to quantify an individual's perception of functional limitations. Outcome scores may help to identify an individual with greater knee laxity who is more susceptible to future injury if that person perceives any limitations in function. In support of this premise, greater amounts of generalized joint laxity have been associated with reduced function on knee-specific self-reported outcome measures.[22] Whereas the KOOS and WOMAC were designed for patients with osteoarthritis, the KOS was designed for a variety of knee conditions and, thus, may provide the most generalizable insight into the effects of knee-joint laxity on perceived knee function. Additionally, the KOS can identify limitations during activities of various intensities using 2 separate forms. The KOS Activities of Daily Living (KOS-ADL) quantifies knee symptoms and functional abilities during activities of daily living, and the KOS Sports Activities Scale (KOS-SAS) quantifies symptoms and function during sports activities. Both forms of the KOS yield reliable measures when administered to individuals with a wide range of knee conditions, including osteoarthritis,[23,24] patellofemoral pain syndrome,[25] and ACL injury[26–28] and correlate well with deficits resulting from knee dysfunction, including knee symptoms (pain), neuromuscular characteristics (strength, range of motion), and functional tests (step test, timed "up-and-go" test, 6-minute walk test).[29] Additionally, lower scores on the KOS have been associated with higher scores on the physical activity subscale of the Fear-Avoidance Beliefs Questionnaire,[30] suggesting that fear of pain or injury during physical activity may contribute to perceived functional deficits.

Yet, despite considerable use of the KOS in patients with knee injuries, we are not aware of any studies that have screened for functional deficits in apparently healthy individuals with higher magnitudes of knee laxity. Other functional scales administered to an unrestricted and healthy population have demonstrated mean scores between 86% and 98%, suggesting that some healthy individuals perceive functional deficits even without a history of knee injury.[31] As such, including a functional outcome assessment in athlete preparticipation screening examinations may reveal perceived functional deficits that indicate an underlying risk of future injury. From this perspective, the extent to which the KOS may identify athletes with laxity profiles that could increase their risk for future injury has not been examined.

Thus, the purpose of our study was to determine the extent to which multiplanar knee laxity predicted perceived knee function in healthy, unrestricted individuals during activities of daily living and sport. Our hypothesis was that higher magnitudes of knee laxity in 1 or more anatomical planes would predict more symptoms and functional limitations on the KOS (ie, lower scores) in males and females.

METHODS

These data represent secondary analyses from a study with the primary aim of examining the effects of nonpathologic joint laxity on gait and postural control. Participants consisted of apparently healthy, active individuals from a university student population (20 men, 20 women) who were between the ages of 18 and 31 years and had no previous history of lower extremity injury. Before data collection, the university's institutional review board approved the study and all participants were informed of study risks and provided written informed consent.

The KOS-ADL and KOS-SAS

Participants completed the KOS-ADL and KOS-SAS before laxity assessment. We selected the KOS over other outcome measures based on its prevalent clinical use; excellent psychometric properties, including reliability (intraclass correlation coefficient [ICC] = 0.94–0.98), internal consistency (Cronbach α = 0.89–0.98), and minimal detectable change score (MDC = 11.4)[32]; and design encompassing a wide range of knee conditions. Participants were asked to read the instructions printed on each KOS survey and respond with the degree to which symptoms affected their level of activity.[19] Both the KOS-ADL and KOS-SAS scores were calculated as a percentage of total points possible (70 and 55, respectively) on a 100-point scale.

Knee Laxity

Sagittal-, frontal-, and transverse-plane knee-laxity measurements were all performed on the left lower extremity to maximize measurement consistency during data collection. Because physical activity can increase one's knee laxity, all laxity measurements were taken after 30 minutes of quiet sitting to allow laxity values to return to baseline before data collection in those who might have engaged in physical activity earlier in the day. We measured knee laxity for the left leg only, as previous studies confirmed that side-to-side differences are generally less than what would be expected because of measurement error.[33,34] Laxity measurements were performed in the same order for all participants, with anterior-posterior knee laxity measured first, followed by varus-valgus and internal-external–rotation knee laxity.

Posterior ($POST_{LAX}$) and anterior (ANT_{LAX}) knee laxity were measured using a KT-2000 knee arthrometer (Medmetric Corp, San Diego, CA) and defined as the amount of posterior and anterior displacement (mm) of the tibia relative to the femur when applying 3 consecutive trials of alternating posteriorly (90 N) and anteriorly (133 N) directed forces to the proximal tibia, respectively. Participant placement and instructions were consistent with previous methods.[35] The average of the last 2 trials was used for analysis; in pilot testing, this yielded the most stable and reproducible measures. To ensure muscle relaxation during testing, participants were instructed to relax, and the real-time load-displacement response was monitored during each trial. Trials were repeated when muscular guarding of the joint was evident. A single examiner who demonstrated excellent interday reliability and precision using the KT-2000 arthrometer (ICC [SEM] = 0.89 [0.6 mm]) performed all measurements.

Frontal- and transverse-plane knee laxities were measured using the Vermont Knee Laxity Device (University of Vermont, Burlington) using established measurement procedures.[34] All measurements were taken by the same investigator, who confirmed excellent interday reliability and precision for valgus laxity (VAL_{LAX}; ICC [SEM] = 0.81 [0.71°]), varus laxity (VAR_{LAX}; ICC [SEM] = 0.79 [0.58°]), internal-rotation laxity (IR_{LAX}; ICC [SEM] = 0.92 [0.77°]), and external-rotation laxity (ER_{LAX}; ICC [SEM] = 0.92 [1.09°]) before data collection. Participants were positioned supine in the Vermont Knee Laxity Device with the thigh securely fixed, knee in 20° of flexion, ankle in neutral, and foot attached to a calibrated 6 degrees-of-freedom force transducer (model SM-50; Interface Inc, Scottsdale, AZ;Figure). Counterweights based on thigh and shank length and circumference were applied to reduce the effect of gravity on the lower extremity and to create an initial zero shear force to the tibiofemoral joint.[36] From this position, the rotational displacement (°) of the tibia relative to the femur was measured during 3 consecutive cycles of 10 Nm of varus (VAR_{LAX}) and valgus (VAL_{LAX}) torques, followed by 3 consecutive cycles of 5 Nm of internal (IR_{LAX})- and external-rotation (ER_{LAX}) torques.[14] Participants were encouraged to relax throughout testing, and muscle guarding was monitored again using the real-time load-displacement response. As with sagittal-plane laxity, the last 2 trials were averaged for analysis.

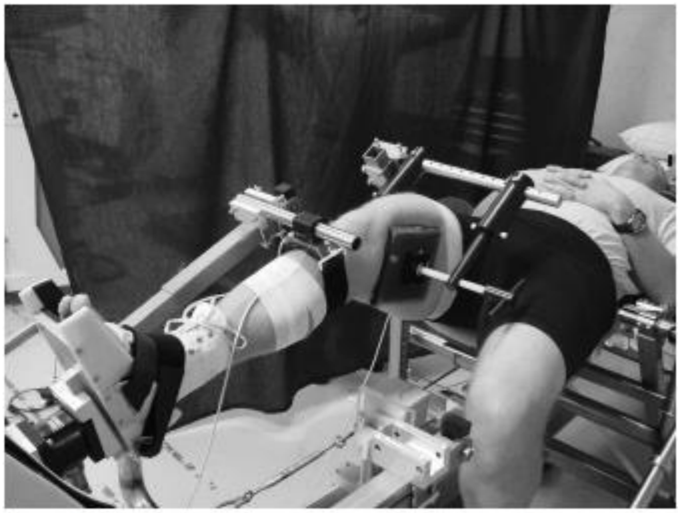

Figure. Participant setup in the Vermont Knee Laxity Device (University of Vermont, Burlington).

Statistical Analysis

All statistical analyses were performed using SPSS statistical software (version 20; IBM Corporation, Armonk, NY). Descriptive values for men and women were calculated for each knee-laxity value (ANT_{LAX}, $POST_{LAX}$, VAR_{LAX}, VAL_{LAX}, IR_{LAX}, ER_{LAX}) and total KOS-ADL and KOS-SAS scores. Because males and females are known to differ in their knee-laxity values,[1–4] independent *t* tests were used to confirm whether sex differences were apparent in our sample. If sex differences were confirmed, we examined relationships between multiplanar knee laxity and perceived knee function using sex-stratified models to control for other sex-dependent confounding associations. Specifically, 2 backward stepwise regression analyses were performed within each sex to determine the extent to which the 6 laxity values predicted total KOS-ADL and KOS-SAS scores. The *P* value tolerance for removal from the model was $\leq .20$. Using this approach, we had 80% power to detect a multiple R^2 of 0.30 to 0.50, depending on how many predictors (1–5) remained in the final model (G-Power version 3.1; Franz Faul, Universitat Kiel, Germany).[37] An R^2 of 0.30 to 0.50 is considered a large effect, and we felt a large effect would be necessary if the KOS is to have any clinical utility in predicting laxity profiles in future prescreening examinations.

RESULTS

The descriptive statistics for demographic information, laxity profiles, and KOS scores for all participants are shown in Table 1. On average, women had greater ANT_{LAX}, $POST_{LAX}$, VAR_{LAX}, VAL_{LAX}, and IR_{LAX} than men ($P < .05$) and trended toward greater ER_{LAX}($P = .053$). No differences in KOS-ADL or KOS-SAS scores were found between sexes.

Table 1. Demographic, Laxity, and Knee Outcome Survey Scores

Variable	Mean ± SD (Range)			
	Men	Women	t_{38}	*P* Value
Age, y	25.2 ± 3.6 (20–31)	21.7 ± 3.1 (18–28)	−3.26	.002[a]
Height, cm	179.4 ± 9.1 (163.5–199)	164.4 ± 3.7 (159.5–174.0)	−6.78	<.001[a]
Mass, kg	83.2 ± 17.2 (50.5–130.0)	65.1 ± 11.1 (48.0–95.0)	−3.95	<.001[a]
Laxity				
Anterior, mm	5.9 ± 1.2 (4.1–8.2)	7.2 ± 1.9 (4.0–11.1)	2.47	.018[a]
Posterior, mm	2.3 ± 0.7 (0.5–4.0)	2.9 ± 1.0 (1.2–4.8)	2.04	.049[a]
Varus, °	2.9 ± 1.1 (1.2–5.2)	4.3 ± 0.7 (3.0–5.5)	5.00	<.001[a]
Valgus, °	3.2 ± 1.4 (1.4–6.9)	5.7 ± 1.4 (2.9–9.0)	5.38	<.001[a]
Internal rotation, °	7.4 ± 1.9 (3.9–10.5)	10.3 ± 3.4 (5.2–18.8)	3.34	.002[a]
External rotation, °	10.3 ± 2.2 (6.2–15.2)	12.2 ± 3.6 (6.72–19.61)	2.01	.053
Knee Outcome Survey Score, %				
Activities of Daily Living	96.9 ± 3.4 (87.1–100)	95.8 ± 6.1 (78.6–100)	−0.69	.497
Sports Activities	95.0 ± 4.9 (85.5–100)	92.9 ± 9.7 (69.1–100)	−0.86	.395

[a] Significant at $P < .05$.

Sex-stratified bivariate correlations of laxity measurements and KOS scores are reported in Table 2. Backward stepwise regression results for men and women are displayed in Table 3. Knee-laxity values were strong predictors of KOS-ADL scores for women and of KOS-SAS scores for both men and women. Results of the final models revealed that greater $POST_{LAX}$ and VAR_{LAX} and less VAL_{LAX}predicted lower scores on the KOS-ADL in women, explaining 74% of the total variance. Results were similar when predicting KOS-SAS scores for women: greater $POST_{LAX}$ and less VAL_{LAX} predicted lower scores during sport activity, explaining 67% of the total variance. In men, the final model for KOS-SAS revealed that greater $POST_{LAX}$ and less ER_{LAX} predicted lower functional scores during sport activity, explaining 49% of the total variance.

Table 2. Bivariate Correlations of Laxity Measurements and Knee Outcome Survey (KOS) Scores in Female and Male Participants

Variable	Laxity						KOS Score	
	Anterior	Posterior	Varus	Valgus	Internal Rotation	External Rotation	Activities of Daily Living	Sports Activities
Laxity								
Anterior	1	0.551[a,b]	0.171[a]	0.491[a,b]	0.358[a]	0.519[a,b]	−0.219[a]	−0.290[a]
Posterior	0.306[c]	1	0.125[a]	0.399[a]	0.427[a]	0.541[a,b]	−0.540[a,b]	−0.670[a,b]
Varus	−0.285[c]	−0.089[c]	1	0.267[a]	−0.182[a]	−0.175[a]	−0.144[a]	−0.116[a]
Valgus	−0.460[b,c]	−0.155[c]	0.696[b,c]	1	0.363[a]	0.126[a]	0.357[a]	0.166[a]
Internal rotation	0.222[c]	0.283[c]	0.418[c]	0.092[c]	1	0.698[a,b]	−0.002[a]	−0.023[a]
External rotation	0.237[c]	0.343[c]	0.352[c]	0.216[c]	0.734[b,c]	1	−0.233[a]	−0.298[a]
KOS Score								
Activities of Daily Living	−0.096[c]	−0.343[c]	0.052[c]	−0.015[c]	0.140[c]	0.020[c]	1	0.914[a,b]
Sports Activities	−0.187[c]	−0.578[b,c]	0.207[c]	0.136[c]	0.092[c]	0.177[c]	0.848[b,c]	1

[a] Female participants.
[b] $P < .05$.
[c] Male participants.

Table 3. Regression Summary Results of the Association Between Multiplanar Knee Laxity and Knee Outcome Survey Score

Knee Outcome Survey Score	Sex	Model	R^2 (*P* Value)	Unstandardized Coefficients, Laxity: Anterior	Posterior	Varus	Valgus	Internal Rotation	External Rotation
Activities of Daily Living	Women	Initial	0.777 (.001)[a]	−0.84	−4.89[b]	−1.77	3.87[b]	−0.18	0.47
		Final	0.735 (<.001)[a]	[c]	−4.80[a]	−2.16[b]	3.31[a]	[c]	[c]
	Men	Initial	0.200 (.767)	−0.32	−1.91	−0.25	−0.25	0.57	0.01
		Final	0.000	[c]	[c]	[c]	[c]	[c]	[c]
Sports Activities	Women	Initial	0.725 (.004)[a]	−0.72	−8.53[b]	−1.24	3.95[b]	0.37	0.24
		Final	0.672 (<.001)[a]	[c]	−8.21[b]	[c]	3.61[b]	[c]	[c]
	Men	Initial	0.520 (.093)[b]	−0.61	−4.69[b]	0.48	−0.77	−0.23	1.18
		Final	0.494 (.003)[a]	[c]	−4.74[b]	[c]	[c]	[c]	0.94[b]

[a] Denotes significance at $P < .05$.
[b] Denotes significance at $P < .10$.
[c] Variable did not load in the final regression model.

Based on these findings and to enable comparison of laxity profiles (Table 4) and KOS scores (Table 5), we used median splits on $POST_{LAX}$ and VAL_{LAX} to separate women into 4 equal groups: (1) high $POST_{LAX}$/low VAL_{LAX}; (2) low $POST_{LAX}$/high VAL_{LAX}; (3) high $POST_{LAX}$/high VAL_{LAX}; and (4) low $POST_{LAX}$/low VAL_{LAX}. Similar quartiles were formed for men to compare laxity profiles and KOS-SAS scores in those with low versus high levels of $POST_{LAX}$ and ER_{LAX}. Qualitative observation of these tables suggests that the groups varied substantially in their laxity profiles across other planes of motion, but only those women with high $POST_{LAX}$ and low VAL_{LAX} had KOS scores substantially lower than 88.6, which exceeds the established MDC value of KOS in a healthy, asymptomatic population.[32] When examining the individual components of the KOS, especially in women, we found that lower scores on the KOS-ADL were primarily due to reports of giving way, limping, weakness, and difficulty with kneeling and squatting, whereas lower scores on the KOS-SAS were attributed to reports of slipping, weakness, and buckling and difficulties with starting and stopping quickly and jumping/landing maneuvers. For men, the quartile comparisons did not reveal clear trends, as both high $POST_{LAX}$ groups tended to report lower KOS scores and similar symptoms and functional limitations.

Table 4. Laxity Profiles, in Degrees (Mean ± SD), of Quartiles Designed From Results of Multiple Regression Analyses in Women and Men

Laxity	Women: High $POST_{LAX}$/Low VAL_{LAX}	Women: Low $POST_{LAX}$/High VAL_{LAX}	Women: High $POST_{LAX}$/High VAL_{LAX}	Women: Low $POST_{LAX}$/Low VAL_{LAX}	Men: High $POST_{LAX}$/Low ER_{LAX}	Men: Low $POST_{LAX}$/High ER_{LAX}	Men: High $POST_{LAX}$/High ER_{LAX}	Men: Low $POST_{LAX}$/Low ER_{LAX}
Anterior	7.3 ± 1.2	6.6 ± 1.9	9.2 ± 1.8	5.6 ± 1.1	6.4 ± 0.9	5.7 ± 1.3	6.6 ± 1.1	5.0 ± 1.1
Posterior	3.7 ± 0.5	2.2 ± 0.4	3.9 ± 0.7	1.9 ± 0.4	3.1 ± 0.7	2.0 ± 0.2	2.7 ± 0.3	1.5 ± 0.6
Varus	4.3 ± 0.4	4.9 ± 1.0	4.3 ± 0.6	4.3 ± 0.9	2.5 ± 0.5	2.9 ± 1.2	2.7 ± 0.7	2.4 ± 1.1
Valgus	5.9 ± 0.7	6.1 ± 0.2	8.3 ± 1.6	4.9 ± 0.4	3.4 ± 0.9	3.9 ± 1.5	3.5 ± 1.0	3.3 ± 1.3
Internal rotation	9.5 ± 1.4	8.4 ± 1.8	13.4 ± 5.1	10.1 ± 2.7	6.7 ± 0.7	8.5 ± 1.6	8.9 ± 1.6	5.5 ± 1.5
External rotation	12.5 ± 3.0	10.0 ± 3.0	14.7 ± 3.8	11.7 ± 3.6	9.7 ± 1.3	11.1 ± 1.5	12.6 ± 1.5	7.9 ± 1.5

Abbreviations: ER_{LAX}, external-rotation laxity; $POST_{LAX}$, posterior laxity; VAL_{LAX}, valgus laxity.

Table 5. Knee Outcome Survey (KOS) Scores (Mean ± SD) by Quartiles Designed From Results of Multiple Regression Analyses in Women and Men[a]

	Women				Men			
KOS Score	High $POST_{LAX}$/ Low VAL_{LAX}	Low $POST_{LAX}$/ High VAL_{LAX}	High $POST_{LAX}$/ High VAL_{LAX}	Low $POST_{LAX}$/ Low VAL_{LAX}	High $POST_{LAX}$/ Low ER_{LAX}	Low $POST_{LAX}$/ High ER_{LAX}	High $POST_{LAX}$/ High ER_{LAX}	Low $POST_{LAX}$/ Low ER_{LAX}
Activities of Daily Living	88.3 ± 7.7	99.4 ± 1.3	97.1 ± 4.2	98.6 ± 1.0	95.7 ± 2.7	98.9 ± 1.9	95.1 ± 5.0	98.0 ± 2.4
Pain	4.2 ± 0.5	4.8 ± 0.4	4.2 ± 0.8	4.6 ± 0.5	4.4 ± 0.5	4.8 ± 0.4	4.2 ± 0.4	4.6 ± 0.5
Stiffness	4.0 ± 1.0	4.8 ± 0.4	4.8 ± 0.4	4.8 ± 0.4	4.4 ± 0.5	5.0 ± 0.0	4.4 ± 0.5	4.4 ± 0.5
Buckling	3.8 ± 0.8	5.0 ± 0.0	4.8 ± 0.4	4.8 ± 0.4	4.4 ± 0.5	5.0 ± 0.0	4.4 ± 0.9	4.8 ± 0.4
Swelling	4.6 ± 0.9	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	4.8 ± 0.4
Limping	3.8 ± 1.3	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0
Weakness	4.0 ± 1.0	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0	4.6 ± 0.5	4.6 ± 0.5	4.8 ± 0.4	5.0 ± 0.0
Walking	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Up stairs	4.8 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Kneeling	4.2 ± 1.3	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0
Sitting	4.4 ± 0.5	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Standing	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0
Down stairs	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0	5.0 ± 0.0
Squatting	4.0 ± 0.7	5.0 ± 0.0	4.8 ± 0.4	4.8 ± 0.4	4.6 ± 0.5	5.0 ± 0.0	4.6 ± 0.5	5.0 ± 0.0
Rise from chair	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Sports Activities	82.6 ± 9.8	98.6 ± 2.4	92.7 ± 11.6	97.8 ± 1.5	91.3 ± 5.7	97.8 ± 3.9	93.8 ± 4.9	97.1 ± 2.8
Pain	3.6 ± 1.1	4.8 ± 0.4	4.0 ± 1.2	4.6 ± 0.5	4.0 ± 0.7	4.8 ± 0.4	4.0 ± 0.7	4.2 ± 0.8
Stiffness	3.8 ± 0.8	4.8 ± 0.4	4.2 ± 1.8	5.0 ± 0.0	4.4 ± 0.5	5.0 ± 0.0	4.4 ± 0.5	4.8 ± 0.4
Partial giving way	3.8 ± 1.3	4.8 ± 0.4	4.8 ± 0.4	4.8 ± 0.4	4.4 ± 0.5	5.0 ± 0.0	4.2 ± 0.8	4.8 ± 0.4
Weakness	3.4 ± 1.1	4.8 ± 0.4	4.4 ± 1.3	4.8 ± 0.4	4.2 ± 0.8	4.8 ± 0.4	4.8 ± 0.4	5.0 ± 0.0
Swelling	4.6 ± 0.9	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	4.8 ± 0.4	4.8 ± 0.4	4.8 ± 0.4
Grinding/grating	4.6 ± 0.5	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	4.8 ± 0.4	4.8 ± 0.4	4.8 ± 0.4
Buckling	4.0 ± 1.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	4.8 ± 0.4	5.0 ± 0.0	4.8 ± 0.4	5.0 ± 0.0
Run straight	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Stop and start	4.4 ± 0.5	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.8 ± 0.4	4.8 ± 0.4	5.0 ± 0.0	5.0 ± 0.0
Jump/land	3.8 ± 1.1	5.0 ± 0.0	4.4 ± 0.9	5.0 ± 0.0	4.4 ± 0.5	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Cut/pivot	4.4 ± 0.5	5.0 ± 0.0	4.2 ± 1.3	4.8 ± 0.4	4.6 ± 0.5	4.8 ± 0.4	4.8 ± 0.4	5.0 ± 0.0

Abbreviations: ER_{LAX}, external-rotation laxity; $POST_{LAX}$, posterior laxity; VAL_{LAX}, valgus laxity.

[a] Each item on the KOS is scored between 0 and 5, with higher numbers indicating less restriction and greater function. Low KOS scores were associated with high $POST_{LAX}$ and low VAL_{LAX} values in women and with high $POST_{LAX}$ and low ER_{LAX} in men.

DISCUSSION

Our primary findings were that greater $POST_{LAX}$ was consistently associated with lower KOS scores in both women and men and that the combinations of $POST_{LAX}$ with less relative VAL_{LAX} (women) or with less relative ER_{LAX} (men) were the strongest predictors of KOS-ADL and KOS-SAS scores. The relationships between knee laxity and KOS scores were stronger in women, who had consistently greater (and more variable) knee laxity across the multiple planes measured than men. Once we accounted for all multiplanar knee-laxity measurements, $POST_{LAX}$ was consistently the strongest independent predictor of lower KOS scores in both men and women, based on the strength of the correlation coefficient. These findings were surprising, given the relatively small range in values of $POST_{LAX}$ when compared with other laxity measures. It is interesting that individuals with high $POST_{LAX}$ did not generally have greater overall laxity profiles, yet they were more likely to report weakness, giving way, and difficulties with stopping, starting, jumping, cutting, and pivoting maneuvers (Table 5). This was particularly apparent in women. Thus, although the KOS results would seem consistent with what one might experience in the presence of higher magnitudes of knee laxity, the data suggest that these reports may be specific to those with larger $POST_{LAX}$ values and not associated with greater knee-laxity profiles in general. However, given the relatively small sample size assigned to each quartile, these results should be interpreted with caution and reproduced in a larger, more athletic population.

Although considerable research has focused on sagittal-plane knee laxity as it relates to ACL injury[13] and knee-joint biomechanics,[16,38] most authors have examined either ANT_{LAX} or total anterior-posterior knee laxity and rarely examined $POST_{LAX}$specifically. The posterior cruciate ligament is the primary restraint to $POST_{LAX}$, with the posterolateral corner, posteromedial joint capsule, and popliteus tendon acting as secondary restraints.[39–42] Additionally, the posterior cruciate ligament contains a rich neural network, including mechanoreceptors that may make the ligament more sensitive to perceptions of instability when the ligament is more lax.[43,44] These findings suggest that $POST_{LAX}$ and its effect on knee performance, injury risk, and perceived knee function may need to be studied more extensively in future injury risk and biomechanical investigations.

Associations between greater $POST_{LAX}$ and KOS scores tended to be stronger in participants who also had less knee valgus (women) or external rotation (men). Although this finding was clearly evident in the quartile comparisons in women, the combined effect was less apparent in men. After we performed median splits based on laxity profiles of the 2 female groups with high $POST_{LAX}$, only the group that also had low VAL_{LAX} reported low KOS-ADL and SAS scores falling below the MDC value (Table 5). The MDC statistic is typically used during rehabilitation, but in an asymptomatic population, it may serve as a threshold when screening for injury risk. The MDC score for the KOS has been reported[32] as 11.4, which may suggest the need for further physical examination in asymptomatic individuals who score less than 88.6. In men, despite ER_{LAX} being a significant predictor in the model, it appears that both quartiles that had high $POST_{LAX}$ had lower KOS scores, whether or not they had high or low ER_{LAX} values; yet neither group's mean scores exceeded the MDC score. Further research examining the sensitivity and specificity of the KOS for detecting distinct laxity profiles is warranted.

The different laxity profiles predicting lower KOS scores in women versus men may in part result from sex differences in anatomy (eg, lower extremity alignment, internal geometry of the knee joint) or the different neuromuscular-control strategies used by males and females that may contribute to differences in coupled motions at the knee (thus the biomechanical stress on capsuloligamentous structures) observed during the transition of the knee from non–weight bearing to weight bearing or a combination of these.[45] For example, when an axial load was applied to the foot to simulate weight bearing, females moved into more knee varus than males, and males and females moved into internal rotation and external rotation, respectively.[45] It is interesting to note that when predicting both ADL and SAS scores in women, the combination of less VAL_{LAX} and more VAR_{LAX} was consistently associated with lower KOS scores. The combination of greater relative VAR_{LAX} (or less relative VAL_{LAX}) with greater $POST_{LAX}$ may suggest a tendency toward posterolateral corner instability, which produces greater symptoms and functional deficits during ADLs and sport-related activities compared with other laxity profiles. Based on our current understanding of knee-joint injury, the combination of greater $POST_{LAX}$ and less ER_{LAX} in men is more difficult to interpret but again suggests a possible rotatory component critical to knee-laxity profiles that is more likely to affect function. Although the data about perceived knee function relative to joint laxity are informative, which laxity profile poses the greatest injury risk remains unknown. More work is needed to understand mechanistically how these multiplanar laxity profiles influence weight-bearing knee-joint function in a way that may affect an individual's perceived function and the potential for episodes of knee instability and knee-joint trauma.

Collectively, laxity values were more predictive of KOS scores in women (R^2 = 73%–78%) than in men (R^2 = 20%–52%), which is likely attributable to the higher average and greater variability of laxity values in females. Sex differences in knee-joint laxity are well established, and females are also more likely to experience substantial changes in their knee laxity during exercise[46] and across the menstrual cycle.[47,48] Consistent with our findings of stronger associations between higher magnitudes of knee laxity and KOS scores in women are reports of stronger associations between higher magnitudes of knee laxity and higher-risk biomechanics in women, such that women with above-average sagittal- and frontal- or transverse-plane laxity were more likely to display stiffer landings[16] and greater hip-adduction and knee-valgus motions,[14] respectively, than men who had above-average knee laxity. These higher-risk biomechanics were further accentuated in those who experienced larger acute changes in knee laxity across the menstrual cycle[2]and during exercise.[49] Although this study was limited to the measurement of resting knee laxity at a single time point in the cycle, the extent to which the variation in magnitude of these changes in knee laxity and knee-joint biomechanics affect one's perceived knee function deserves further study.

The lower range (and greater stability) of knee-laxity values in males may explain why knee laxity was predictive only of KOS-SAS scores and not KOS-ADL scores. The KOS-SAS targets higher-intensity activities, such as running and jumping, compared with the KOS-ADL, which measures perceived function during daily activities such as walking and stair climbing. Because, on average, men had lower knee-laxity values than women, it may be that functional deficits were perceived only during higher-level sport-related activities. Greater associations between higher magnitudes of knee laxity and perceived function during sport-related activity are also consistent with previous work,[22] as generalized joint laxity more strongly affected sport-related KOOS than activity-of-daily-living KOOS scores.

Even though the KOS has been used in patients with knee conditions, we are not aware of any studies that have used this tool to screen for functional deficits in apparently healthy individuals with higher magnitudes of knee laxity. Consistent with the study of other self-reported outcome measures,[31] we noted a considerable range of scores for both forms of the KOS. This finding suggests that although these outcome scales were designed for patients with knee injuries, the KOS-ADL and KOS-SAS may also be useful as screening tools in apparently healthy individuals who may perceive functional deficits. Specific to the results of this study, the KOS may be useful in identifying individuals with laxity profiles that may place them at greater risk for injury. However, to further validate the clinical usefulness of the KOS as a preseason screening tool for this purpose, further prospective research is needed to determine if the perceived functional deficits associated with the aforementioned laxity profiles are ultimately associated with one's potential for injury risk.

In summary, our findings suggest that self-reported episodes of pain, weakness, and giving way and difficulties with sport-related tasks may affect individuals with relatively high levels of $POST_{LAX}$. However, our investigation represents an initial exploratory analysis and is limited to a relatively small sample of collegiate students of varying activity levels and a single outcome measure (KOS). Despite these limitations, we believe the strength of associations observed between knee laxity and perceived functional deficits warrants future research, particularly when considering that higher magnitudes of knee laxity have prospectively been associated with ACL injury risk.[11,13] We need to duplicate these findings in a larger sample of those most at risk for ACL injury and other knee conditions, while controlling for injury history and physical activity status.

Additionally, this study was limited to measurement of resting baseline knee laxity at a single time point in the cycle; thus, we did not control or account for changes in knee laxity due to hormone changes across the menstrual cycle. A more refined analysis to identify the absolute baseline in each woman would have required daily tracking across 1 complete menstrual cycle, given the substantial individual variation in the magnitude and timing of these changes.[35] Although this might have introduced some variability to the knee-laxity values obtained in women, this variability would have essentially introduced more random error in the data and likely lessened our ability to identify meaningful relationships between knee laxity and KOS scores. Moreover, participants complete the KOS based on their overall function rather than their perceived function at a specific point in time. Thus, although the extent to which these acute variations affect an individual's perception of overall function deserves further study, we do not feel this posed a serious limitation to the current findings.

Examining other functional outcome scales may also be appropriate to determine which screening tests are most sensitive to laxity effects. Should our results be upheld in future studies, prospective trials are then needed to determine if the lower functional outcome scores associated with particular multiplanar knee-laxity profiles ultimately predict future injury risk. The relationship between injury risk and the KOS could be ascertained by including this self-report outcome measure in future preparticipation screening batteries with careful documentation of injuries. Furthermore, identifying the threshold value that yields the greatest specificity and sensitivity in identifying individuals at risk for subsequent injury would also be important for clinical utility in allowing clinicians to best target those in need of intervention.

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