Measurement of varus–valgus and internal–external rotational knee laxities in vivo—Part II: relationship with anterior–posterior and general joint laxity in males and females

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Abstract:

We examined sex differences in general joint laxity (GJL), and anterior–posterior displacement (ANT–POST), varus–valgus rotation (VR–VL), and internal–external rotation (INT–EXT) knee laxities, and determined whether greater ANT and GJL predicted greater VR–VL and INT–EXT. Twenty subjects were measured for GJL, and scored on a scale of 0–9. ANT and POST were measured using a standard knee arthrometer at 133 N. VR–VL and INT–EXT were measured using a custom joint laxity testing device, defined as the angular displacements (deg) of the tibia relative to the femur produced by 0–10 Nm of varus–valgus torques, and 0–5 Nm of internal–external torques, respectively. INT–EXT were measured during both non-weight-bearing (NWB) and weight-bearing (WB = 40% body weight) conditions while VR–VL were measured NWB. All laxity measures were greater for females compared to males except for POST. ANT and GJL positively predicted 62.5% of the variance in VR–VL and 41.8% of the variance in WB INT–EXT. ANT was the sole predictor of INT–EXT in NWB, explaining 42.3% of the variance. These findings suggest that subjects who score higher on clinical measures of GJL and ANT are also likely to have greater VR–VL and INT–EXT knee laxities.

Keywords: sex and knee laxity | knee joint laxity | anterior–posterior knee laxity | rotational joint laxity

Article:

Anterior knee laxity (ANT) has been the primary variable when examining the effects of knee laxity on knee joint neuromechanics in weight bearing.[1–3] Cadaveric studies show that in the range of 20–30° of knee flexion with the knee nonweight bearing, the anterior cruciate ligament (ACL) is the primary restraint to anterior knee laxity, while the medial collateral ligament (MCL) either alone or in combination with the ACL is the most important structure resisting applied valgus and internal/external torques.[4–6] Given the different, but overlapping, capsulo-ligamentous restraints to these motions, ANT may or may not be representative of varus–valgus (VR–VL) and internal–external (INT–EXT) laxities within a person. Whether non-weight-bearing knee laxity represents weight-bearing knee laxity once contributions from condylar geometry, tibiofemoral contact forces, and active muscles are added has also received little attention.[3] Examining these relationships may help us to better measure and characterize knee joint laxity, and improve our understanding of its impact on weight-bearing knee function.

In vivo, females have been observed to have greater general joint laxity (GJL)[7–9] and ANT[1,10–12] compared to males,[13] yet limited studies have examined if females also have greater VR–VL or INT–EXT knee laxities compared to males. Data from Markolf et al.[14] report greater anterior–posterior (ANT–POST) and VL laxity values in females, while Sharma et al.[15] reported greater VL without finding sex differences in ANT–POST knee laxity. While no in vivo studies were found comparing INT–EXT laxities by sex, a recent cadaveric study reported greater VL and INT–EXT but not ANT–POST knee laxities in females.[16] These later three studies compared males and females on total anterior–posterior laxity rather than anterior knee laxity, which may yield different results given the lack of published reports on sex differences in posterior knee laxity. We are not aware of any in vivo studies that have comprehensively examined sex differences in GJL, and ANT–POST, VR–VL, and INT–EXT laxities, or examined the extent to which these measures may be related. While ANT laxity and GJL have been identified as risk factors for ACL injury in females,[13] other measures of knee laxity may be stronger predictors of knee ligament injury, or a combination of knee laxities may provide a more comprehensive characterization of knee laxity and its relationship to ACL injury risk. Before exploring this hypothesis in a prospective study design, we need to fully understand the effect of sex on all relevant measures of knee laxity and their relationship to one another.

This study is part of a broader project designed to validate the use of the Vermont Knee Laxity Device (VKLD; University of Vermont, Burlington, VT) in assessing VR–VL and INT–EXT knee laxities.[17] Our purpose was to determine whether: 1) females who had greater ANT laxity and GJL also had greater POST, VR–VL, and INT–EXT laxities compared to males; and 2) whether ANT and GJL were significant predictors of VR–VL and INT– EXT laxities. Secondarily, we examined the extent to which ANT and VR–VL predict INT–EXT laxities. Females with greater ANT and GJL compared to males were expected to have greater POST, VR–VL, and INT–EXT laxities, and ANT and GJL were expected to positively predict VR– VL and INT–EXT laxities.

METHODS

Twenty subjects, 10 males (27.3 ± 3.4 years of age, 177.3 ± 6.8 cm, 81.1 ± 7.0 kg) and 10 females (22.9 ± 1.5 years of age, 169.0 ± 7.1 cm, 66.1 ± 11.4 kg), participated after signing a consent form approved by the University's institutional review board. Subjects had no previous

history of knee ligament injury or surgery, no significant lower extremity injury or chronic pain in the past 6 months, and were otherwise healthy. All measures were acquired in one session on both the left and right knees. GJL and ANT–POST laxity were acquired first, followed by VR–VL, and finally INT– EXT laxities. The first leg tested (left, right) and first direction of applied torque (i.e., VR vs. VL, INT vs. EXT) was counterbalanced across all subjects.
The Beighton and Horan Joint Mobility Index[18] assessed GJL by examining left and right fifth finger extension (>90°), elbow hyperextension (>10°), thumb opposition (ability to touch forearm), knee hyperextension (>10°), and trunk flexion (palms flat on the floor). Subjects received a score of 1 for each criteria met, resulting in a score ranging from 0–9.[18]

ANT and POST laxity was measured as the anterior and posterior displacement of the tibia relative to the femur with an applied force of 133 N using the KT 2000™ (MEDmetric® Corp; San Diego, CA). One investigator with established day-to-day measurement reliability ($ICC_{2,k}$ = 0.91–0.97; SEM = 0.44–0.69 mm) performed all measures per manufacturer guidelines. With the subject lying supine and the knee flexed over a thigh bolster at 25° (±5°), three posterior directed forces were applied to the tibia to establish a zero reference point, followed by an anterior directed force of 133 N to measure ANT. The same procedures were followed in the opposite directions for POST. To insure consistent measures, the thighs were stabilized with a Velcro strap to minimized lower extremity rotation, and a bubble level affixed to the device insured a direct A–P line of pull. Three measures were recorded for both ANT and POST.

VR–VL and INT–EXT knee laxities were measured with the Vermont Knee Laxity Device. In previous work,[17] we have described in detail the measurement procedures for VR–VL and INT–EXT knee laxities, and the day-to-day consistency of these measures. For all measures, the subject was positioned supine in the VKLD with the knee flexed to 20°, the thigh securely fixed, the foot and ankle tightly restrained in the foot cradle, and counterweights applied to the thigh and shank to create an initial condition of zero shear and compressive load across the tibiofemoral joint. To create a 10 Nm VL and VR torque at the knee, respectively, a known force (mean force = 29.33 ± 1.7 N) was applied to the medial and lateral aspect of the distal tibia at a known distance from the knee (mean distance = 34.20 ± 1.94 cm) using a handheld force transducer (Model SM-50, Interface, Scottsdale, AZ). INT–EXT laxity was measured by applying INT and EXT torques from 0 to 5 Nm about the long axis of the tibia using a T-handle connected to a six degree-of-freedom (6 DOF) force transducer (Model MC3A, Advanced Medical Technology, Inc., Watertown, MA) affixed to the foot cradle. INT–EXT measures were recorded while the leg was NWB and WB (a compressive load of 40% body weight applied to the foot) and VR–VL was measured during NWB. For INT–EXT_{WB}, we reconfirmed the 20° knee angle with real-time goniometry after the subject accepted the 40% WB load. Following three familiarization trials, three loading cycles were collected for each motion. Signals from the handheld (VR–VL) and 6 DOF (INT–EXT) force transducers were interfaced with the data collection software (Motion Monitor, Innovative Sports Training, Chicago, IL) to allow simultaneous collection of force and displacement measures at 100 Hz.

Electromagnetic position sensors (Mini Birds, Ascension Technologies, Colchester, VT) attached to the lateral thigh and proximal tibial shaft measured knee motion. The VKLD was constructed with fiberglass reinforced plastic and nonmagnetic 300 series stainless steel to minimize the amount of metal that could potentially interfere with the signal from the sensors. Hip, knee, and ankle joint centers were estimated and segmental coordinate systems were constructed as previously described.[3] The signals from the position sensors and both hand and 6 DOF force transducers were low-pass filtered at 10 Hz and 20 Hz, respectively, using a 4th order zero lag Butterworth filter. For each segment, the +Y axis was directed superiorly, the +Z axis directed laterally (right leg) or medially (left leg), and the +X axis directed anteriorly. Euler's equations describe knee joint motion using a rotational sequence of Z Y' X". [19]

ANT and POST laxities were recorded as the average of three trials, and GJL was recorded as the total score (0–9). VR–VL laxities were calculated as the angular displacements (deg) produced by 0–10 Nm torques during NWB, and INT–ER laxities were calculated as the angular displacements produced by 0–5 Nm torques during NWB and WB conditions, averaged over three cycles for each leg. Separate 2 (sex) × 2 (side) × 2 (direction of applied torque) repeated measures ANOVA compared males and females on ANT–POST, VR–VL, $INT–EXT_{WB}$, and $INT–EXT_{NWB}$ laxities. An independent *t*-test compared sex on total GJL scores. Pearson correlations and stepwise linear regressions examined the extent to which ANT and GJL would predict VR–VL (NWB) and INT–EXT (NWB and WB). Similar stepwise linear regressions explored the extent to which ANT and VR–VL would predict $INT–EXT_{NWB}$ and $INT–EXT_{WB}$.

RESULTS

Table 1 presents the means and standard deviations for all laxity measures by sex. Since no appreciable differences were noted by side, the table represents the pooled mean for left and right sides. GJL was greater in females compared to males ($p = 0.013$). Sex differences in ANT–POST laxity were direction dependent ($p = 0.003$); females had greater ANT (8.1 mm vs. 5.6 mm) but not POST (5.4 mm vs. 5.0 mm) laxity compared to males. Females had greater total VR–VL (11.38 vs. 7.98; $p = 0.001$), total $INT–EXT_{NWB}$ (27.5° vs. 20.2°; $p = 0.016$) and total $INT–EXT_{WB}$ (14.0° vs. 7.5°; $p = 0.001$) compared to males. VL was greater than VR laxity (5.2° vs. 4.4°; $p = 0.011$), but this did not differ by sex ($p = 0.125$). EXT_{NWB} was greater than INT_{NWB} laxity (13.5° vs. 10.3°; $p = 0.002$), but this did not differ by sex ($p = 0.439$). The difference between EXT_{WB} and INT_{WB} was significantly greater in females (9.0° vs. 4.9°) compared to males (4.5° vs. 3.0°) ($p = 0.004$).

Table 2 presents the regression summary results when predicting VR–VL and INT–EXT from ANT and GJL. Pearson correlations revealed consistently positive relationships with ANT laxity (range, 0.313–0.737; all $p < 0.05$ with the exception of EXT_{NWB}). Except for INT_{NWB}, correlations with GJL were also positive (range, 0.245–0.612), and were substantially stronger for $INT–EXT_{WB}$ compared to $INT–EXT_{NWB}$. During non-weight bearing, ANT was the stronger predictor of VR–VL and INT–EXT, with GJL often explaining additional variance in the measures. During weight bearing, GJL explained more variance than ANT. Overall, ANT and GJL were stronger predictors of VL and EXT laxities than VR and INT laxities.

Table 1. Comparison of Mean ± SD Laxity Values for Females and Males

Variable	Females	Males	Total Sample
General joint laxity (Score 0–9)			
Total score	2.0 ± 2.2^a	0.1 ± 0.1	
Anterior–posterior knee laxity (mm)			
Anterior (ANT)	8.1 ± 2.5^a	5.6 ± 1.0	6.9 ± 2.3
Posterior (POST)	5.4 ± 1.2	5.0 ± 0.7	5.2 ± 1.0
Total motion (ANT–POST)	13.5 ± 3.6	10.6 ± 1.2	
Varus–valgus rotation laxity (°)			
Varus (VR)	5.0 ± 0.8	3.8 ± 0.9	4.4 ± 1.0
Valgus (VL)	6.3 ± 1.8	4.1 ± 1.1	5.2 ± 1.8^b
Total motion (VR–VL)	11.3 ± 2.4^a	7.9 ± 1.5	
Internal–external rotation laxity, NWB (°)			
Internal (INT_{NWB})	11.8 ± 4.8	8.9 ± 2.5	10.3 ± 4.0
External (EXT_{NWB})	15.7 ± 3.3	11.3 ± 3.5	13.5 ± 4.0^b
Total motion ($INT–EXT_{NWB}$)	27.5 ± 7.5^a	20.2 ± 4.1	
Internal-external rotation laxity, WB (°)			
Internal (INT_{WB})	4.9 ± 1.9	3.0 ± 1.1	4.0 ± 1.8
External (EXT_{WB})	9.0 ± 2.8^c	4.5 ± 2.2	6.8 ± 3.4^b
Total motion ($INT\text{-}EXT_{WB}$)	14.0 ± 4.4^a	7.5 ± 3.1	

[a]Females > males.
[b]Valgus > varus and external > internal.
[c]Difference between EXT and INT greater in females than males (all $p < 0.05$).

Table 3 presents the regression summary results when predicting $INT–EXT_{NWB}$ and $INT–EX_{TWB}$ from ANT and VR–VL. Moderate to strong correlations were noted between VR–VL and INT–EXT laxities (range, 0.470–0.878). Except for INT_{NWB}, VR–VL was the sole predictor of INT–EXT laxities, explaining 45%–78% of the variance. VR–VL was only moderately related to INT_{NWB} on the right side, and ANT was the primary predictor on the left side.

DISCUSSION

Our primary findings were that females with greater ANT compared to males also had greater VR–VL and INT–EXT laxities, and that ANT and GJL were significant predictors of VR–VL during non-weight bearing and INT–EXT laxities during both non-weight bearing and weight bearing.

Table 2. Prediction of Varus (VR)–Valgus (VL) and Internal (INT)–External (EXT) Laxities with Anterior (ANT) and Generalized (GJL) Joint Laxities[a]

Variable	Mean ± SD (°)	ANT		GJL		1st Step R Squared		2nd Step R Squared	
		Pearson R	(*p*-Value)	Pearson R	(*p*-Value)	Adj R Square	Sig F Ch	Adj R Square	Sig F Ch
VL									
Right	4.9 ± 1.8	0.733	(<0.0001)	0.400	(0.040)	0.512 (ANT)	(<0.0001)	0.589 (ANT + GJL)	(0.050)
Left	5.6 ± 2.1	0.716	(<0.0001)	0.499	(0.013)	0.486 (ANT)	(<0.0001)	0.599 (ANT + GJL)	(0.025)
VR									
Right	4.1 ± 1.4	0.530	(0.008)	0.511	(0.011)	0.241 (ANT)	(0.016)	0.419 (ANT + GJL)	(0.020)
Left	4.7 ± 1.0	0.426	(0.030)	0.245	(0.149)	0.136 (ANT)	(0.061)		
Total VR–VL									
Right	8.9 ± 2.9	0.695	(<0.0001)	0.483	(0.015)	0.454 (ANT)	(0.001)	0.598 (ANT + GJL)	(0.014)
Left	10.3 ± 2.6	0.737	(<0.0001)	0.494	(0.013)	0.518 (ANT)	(<0.0001)	0.625 (ANT + GJL)	(0.024)
INT (NWB)									
Right	9.8 ± 4.5	0.390	(0.045)	0.075	(0.377)	0.105 (ANT)	(0.089)		
Left	10.8 ± 4.0	0.587	(0.003)	0.125	(0.300)	0.308 (ANT)	(0.007)		
EXT (NWB)									
Right	13.6 ± 3.8	0.313	(0.089)	0.375	(0.052)	0.093 (GJL)	(0.103)	0.119 (GJL + ANT)	(0.231)
Left	13.4 ± 4.6	0.610	(0.002)	0.395	(0.042)	0.337 (ANT)	(0.004)	0.382 (ANT + GJL)	(0.148)
Total INT–EXT (NWB)									
Right	23.5 ± 7.1	0.410	(0.036)	0.245	(0.149)	0.122 (ANT)	(0.072)		
Left	24.2 ± 7.7	0.674	(0.001)	0.302	(0.098)	0.423 (ANT)	(0.001)		
INT (WB)									
Right	4.0 ± 1.8	0.435	(0.028)	0.436	(0.027)	0.145 (GJL)	(0.055)	0.258 (GJL + ANT)	(0.031)
Left	3.9 ± 2.1	0.553	(0.006)	0.291	(0.107)	0.267 (ANT)	(0.011)		
EXT (WB)									
Right	7.0 ± 3.5	0.448	(0.024)	0.501	(0.012)	0.210 (GJL)	(0.024)	0.330 (GJL + ANT)	(0.052)
Left	6.5 ± 3.8	0.496	(0.013)	0.612	(0.002)	0.340 (GJL)	(0.004)	0.460 (GJL + ANT)	(0.040)
Total INT–EXT (WB)									
Right	11.0 ± 5.1	0.461	(0.020)	0.498	(0.013)	0.206 (GJL)	(0.025)	0.339 (GJL + ANT)	(0.047)
Left	10.4 ± 5.5	0.549	(0.006)	0.527	(0.008)	0.262 (ANT)	(0.012)	0.418 (GJL + ANT)	(0.027)

[a] $N = 20$.

Table 3. Prediction of Internal (INT)–External (EXT) Laxities (NWB and WB) with Anterior (ANT) and Varus (VR)–Valgus (VL) Joint Laxities[a]

		ANT		VR–VL Laxity		1st Step R Squared		2nd Step R Squared	
Variable	Mean ± SD	Pearson R	(*p*-Value)	Pearson R	(*p*-Value)	Adj R Square	Sig F Ch	Adj R Square	Sig F Ch
INT (NWB)									
Right	9.8 ± 4.5	0.390	(0.045)	0.470	(0.018)	0.178 (VR–VL)	(0.037)		
Left	10.8 ± 4.0	0.587	(0.003)	0.490	(0.014)	0.308 (ANT)	(0.007)		
EXT (NWB)									
Right	13.6 ± 3.8	0.313	(0.089)	0.758	(<0.0001)	0.551 (VR–VL)	(<0.0001)	0.623 (VR–VL + ANT)	(0.050)
Left	13.4 ± 4.6	0.610	(0.002)	0.878	(<0.0001)	0.758 (VR–VL)	(<0.0001)		
Total INT–EXT (NWB)									
Right	23.5 ± 7.1	0.410	(0.036)	0.696	(<0.0001)	0.456 (VR–VL)	(0.001)		
Left	24.2 ± 7.7	0.674	(0.001)	0.783	(<0.0001)	0.592 (VR–VL)	(<0.0001)		
INT (WB)									
Right	4.0 ± 1.8	0.435	(0.028)	0.716	(<0.0001)	0.486 (VR–VL)	(<0.0001)		
Left	3.9 ± 2.1	0.553	(0.006)	0.711	(<0.0001)	0.478 (VR–VL)	(<0.0001)		
EXT (WB)									
Right	7.0 ± 3.5	0.448	(0.024)	0.856	(<0.0001)	0.719 (VR–VL)	(<0.0001)	0.749 (VR–VL + ANT)	(0.092)
Left	6.5 ± 3.8	0.496	(0.013)	0.755	(<0.0001)	0.546 (VR–VL)	(<0.0001)		
Total INT–EXT (WB)									
Right	11.0 ± 5.1	0.461	(0.020)	0.841	(<0.0001)	0.691 (VR–VL)	(<0.0001)	0.706 (VR–VL + ANT)	(0.185)
Left	10.4 ± 5.5	0.549	(0.006)	0.785	(<0.0001)	0.596 (VR–VL)	(<0.0001)		

[a] $N = 20$.

Sex Differences

While we did not purposely recruit females with greater ANT laxity compared to males, these data effectively show that females who had greater ANT laxity also had greater VR–VL and INT– EXT laxities. No differences were observed in POST laxity. This may explain, at least in part, why previous studies of sex differences in VR–VL and INT–ER laxities did not observe sex differences in total A–P laxity.[15,16] In our study, the magnitude of sex differences were fairly consistent across all non-weight-bearing measures, with females having 25%–30% greater motion than males for ANT, VR, VL, INT, and EXT. These findings are consistent with other reports of sex differences in VR–VL and INT–EXT laxities.[15,16] While Sharma et al.[15] reported lower total VR–VL laxity values (means of 3.6° females, 2.7° males) in comparison to our study, the percent mean difference between sex (25%) was similar. Hsu et al.[16] also reported 25%–30% greater VL and INT–EXT laxities in females versus males with a combined 10-Nm valgus and 5-Nm internal tibial torque at 15° and 30° knee flexion during nonweight bearing. Their values for VL at 30° (5.7° females, 4.0° males) and INT–EXT laxity at 15° knee flexion (20.6° for females, 15.1° for males) are quite similar to our values at 20° knee flexion.

To our knowledge, this is the first study to report sex differences in INT–EXT laxities during WB in vivo. During NWB, the capsule-ligamentous structures are thought to provide the primary restraints to joint motion.[20]During weight bearing, other factors including condylar geometry, muscle activation, and tibiofemoral contact forces also come into play to resist joint motion.[20] Hence, one might expect that sex differences in INT–EXT laxity would decrease during the weight-bearing condition if the increased laxity was due to capsule-ligamentous structures alone. Our results revealed that when an axial compressive load of 40% body weight was applied to the joint, total motion decreased in both females and males as expected, but the magnitude of the sex difference increased, with females having 50%–60% greater motion during weight bearing. These findings are clinically important because they suggest that females who have increased non-weight-bearing knee laxity may experience greater rotational motion during weight-bearing activity, potentially requiring greater active muscle forces to stabilize the knee. This contention is supported by studies that have reported greater anterior tibial translation relative to the femur when transitioning from non-weight-bearing to weight-bearing[3] and greater lateral hamstring activation during weight-bearing tasks[1,2] in females who have greater ANT knee laxity values. Future studies examining sex differences in knee laxity and weight-bearing knee joint mechanics are warranted.

Predicting VR–VL and INT–EXT Laxities with ANT and GJL

Because commercially available devices are not readily accessible to most clinicians for measuring VR–VL and INT–EXT knee laxities, we examined the extent to which common clinical measures of ANT and GJL may predict VR–VL and INT–EXT laxities.

Predicting VR–VL Laxities

ANT and GJL explained nearly 60% of the variance in VL and total VR–VL knee laxities (Table 2). To a lesser extent, ANT and GJL were also predictive of VR laxity (42%), but only on the right knee. Guidelines for interpreting small, medium, and large effect sizes suggest an R^2 value greater than 0.25 is considered a large effect.[21] This would indicate that while GJL explained additional variance (10%–15%), the relationship between ANT laxity alone with VL, VR, and VR–VL laxities was quite strong. Based on these data, ANT laxity as measured with the KT-2000™ appears to be a good indicator of one's VR–VL knee laxity.

Predicting INT–EXT Laxities

Although relationships were somewhat weaker, ANT and GJL were also strong predictors of INT_{NWB}, EXT_{NWB}, and $INT–EXT_{NWB}$ on the left side, and INT_{WB}, EXT_{WB}, and $INT–EXT_{WB}$ for both left and right sides, explaining anywhere from 25% to 46% of the variance. We are unsure why prediction models were not as strong for the right leg during non-weight bearing, as measurement reliability for these measures was equal to the left side.[17] We observed no differences in testing or patient comfort when doing left and right tests.

Of interest, the relationship between ANT laxity and GJL with INT–EXT laxity was different between non-weight-bearing and weight-bearing conditions. ANT laxity tended to be the stronger predictor of $INT–EXT_{NWB}$ laxity, while GJL contributed little to the regression model. For INT– EXT_{WB}, GJL often explained an equal or greater amount of the variance than ANT laxity. These findings suggest that ANT laxity and GJL represent unique characteristics of knee joint laxity, which is supported by the low correlation between these measures ($r = 0.125$). Given these findings, and that both GJL and ANT laxity have been considered relevant risk factors for knee ligament injury,[13,22,23] both measures should be included in future studies to further clarify the relationship between knee joint laxity, weight-bearing knee joint neuromechanics and injury risk.

Predicting INT–EXT Laxities with ANT and VR–VL Laxities

Our primary goal was to determine the extent to which clinical measures of ANT laxity and GJL predict VR–VL and INT–EXT laxities. However, because cadaveric studies have shown that the MCL in isolation or in combination with the ACL provides the majority of restraint to INT–EXT laxity,[4–6] we also explored the extent to which ANT and VR–VL laxities predicted INT–EXT laxities. VR–VL was the primary predictor of INT–EXT laxity, and explained a substantially larger proportion of the variance in INT–EXT laxities (range, 17.8%–75.8%) compared to what was explained by ANT laxity and GJL (range, 9.3%–46%) (see Tables 2 and 3). The relationships between VR–VL and INT–EXT laxities were fairly consistent between non-weight-bearing and weight-bearing conditions. Hence, commercially available devices capable of measuring VR–VL laxity may help clinicians better predict INT–EXT knee laxities than what can currently be determined from ANT and GJL.

Summary

Research in recent years has explored the relationship between knee joint laxity and the risk of suffering an ACL injury, and this relationship has largely been limited to measures of ANT laxity and GJL. A prospective study by Uhorchak et al.[13] reported that females with knee laxity values greater than 1 SD of the mean had a 2.7 greater relative risk of suffering an ACL injury compared to females with lower knee laxity values. Their report13 and other retrospective studies[8,23] also indicate that GJL may be a relevant risk factor for ACL injury. To better understand the extent to which these clinical measures characterize knee joint laxity, our results provide strong evidence that individuals who have greater ANT laxity and GJL compared to others will also have greater VR–VL and INT–EXT laxities. The fact that these relationships were somewhat stronger for INT– EXT laxities during weight-bearing compared to non-weight-bearing conditions suggests that increased knee joint laxity may create substantial challenges for the neuromuscular system in order to maintain joint stability during weight-bearing activities. This may be particularly relevant during tasks that involve components of valgus and either internal or external rotation at the knee, motions consistent with many ACL injury mechanisms.[24,25] Future studies should examine these relationships at multiple knee flexion angles and during combined motion patterns that better mimic knee joint motion during sport activity. Future studies should also examine these relationships at various times of the menstrual cycle when anterior knee laxity is known to vary.[11,26]

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