Relationships Between Lower Extremity Alignment and the Quadriceps Angle

By: Nguyen, Anh-Dung; Boling, Michelle C; Levine, Beverly; Shultz, Sandra J

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Abstract:

Objective: To determine the extent to which select lower extremity alignment characteristics of the pelvis, hip, knee, and foot are related to the Q angle.

Design: Descriptive cohort study design.

Setting: Applied Neuromechanics Research Laboratory.

Participants: Two hundred eighteen participants (102 males, 116 females).

Assessment of Risk Factors: Eight clinical measures of static alignment of the left lower extremity were measured by a single examiner to determine the impact of lower extremity alignment on the magnitude of Q angle.

Main Outcome Measures: Q angle, pelvic angle, hip anteversion, tibiofemoral angle, genu recurvatum, tibial torsion, navicular drop, and femur and tibia length.

Results: Once all alignment variables were accounted for, greater tibiofemoral angle and femoral anteversion were significant predictors of greater Q angle in both males and females. Pelvic angle, genu recurvatum, tibial torsion, navicular drop, and femur to tibia length ratio were not significant independent predictors of Q angle in males or females.

Conclusions: Greater femoral anteversion and tibiofemoral angle result in greater Q angle, with changes in tibiofemoral angle having a substantially greater impact on the magnitude of the Q angle compared with femoral anteversion. As such, the Q angle seems to largely represent a frontal plane alignment measure. As many knee injuries seem to result from a combination of both frontal and transverse plane motions and forces, this may in part explain why Q angle has been found to be a poor independent predictor of lower extremity injury risk.

Article:

INTRODUCTION

Anatomical alignment of the lower extremity has been proposed as a risk factor for lower extremity injuries, in particular, knee injuries.[1-7] Among these lower extremity alignment variables, the quadriceps angle (Q angle) has been frequently studied, which is defined as the angle formed by a line from the anterior superior iliac spine to the patella center and a line from the patella center to the tibial tuberosity.[8] As Q angle represents the direction of the quadriceps muscle force vector in the frontal plane,[9] excessive angulation is thought to predispose individuals to injuries caused by abnormal quadriceps forces acting at the knee and patellofemoral joints. However, the extent to which excessive Q angle increases the risk of knee injury remains unclear. Although the Q angle has been suggested as a risk factor for anterior cruciate ligament injury (ACL),[10-13] retrospective risk factor studies [4,5,14] have failed to confirm this relationship. Q angle has also been associated with patellofemoral pain syndrome,[15-17] but others [18-21] have observed no difference in Q angle when comparing patients with patellofemoral pain with healthy individuals. Moreover, the degree of angulation that is thought to be excessive and predispose one to knee pathology remains unclear.[15-17]

A reason for these inconsistent findings may be in part due to the multiple anatomical factors that may influence the magnitude of the Q angle, which may differentially impact how the Q angle relates to dynamic knee function. It has been suggested that the Q angle is a composite measure of pelvic position, hip rotation, tibial rotation, patella position, and foot position.[22-24] Specifically, Q angle may increase with excessive anterior pelvic tilt (changing the orientation of the acetabulum and internally rotating the femur), femoral anteversion and knee valgus (displacing the patella medially relative to the anterior superior iliac spine and tibial tuberosity), and external tibial rotation (displacing the tibial tuberosity laterally).[24] Although a change in any one of these alignment characteristics could theoretically change the position of 1 or more landmarks used to measure the Q angle, and thus its magnitude, research has yet to examine the collective anatomical contributions to the Q angle. Determining the anatomical factors that have the potential to impact the magnitude of the Q angle may allow clinicians and researchers to better determine its role in dynamic motion and risk of knee injury. Hence, the purpose of this study was to determine the extent to which lower extremity alignment characteristics of the pelvis, hip, knee, and foot are related to the Q angle. Based on their potential to change the orientation of anatomical landmarks used in the measurement of Q angle, our expectation was that greater anterior pelvic tilt, femoral anteversion, knee valgus, and pronation would be predictive of greater Q angle in both males and females.

METHODS

Subjects

Two hundred eighteen subjects (102 males: 23.1 ± 3.2 years, 177.3 ± 8.4 cm, 80.8 ± 13.0 kg; 116 females: 21.8 ± 2.7 years, 163.5 ± 7.4 cm, 63.4 ± 12.4 kg) participated in this investigation. Participants were predominantly college-aged students and had no current injury to the lower extremity or any previous history that would affect the alignment of the lower extremity joints (ie, fractures or surgery). The population of this study was part of an ongoing database of which sex differences, bilateral asymmetries, and postural relationships among lower extremity alignment characteristics have been previously reported.[25-27] All participants read and signed an informed consent form approved by the University's Institutional Review Board for protection of human subjects before participation.

Procedures

Before assessment of alignment characteristics, demographics of age, height, and weight were recorded for each subject. Eight alignment characteristics were measured on the left pelvis and lower extremity. These alignment characteristics were based on commonly identified variables suggested to influence dynamic motion and risk of lower extremity injuries. All measurement procedures were performed by a single examiner who had previously established good to excellent test-retest reliability on all measures ($ICC_{2,3} >= 0.87$).[28,29] All standing measures were taken in a standardized stance with the left and right feet spaced equal to the width of the left and right acromion processes and toes facing forward. The stance was achieved by instructing subjects to march in place and then take a step forward. Subjects were instructed to look straight ahead during all standing measures with equal weight over both feet. Each measure was repeated 3 times.

Outcome Measures

All alignment characteristics were measured using identical techniques that have been previously described in detail.[25,28-30] Q angle was measured in the standardized stance using a goniometer and represented the angle formed by a line from the anterior superior iliac spine to the patella center and a line from the patella center to the tibial tuberosity. Pelvic angle was measured in the standardized stance using an inclinometer and represented the angle formed by a line from the anterior superior iliac spine to the posterior superior iliac spine relative to the horizontal plane.[31]Femoral anteversion was measured with a goniometer with subjects in a prone position and the knee flexed to 90 degrees.[32] The angle between the true vertical and the shaft of the tibia was measured, whereas the greater trochanter was palpated to be in its most lateral position. Tibiofemoral angle was measured in the standardized stance with a goniometer and represented the angle formed by the anatomical axis of the femur and tibia in the frontal plane.[28] Genu recurvatum was measured with a goniometer in a supine position with a bolster positioned under the distal tibia and represented the sagittal plane alignment of the femur and tibia.[28] Tibial torsion was measured in a supine position with a goniometer and represented the angle between the true vertical and a line bisecting the bimalleolar axis with the femur positioned parallel to the horizontal plane.[33] Navicular drop was measured in the standardized stance with a ruler and represented the difference between the height of navicular in subtalar joint neutral and a relaxed stance.[28] Femur length and tibia length were measured in the standardized stance using a sliding anthropometric caliper. Femur length represented the distance from the superior aspect of the greater trochanter to the lateral joint line of the knee, whereas tibia length was the distance from the medial joint line of the knee to the inferior medial malleolus.[28]

Data Reduction and Statistical Analysis

The average of 3 measurements for each alignment characteristic and the femur to tibia length ratio (femur/tibia) were computed and used for data analysis. Multiple linear regression, with all variables entered simultaneously into the model, was used to examine the extent to which the lower extremity alignment variables predicted Q angle for males and females. We chose to run separate regression models for males and females because both the quadriceps angle [5,15,25,34-37] and many of the other alignment characteristics we examined [25] are known to significantly differ by sex, and it is possible that the relationships may not be the same for males and females. Power calculations determined that with alpha level set at $P = 0.05$, and a maximum of 8 predictor variables, 100 subjects were required to have 95% power to detect a multiple R^2 of 0.20, which is considered a moderate to large effect.[38] These criteria were considered acceptable because a relatively large effect would be required to establish lower extremity alignment variables as meaningful and accurate predictors of Q angle.

Alignment Characteristic	Males		Females	
	Mean (SD)	Range	Mean (SD)	Range
Quadriceps angle, degrees	9.3 (4.2)	2.0-21.3	13.5 (5.1)	3.3-31.3
Pelvic angle, degrees†	9.0 (3.9)	−1.0-19.0	12.1 (4.4)	−1.7-24.0
Femoral anteversion, degrees	8.6 (4.7)	0.3-23.3	14.7 (6.1)	3.7-35.0
Tibiofemoral angle, degrees†	9.6 (2.7)	4.0-16.7	11.5 (2.5)	5.0-16.7
Genu recurvatum, degrees	3.2 (3.0)	−2.0-13.0	5.6 (4.2)	−2.0-21.0
Tibial torsion, degrees†	18.2 (7.0)	2.0-35.3	19.8 (6.9)	−4.3-35.0
Navicular drop, mm	6.2 (3.0)	−2.0-15.3	6.8 (3.8)	−2.7-18.0
Femur to tibia length ratio	1.2 (0.06)	0.9-1.3	1.2 (0.05)	1.0-1.4

*Portions of these data have been previously reported.[26,29]

†Positive values for pelvic angle, tibiofemoral angle, and tibial torsion represent anterior pelvic tilt, valgus angle, and outward tibial torsion, respectively.

TABLE 1. Mean, Standard Deviation, and Range (minimum-maximum) for Lower Extremity Alignment Characteristics

Alignment Characteristic	Males				Females			
	Unstandardized Coefficients				Unstandardized Coefficients			
	B	SE	*t* Value	*P* Value	B	SE	*t* Value	*P* Value
Constant (intercept)	−14.443	9.513	−1.518	0.132	−4.727	11.675	−0.405	0.686
Pelvic angle	0.174	0.103	1.693	0.094	0.125	0.105	1.189	0.237
Femoral anteversion	0.180	0.087	2.082	0.040*	0.178	0.078	2.279	0.025*
Tibiofemoral angle	0.604	0.169	3.579	0.001*	0.621	0.193	3.220	0.002*
Genu recurvatum	−0.157	0.139	−1.130	0.262	−0.229	0.121	−1.889	0.062
Tibial torsion	0.084	0.058	1.449	0.151	0.072	0.069	1.041	0.300
Navicular drop	0.081	0.135	0.602	0.548	−0.001	0.130	−0.010	0.992
Femur to tibia length ratio	11.422	7.223	1.581	0.117	5.731	9.289	0.617	0.539

*Significant at $P < 0.05$.

TABLE 2. Regression Summary Results When Predicting Quadriceps Angle Based on Other Alignment Characteristics Stratified by Sex

RESULTS

Means, standard deviations, and ranges (minimum to maximum) for each alignment characteristic by sex are pre Multiple linear regression summary results for males and females are presented in Table 2. The amount of variar explained by the 7 alignment characteristics was 19.1% ($P < 0.005$) and 17.9% ($P = 0.003$) for males and female all alignment variables were accounted for, greater tibiofemoral angle and femoral anteversion were statistically predictors of greater Q angle in both males (tibiofemoral angle $P = 0.001$, femoral anteversion $P = 0.040$) and fe angle $P = 0.002$, femoral anteversion $P = 0.025$). Considering only these significant predictors, the largest predic angle (in terms of magnitude of change) in males was due to tibiofemoral angle, with a predicted 0.60-degree ch 1-degree change in tibiofemoral angle. Similarly, tibiofemoral angle was also the predictor of the largest change angle in females, with a predicted 0.62-degree change in Q angle for each 1-degree change in tibiofemoral angle females, a 1-degree change in femoral anteversion predicted a 0.18-degree change in Q angle. Measures of pelvi recurvatum, tibial torsion, navicular drop, and femur to tibia length ratio were not found to be significant indepe angle in males or females when all alignment variables were accounted for.

DISCUSSION

Our primary finding was that alignment of the knee and hip is associated with the magnitude of the Q angle in l females. Specifically, tibiofemoral angle and femoral anteversion had the strongest association with greater Q a impact on the magnitude of Q angle was similar in both males and females.

These findings in part support our hypothesis that lower extremity alignment characteristics may change the po anatomical landmarks used to measure the Q angle, thus impacting its magnitude. Specifically, increased tibiof which represents the valgus angle formed by the anatomical axes of the femur and tibia, would move the patell to the anterior superior iliac spine (as the femur is in an adducted position) and the tibial tuberosity laterally (as abducted position),[24,37,39] thus increasing the Q angle. Femoral anteversion on the other hand represents a me femur as the femoral neck is projected forward relative to the femoral condyles.[32,40] Excessive femoral anteve essentially place the femur into a more medially rotated position, potentially resulting in a medial displacement addition, excessive femoral anteversion is associated with an intoeing gait [41] that is compensated by an externa tibia on the femur,[42] which would displace the tibial tuberosity in a more lateral position.

Although both measures seem to have the potential to alter the position of the landmarks used to measure the Q statistically significant predictors of the magnitude of the Q angle, changes in tibiofemoral angle seem to have a greater impact on the magnitude of the Q angle than femoral anteversion. This is based on interpretation of the coefficients (B), which revealed that every 1-degree change in tibiofemoral angle predicted approximately a 0.6 in Q angle in both males and females, whereas every 1-degree change in femoral anteversion predicted only a 0 in Q angle. This suggests that a greater change in the magnitude of femoral anteversion is required before an ap in the frontal plane positions of the landmarks is reflected in the measure of Q angle. This may be explained by [43] that in weight-bearing, rotation of the femur may occur underneath the patella and potentially not change its in a minimal medial displacement of the patella. Collectively, these findings suggest that although various mala hip and knee are related to changes in Q angle, those that involved frontal plane deviations seem to have a grea magnitude of change compared with deviations in other planes.

Further supporting this premise is the lack of relationships between pelvic angle and navicular drop with the Q clinical expertise and observation,[3,22-24,44-46] we hypothesized that greater anterior pelvic tilt and pronation navicular drop) would also predict Q angle magnitude. Specifically, we expected that greater anterior tilt of the change the spatial orientation of the anatomical landmarks similar to hip anteversion where the patella would d and the tibial tuberosity would displace laterally. This was based on a previous report [47] that an anterior pelvic acetabulum shifting backward, causing the femur to internally rotate on the pelvis. Our hypothesis that a greate would also be a predictor of greater Q angle was based on previous studies that reported that an excessive prona with internal rotation of the lower extremity and increased knee valgus [3,44] and is therefore suggested to result angle.[45,46] As previously discussed, both increased anterior pelvic tilt and navicular drop would result in rotat the femur and tibia,[3,22-24,44-46] displacing the patella medially and the tibial tuberosity laterally, which do no sufficient to alter the frontal plane landmarks used in the measurement of Q angle.

Sex Differences in Quadriceps Angle

The literature consistently demonstrates that females have greater Q angles compared with their male counterpa [37,48]; however, reasons for this sex difference are still unknown. Previously, it was thought that the greater Q was a result of females having a wider pelvis compared with males; however, this has been well disputed.[34,35 knowledge, a study by Pantano et al [50] is the only study that has empirically shown that sex differences in anat characteristics contribute to greater Q angle in females. They report that subjects with a high Q angle (>=17 de pelvic width to femur length ratio compared with subjects with a low Q angle (<=8 degrees). The limitation wi that these results are based on a relatively small sample size (n = 10 per group). Although not the primary purp our results suggest that greater Q angle in females may be a result of females having greater structural femoral tibiofemoral angle compared with males. This is based on previous work noting that each of these values is gre compared with males [25] and our current observations that greater femoral anteversion and tibiofemoral angle w with greater Q angle, regardless of sex.

Implications for Risk Factor Assessment of Knee Injuries

As previous studies examining Q angle as a risk factor for knee injuries have reported inconsistent findings,4,5 the anatomical factors that may influence the anatomical landmarks from which the Q angle is derived may hel dynamic knee function. Given that more than 1 anatomical variable has the potential to alter the Q angle and th independent effects differ in magnitude, it may be that the measurement of Q angle alone is not sufficient to ide risk for knee injury. Rather, it may be the unique combination of alignment characteristics that collectively con increased risk of knee injury.

For example, a dynamic alignment characterized by a combination of hip adduction and internal rotation and kn been observed to be a mechanism and predictor of ACL injuries.12,51,52 Based on our finding that the impact alignment on Q angle was low compared with alignments in the frontal plane, it is not surprising that the measu alone was not predictive of the likelihood of suffering an ACL injury in retrospective risk factor studies.4,5,14 that a combination of static alignment characteristics increases the valgus and rotational positions common to A fact, previous studies have reported an interactive effect of frontal and transverse plane alignment variables on function 53 and when identifying risk factors for ACL injuries.4-6 Whether a unique combination of excessive both frontal and transverse plane alignment measures may predispose individuals to land and cut with greater d valgus angles and moments is unknown and warrants further investigation.

In regard to pathologies of the patellofemoral joint, greater Q angle has been shown to be highly correlated (r = laterally directed muscle force vector on the patella.9 This larger laterally directed muscle force may in turn lea tracking 9 and an increase in patellofemoral contact pressures,54 which are thought to predispose an individual pain.24 However, a relationship between excessive Q angle and the development of patellofemoral pain has no established.15-21 The lack of consistent findings in these investigations may again be explained by the influenc extremity alignment factors (ie, rotational deformities), along with Q angle, that have been suggested to result i patellofemoral mechanics.24,55 Because rotational lower extremity malalignments are largely not accounted fo measurement of Q angle, investigating the effects of other lower extremity alignment variables along with Q an clearer picture as to the role that lower extremity static alignment plays in the development of patellofemoral pa

The relationships identified among the lower extremity alignment characteristics in the current study are limite characteristics measured by a single examiner with known measurement reliability. We also acknowledge that and postural measures could potentially influence Q angle (eg, coxa vara, joint laxity, patella mobility, muscula knee version) and impact dynamic motion and knee injury risk. In fact, approximately 80% of the variance in th unexplained by the alignment measures studied in the current investigation. Although we are continuing work i hope that the findings of this study lead to a more comprehensive approach in the examination of a lower extre when considering anatomical contributions to dynamic lower extremity motion and knee injury risk.

CONCLUSIONS

Excessive Q angle has been identified as a potential risk factor for knee injuries, but evidence to support this re unclear. A reason for these inconsistent findings may be in part due to limited understanding of how other anat characteristics influence the magnitude of the Q angle. This is the first study to our knowledge that has examin alignment of the lower extremity and its relationship to Q angle. Our findings that the Q angle largely represent measure suggest that independently examining the Q angle for its effects on lower extremity injuries may not b rotational alignments not accounted for in the Q angle may be important factors toward understanding knee inj thought to result from a combination of transverse and frontal plane motions. Until all relevant postural charact accounted for in future study designs, the relationships between static alignment, dynamic knee function, and i remain largely theoretical. Continuing to understand the relationship among alignment characteristics may help effectively identify those that may be at greater risk for injury and therefore help us develop intervention strate subsequently reduce the risk of a lower extremity injury.

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