

Research article

LOWER EXTREMITY MALALIGNMENTS AND ANTERIOR CRUCIATE LIGAMENT INJURY HISTORY

Jay Hertel ¹✉, Jennifer H. Dorfman ² and Rebecca A. Braham ³

¹ University of Virginia, 210 Emmett Street South, Charlottesville, VA, USA.

² Westtown School, Westtown, PA, USA

³ University of Western Australia, Crawley, WA, Australia

Received: 25 July 2004 / Accepted: 19 September 2004 / Published (online): 01 December 2004

ABSTRACT

To identify if lower extremity malalignments were associated with increased propensity of a history of anterior cruciate ligament (ACL) ruptures in males and females using a case control design. Twenty subjects (10 males, 10 females) had a history of ACL injury and twenty (10 males, 10 females) had no history of ACL injury. Subjects were assessed for navicular drop, quadriceps angle, pelvic tilt, hip internal and external rotation range of motion, and true and apparent leg length discrepancies. Statistical analysis was performed to identify differences in these measures in regard to injury history and gender, and to identify if any of these measures were predictive of ACL injury history. Increased navicular drop and anterior pelvic tilt were found to be statistically significant predictors of ACL injury history regardless of gender. Limbs that had previously suffered ACL ruptures were found to have increased navicular drop and anterior pelvic tilt compared to uninjured limbs. Based on the results of this retrospective study, the lower extremity malalignments examined do not appear to predispose females to tearing their ACLs more than males.

KEY WORDS: Hyperpronation, navicular drop, pelvic tilt, quadriceps angle.

INTRODUCTION

Female athletes are two to eight times more susceptible than males to tear their anterior cruciate ligaments (ACL) (Arendt and Dick, 1995; Arendt et al., 1999). Several factors have been hypothesized to be related to this heightened injury risk including gender differences in lower extremity anatomical structure, movement patterns, neuromuscular recruitment strategies, and reproductive hormone levels. (Huston, et al., 2000) The specific focus of this study was to investigate the association between gender, lower extremity malalignments, and history of ACL rupture.

Prior investigators have investigated the relationship of malalignments such as foot hyperpronation (Beckett et al., 1992; Woodford-Rogers et al., 1994; Loudon et al., 1996), quadriceps

angle (q-angle) (Loudon et al., 1996; Shambaugh et al., 1991), leg length discrepancy (Soderman et al., 2001; Twellaar et al. 1997), and pelvic tilt (Loudon et al., 1996; Twellaar et al., 1997) on risk of knee injury in athletes. These malalignments have been hypothesized to be associated with increased risk of ACL injury because they may place increased strain on the ACL. For example, hyperpronation is associated with increased tibial internal rotation; a large q-angle would be associated with increased knee valgus; a leg length discrepancy would result in hyperpronation on the "short" leg; and pelvic obliquity may be associated with increased hip internal rotation. All of these mechanical consequences could influence the ACL adversely.

With the exception of hyperpronation as assessed by navicular drop (ND) (Beckett et al., 1992; Woodford-Rogers et al., 1994; Loudon et al., 1996), genu recurvatum (Loudon et al., 1996), and

anterior pelvic tilt (Loudon et al., 1996), measures of lower extremity malalignment have not been reported to be statistically associated with increased ACL injury risk. There is a lack of definitive evidence-based associations between different lower extremity malalignments and ACL injury risk.

The purposes of this study were: 1) to identify if lower extremity malalignment differences exist between those with and without a history of ACL injury, and 2) to investigate the relationship of ACL injury history to gender, ND, q-angle, leg length, hip internal and external rotation range of motion (ROM), and pelvic tilt using a retrospective, case control design. We hypothesized that increased ND, increased q-angle, negative leg length discrepancy (short leg), increased hip rotation ROM, and greater anterior pelvic tilt will be significantly associated with having a history of ACL injury.

METHODS

Subjects

Volunteers for the study were recruited by placing flyers describing the study at several locations on a large university campus. Twenty participants (10 males, 10 females, age = 20.4 ± 1.2 yrs, height = 1.73 ± 0.09 m, mass = 72.2 ± 12.1 kg) had no history of ACL injury to either limb and served as controls. Twenty others (10 males, 10 females, age = 20.7 ± 1.4 yrs, height = 1.75 ± 0.09 m, mass = 72.5 ± 17.7 kg) had a history of ACL injury. Four of these females had bilateral ACL injury history. All ACL injuries occurred during sport participation between 3 and 84 months before the study and all had been surgically reconstructed. Injury mechanism and length of time since injury were obtained from a questionnaire. Each subject provided informed consent prior to the beginning of the study. Subject demographics are summarized in table 1.

Measurements

The following measurements taken: 1) ND, 2) q-angle, 3) apparent leg length, 4) true leg length, 5) hip internal rotation ROM, 6) hip external rotation ROM, and 7) pelvic tilt. All measurements were

taken by the same examiner (JHD) who practiced each measurement technique during pilot testing until test-retest reliability analysis revealed intraclass correlation coefficients greater than 0.7 were obtained for each measure. Three trials of each measure were taken on both the right and left limbs and the mean measure on each side was used for analysis.

Navicular drop was measured using the Brody (1982) method. The subject sat in a chair with their bare feet flat on the ground. The examiner held an index card on the floor and marked the point of the subject's navicular drop. The subject then stood up and the position of the navicular tuberosity was again measured. The examiner then measured the distance between the two points.

Quadriceps angle was measured with subjects lying supine on a table. Lines were drawn from the ASIS to the midpoint of the patella and from the tibial tuberosity to the midpoint of the patella. A goniometer was used to measure the acute angle of the bisection of these lines.

Apparent leg length was measured from the umbilicus to the medial malleolus, while true leg length was measured from the ASIS to the medial malleolus (Hoppenfeld, 1976). Both measures were taken with subjects lying supine. For each measure, leg length discrepancy was determined subtracting the left leg length from the right leg length.

Hip internal and external rotation active ROMs were measured with subjects lying prone. The subject's knee was flexed to 90 degrees and the moving arm of the goniometer was aligned with the tibia. The subject then actively internally rotated their hip to its endpoint and a measure was made in degrees. Hip external rotation was then similarly measured.

Pelvic tilt was measured with an inclinometer (Palm-o-meter[®], Performance Attainment Associates, St. Paul, MN) using previously described methods (Krawiec et al., 2003). Subjects stood with their bare feet spread shoulder width apart. The examiner palpated the right ASIS and PSIS and placed the tips of the inclinometer on these landmarks. Pelvic tilt was measured in degrees. A positive value

Table 1. Descriptive statistics of injured and uninjured limbs. Each limb is treated as a single subject. Uninjured limbs (n = 24) are from healthy control subjects and are side-matched to the ACL-injured limbs (n = 24). Data are means (\pm SD).

	Uninjured Limbs	Injured Limbs
Hip Internal Rotation (°)	41.20 (9.13)	39.14 (8.31)
Hip External Rotation (°)	30.51 (8.98)	31.41 (8.88)
Innominate Rotation (°)	1.68 (2.32)	3.19 (2.26) *
Navicular Drop (cm)	.68 (.27)	.84 (.25) *
Q-Angle (°)	11.84 (2.65)	11.16 (3.83)
Months since ACL injury (months)	---	36.95 (28.72)

* denotes significant difference between groups at the $p < 0.05$ level.

represented an anterior tilt and a negative value represented a posterior tilt. Measures were then taken on the left side.

Table 2. Results of the stepwise regression analysis assessing the relationship of gender and the 7 malalignment measures to ACL injury history.

Measure	r	p
Gender	.17	.17
Navicular Drop	.38	.02*
Q-Angle	.22	.25
True Leg Length Discrepancy	.18	.33
Functional Leg Length Discrepancy	.03	.85
Hip Internal Rotation ROM	.17	.30
Hip External Rotation ROM	.16	.35
Pelvic Tilt	.39	.04*

* $p < 0.05$.

Statistical Analysis

Each limb in the study was treated as an individual subject. For each of the seven dependent variables, separate 3x2x2 factorial ANOVAs were conducted. The factors were group (ACL injury history, control), gender (males, females), and side (involved, uninvolved). Using this design scheme, individuals with bilateral ACL injury history could thus be classified as having both sides as "involved". The level of significance was set a priori at $p < 0.05$.

To determine the influence of gender and which malalignments were most associated with ACL injury history, a pair of stepwise logistic regression analyses was performed comparing the injured limbs and the side-matched limbs of the uninjured controls. Injury status was defined as "0" for no injury history and "1" corresponded to history of ACL injury. Gender was coded with males as "1" and females as "2". For each malignment measure, the rules of thirds was applied and the lowest 33.3% of cases were classified as a "1", the middle 33.3% of cases were classified as a "2", and the highest

33.3% of cases was classified as a "3". Initially, all 8 dependent measures were entered into the regression analysis, gender was entered first followed by the malalignments. ND and innominate rotation were the only variables that attained a statistically significant association with ACL injury status ($p < 0.05$). Therefore a second stepwise logistic regression analysis was performed with only ND and pelvic considered in the model. Odds ratios and their 95% confidence intervals were then computed relative to a baseline category (lowest third of cases) for these two variables.

RESULTS

Females, regardless of injury history, demonstrated significantly larger q-angle measurements (females $12.7^\circ \pm 0.62^\circ$, males $10.2^\circ \pm 0.52^\circ$, $p = 0.004$) and more anterior pelvic tilt (females $3.5^\circ \pm .42^\circ$, males $1.5^\circ \pm .35^\circ$, $p < 0.0005$). Previously injured limbs demonstrated significantly more anterior pelvic tilt and navicular drop than uninjured limbs (see Table 1).

Table 2 summarizes the results of the initial regression analysis. Navicular drop ($r^2 = 0.14$, $p = 0.02$) and pelvic tilt ($r^2 = 0.15$, $p = 0.04$) were the only two measures significantly associated with ACL injury history. Table 3 shows the results of the subsequent logistic regression model including ND and pelvic tilt produced an r^2 value of 0.42 ($p = 0.001$). Individuals with a measured ND between 0.63 and 0.80 cm and greater than 0.80 cm were 16 and 20 times, respectively, more likely to have sustained an ACL injury than individuals with less than 0.63 cm ND. Individuals with an anterior pelvic tilt of greater than 3.89° were 5.2 times more likely to have sustained an ACL injury than those with less than 1° anterior pelvic tilt. The logistic regression model combining ND and pelvic tilt correctly predicted the ACL injury history of 73.9% of the injured limbs and 76% of the uninjured limbs.

Table 3. Adjusted odds ratio for the relationship between navicular drop, innominate rotation and ACL injury status. The regression model has an R^2 value of 0.42.

Measure	Odds Ratio	95% Confidence Interval for Odds Ratio	p
Navicular Drop			
<0.63 cm	1.00		
0.63-0.80 cm	16.43	(1.65, 163.97)	.02*
>0.80 cm	20.25	(1.83, 223.77)	.01*
Innominate rotation			
< 1.0°	1.00		
$1.0^\circ - 3.89^\circ$	1.12	(0.21, 5.92)	.90
> 3.89°	5.22	(0.90, 30.13)	.05*

* $p \leq 0.05$.

DISCUSSION

The results of our study suggest increased ND and anterior pelvic tilt, regardless of gender, are significantly associated with a history of ACL rupture. While females demonstrated larger q-angle measures than males, this difference was independent of ACL injury history. These findings suggest that malalignments at the foot and the pelvis influence risk of ACL injury.

Excessive pronation was found to be the factor most associated with ACL injury history. This finding is in agreement with other retrospective studies (Beckett et al., 1992; Woodford-Rogers et al., 1994; Loudon et al., 1996). Subjects in our study with greater than 0.80 cm ND were 20 times more likely to have torn their ACL than subjects with less than 0.63 cm ND. Subjects with between 0.63 and 0.80 cm were 16 times more likely than those with less the 0.63 cm ND to have torn their ACL. It has been previously demonstrated that increased pronation is correlated to greater internal rotation in the transverse plane at the knee (Coplan, 1989). This increased rotation may place additional strain on the ACL during deceleration activities and increase the risk of rupture. We are unaware of any intervention studies that have examined the role of foot orthotics as a prophylactic means of preventing ACL ruptures in athletes who hyperpronate.

Increased anterior pelvic tilt was also found to be significantly associated with ACL injury history. While we found that females had more anterior pelvic tilt than males, we did not find a significant interaction between gender and injury history related to this measure. In other words, increased anterior pelvic tilt was associated with ACL injury history in both males and females. This suggests that anterior pelvic tilt is not a risk factor of ACL ruptures exclusive to females.

Loudon et al. (1996) found that in females anterior pelvic tilt was significantly related to having a history of ACL injury when assessed statistically in a univariate analysis, however it was not a significant factor when examined in a multivariate analysis. The 3 significant predictors of ACL injury history in Loudon et al.'s multivariate analysis were genu recurvatum, ND, and static rearfoot position. While we did not assess for genu recurvatum in our study, it is plausible that as the pelvis tilts farther anteriorly that the knees would be able to hyperextend further (Ireland et al., 1997). Loudon et al. (1996) concluded that the combination of hyperpronation and genu recurvatum were significantly associated with ACL injury risk in female athletes.

In addition to being associated with genu recurvatum, increased anterior pelvic tilt places the

hamstrings in an elongated position. Lengthening of the hamstrings may slow their neuromuscular response time (Trontelj, 1993), and thus, their capacity to serve as dynamic agonists to the ACL. Conversely, anterior tilt is associated with shortening of the hip flexors, including the rectus femoris (Lee et al., 1997). This may allow for faster neuromuscular facilitation of this muscle (Trontelj, 1993) and contribute to the phenomenon of quadriceps dominance hypothesized by Huston and Wojtys (1996). Specific relationships between structural alignments and altered neuromuscular function that may cause injury predispositions are not clearly understood and warrant further research. Likewise, it is unknown if manual therapy techniques, such as muscle energy, may be used to permanently influence excessive pelvic tilt and lessen injury risk associated with these malalignments.

Females in our study, regardless of injury history, demonstrated significantly greater q-angle measures than males. This is consistent with previous findings (Horton and Hall, 1989; Woodland and Francis, 1992; Moul, 1998). We did not, however, demonstrate a significant relationship between increased q-angle and ACL injury history. Increased q-angle is often anecdotally stated as a possible explanation for the increased prevalence of ACL injuries among females, however two recent extensive literature reviews could not identify published research to support this hypothesis (Huston et al, 2000; Murphy et al., 2003). This illustrates that not all gender differences related to the knee are directly related to increased risk of ACL injury in female athletes.

We did not identify significant relationships between ACL injury history and either leg length discrepancy or hip internal and external ROM. We included these variables in our study because they had not been extensively examined in previous studies of lower extremity structural alignment and ACL injury risk. We hypothesized that limbs shorter than the contralateral side may be more associated with ACL injury risk because the shorter limb would tend to pronate, and thus rotate, more than longer limbs. Likewise we hypothesized that increased ROM for rotation at the hip could also increase ACL injury risk. These hypotheses were refuted.

Our study was retrospective in nature and thus has inherent limitations. It is possible that the increased ND and anterior pelvic tilt found in previously injured limbs could be the result of post-traumatic or post-surgical adaptations of the lower extremity rather than risk factors for initial ACL injury. Because of the biomechanical and neuromuscular relationships of these malalignments to the ACL proposed earlier we doubt that this is

true, but the possibility cannot be definitively disproved. A prospective study examining the risk factors to ACL injury identified here would help to further elucidate the relationship between lower extremity malalignment and increased injury risk. Lastly, the combination of ND and anterior pelvic tilt explained only 42% of the variance associated with ACL injury history in our subjects. It is likely that risk factors such as neuromuscular recruitment strategies, movement patterns, and hormonal fluctuations are associated with the unexplained variance in ACL injury risk not related to lower extremity malalignment.

Our findings, along with other previously published retrospective studies, provide a starting point for further investigation of ACL injury risk. Identification of significant relationships between lower extremity malalignments and ACL injury history is clinically relevant as it confirms the existence of increased injury risk with certain patterns of skeletal alignment. However, there is still a clear need for larger scale retrospective and prospective studies that examine the relationships between lower extremity malalignments and ACL injury risk with larger sample sizes and increased statistical power. Likewise, the study of intervention techniques aimed at correcting hyperpronation (with foot orthotics) and anterior pelvic tilt (muscle energy) in an effort to prevent ACL injuries may also be warranted.

CONCLUSIONS

Increased navicular drop and anterior pelvic tilt were significantly associated with history of ACL rupture regardless of gender. Potential explanations have been made as to why these two factors may be associated with ACL injury risk. While females were found to have greater q-angle measures than males, this was not significantly related to ACL injury history. These findings illustrate that not all structural differences identified between genders are necessarily related to the increased risk of ACL injury among females.

REFERENCES

- Arendt, E.A. and Dick, R. (1995) Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. *American Journal of Sports Medicine* **23**, 694-701.
- Arendt, E.A., Agel, J. and Dick, R. (1999) Anterior cruciate ligament injury patterns among collegiate men and women. *Journal of Athletic Training* **34**, 86-92.
- Beckett, M.E., Massie, D.L., Bowers, K.D. and Stoll, D.A. (1992) Incidence of hyperpronation in the ACL injured knee: a clinical perspective. *Journal of Athletic Training* **27**, 58-62.
- Brody, D. (1982) Techniques in the evaluation of the injured runner. *Orthopedic Clinics of North America* **13**, 542-558.
- Coplan, J.A. (1989) Rotational motion of the knee: a comparison of normal and pronating subjects. *Journal of Orthopedic and Sports Physical Therapy* **10**, 366-369.
- Hoppenfeld, S. (1976) *Physical examination of the spine and extremities*. Prentice Hall, Upper Saddle River, NJ, USA.
- Horton, M.G. and Hall, T.L. (1989) Quadriceps femoris muscle angle: normal values and relationships with gender and selected skeletal measures. *Physical Therapy* **69**, 897-901.
- Huston, L.J. and Wojtys, E.M. (1996) Neuromuscular performance characteristics in elite female athletes. *American Journal of Sports Medicine* **24**, 427-436.
- Huston, L.J., Greenfield, M.L.V.H. and Wojtys, E.M. (2000) Anterior cruciate ligament injuries in female athletes. *Clinical Orthopedics and Related Research* **372**, 50-63.
- Ireland, M.L., Gaudettem, M. and Crook, S. (1997) ACL injuries in the female athlete. *Journal of Sport Rehabilitation* **6**, 97-110.
- Krawiec, C.J., Denegar, C.R., Hertel, J., Salvaterra, G.F. and Buckley, W.E. (2003) Static innominate asymmetry and leg length discrepancy in asymptomatic collegiate athletes. *Manual Therapy* **8**, 207-213.
- Lee, L.W., Kerrigan, D.C. and Della Croce, U. (1997) Dynamic implications of hip flexion contractures. *American Journal of Physical Medicine and Rehabilitation* **76**, 502-508.
- Loudon, J.K., Jenkins, W. and Loudon, K.L. (1996) The relationship between static posture and ACL injuries in female athletes. *Journal of Orthopedic and Sports Physical Therapy* **24**, 91-97.
- Moul, J.L. (1998) Differences in selected predictors of anterior cruciate ligament tears between male and female NCAA division I collegiate basketball players. *Journal of Athletic Training* **33**, 118-121.
- Murphy, D.F., Connolly, D.A. and Beynon, B.D. (2003) Risk factors for lower extremity injury: a review of the literature. *British Journal of Sports Medicine* **37**, 13-29.
- Shambaugh, J.P., Klein, A. and Herbert, J.H. (1991) Structural measures as predictors of injury in basketball players. *Medicine and Science in Sports and Exercise* **23**, 522-527.
- Soderman, K., Alfredson, H., Pietila, T. and Werner, S. (2001) Risk factors for leg injuries in female soccer players: a prospective investigation during one outdoor season. *Knee Surgery, Sports Traumatology, and Arthroscopy* **9**, 313-321.
- Trontelj, J.V. (1993) Muscle fiber conduction velocity changes with length. *Muscle and Nerve* **16**, 506-512.
- Twellaar, M., Verstappen, F.P., Huson, A. and van Mechelen, W. (1997) Physical characteristics as risk factors for sports injuries: a four year

prospective study. *International Journal of Sports Medicine* **18**, 66-71.

Woodford-Rogers, B., Cyphert, L. and Denegar, C.R. (1994) Risk factors for anterior cruciate ligament injury in high school and college athletes. *Journal of Athletic Training* **29**, 343-346.

Woodland, L.H. and Francis, R.S. (1992) Parameters and comparisons of the quadriceps angle of college-aged men and women in the supine and standing positions. *American Journal of Sports Medicine* **20**, 208-211.

AUTHORS BIOGRAPHY

Jay HERTEL

Employment

University of Virginia, Kinesiology Program

Degree

PhD, ATC

Research interest

Ankle instability, knee injuries, postural and neuromuscular control.

E-mail: jhertel@virginia.edu

Jennifer H. DORFMAN

Employment

Athletic trainer and health teacher at Westtown School

Degree

MSEd, ATC

Research interest

Knee injuries, exertional heat illness.

E-mail: Jennifer.Dorfman@westtown.edu

Rebecca A. BRAHAM

Employment

University of Western Australia, School of Human Movement and Exercise Science

Degree

PhD

Research interest

Injury prevention, community sports injuries, physical activity.

E-mail: rab41@psu.edu

KEY POINTS

- Hyperpronation and greater anterior pelvic tilt were the two malalignments most associated with history of ACL injury.
- Females had larger quadriceps angles than males, but this measure was not significantly related to ACL injury history.
- Not all structural differences between genders help explain the increased risk of ACL injuries in female athletes.

✉ Jay Hertel

University of Virginia, 210 Emmett Street South, Charlottesville, VA 22904-4407, USA.