Bilateral Asymmetries in Clinical Measures of Lower-Extremity Anatomic Characteristics

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Abstract:

Objective: To quantify side-to-side differences in lower-extremity anatomic characteristics, and to compare the magnitude of left-right differences with the measurement error for each variable.
Design: Descriptive.
Setting: Applied neuromechanics research laboratory.
Participants: One hundred healthy participants (50 male, 50 females).
Assessment of Risk Factors: One examiner measured 14 anatomic characteristics on the left and right lower extremities. The value on the left was subtracted from value on the right, and 68% (±1 SD) and 95% (±1.96 SD) confidence intervals were constructed around the mean differences, respectively. These values were compared with the examiner's absolute measurement error for each measure.
Main Outcome Measurements: Total leg length, pelvic angle, hip anteversion, standing and supine quadriceps angle, tibiofemoral angle, knee laxity, genu recurvatum, femur and tibia length, tibial torsion, rearfoot angle, and navicular drop.
Results: Left-right differences in pelvic angle, tibial torsion, and navicular drop exceeded the measurement error in more than 32% of the cases. Five to thirty-two percent of the cases had left-right differences exceeding the measurement error for hip anteversion, standing and supine quadriceps angle, tibiofemoral angle, knee laxity, genu recurvatum, and femur length. Asymmetries in limb length were not observed.
Conclusions: Bilateral asymmetries exist in many clinical alignment characteristics, indicating that measurements taken on one limb may not be representative of the contralateral limb. We recommend measuring both extremities when anatomic characteristics are included as part of preseason screenings and prospective study designs to ensure valid comparison.

Keywords: lower-extremity alignment | risk factor assessment | limb symmetry | limits of agreement

Article:

INTRODUCTION

Retrospective and prospective studies have sought to determine whether lower-limb anatomic characteristics are a risk factor for overuse [1] and acute [2-6] knee injury. Although associations have been found between limb morphology and injury risk in these studies, the variables examined and relationships noted have varied considerably. This may be largely attributable to inadequate sample sizes and the number of variables that can reasonably be examined while still achieving adequate statistical power. As such, many authors have cited the need for larger retrospective and prospective studies to further examine these relationships.[1,3,5,6]

One of the many important considerations when designing these large-scale studies is which limb to measure. Some retrospective injury-risk studies have examined the injured limb,[3,4] and one has compared the uninjured limb [6] with matched, uninjured control limbs. Other studies (both retrospective and prospective studies) report measuring both sides, but these studies seem not to have matched the side measured to injured limb status.[1,2,5] Choosing the appropriate side for measurement comparisons is an important consideration for both prospective and retrospective injury-risk-factor studies, because concerns of validity have been raised relative to the assumptions made with each of these choices. Many suggest that valid measures cannot be taken on the affected side after injury, because the injury modifies the risk factors.[7-14] Conversely, measuring the uninjured (retrospectively) or only a representative side (prospectively) also has been questioned, because studies of isolated anatomic factors have indicated that bilateral symmetry cannot always be assumed.[15-17] However, there remains a paucity of data that has critically examined the prevalence and magnitude of bilateral asymmetries in lower-limb anatomic characteristics to aid clinicians and researchers in making these determinations.

Whereas left and right sides have been compared in previous studies on select alignment factors (ie, knee laxity, navicular drop, rearfoot angle, tibial torsion, quadriceps angle, hip anteversion), these comparisons have largely compared the mean difference using *t* and ANOVA statistics.[2,6,15,17-20] Because these analyses often find no statistical differences between the left and right limbs in a sample, it may be assumed that the left and right sides are symmetrical. However, these analyses are only sensitive to systematic differences in mean values between the left and right sides, and they do not allow one to quantify the range and magnitude of left-right differences measured within each subject. In the few studies that have reported mean left-right differences within subjects, substantial asymmetries have been noted in quadriceps angle,[15] rearfoot eversion,[17] and hip anteversion.[21] Results are conflicting regarding the extent of bilateral asymmetry for knee laxity [10,22] and tibial torsion.[23,24] Only four of these studies were based on clinical measurement methods in healthy adults [10,15,17,22]-methods by which clinicians and researchers often rely on.

We are not aware of any studies that have examined bilateral asymmetries in a comprehensive set of clinical anatomic characteristics in a relatively large cohort of healthy subjects. Further, we are not aware of any studies that have critically examined the magnitude of bilateral asymmetries to what would be expected simply because of measurement error, to better determine the extent to which observed asymmetries reflect true left-right differences. Knowing what lower-limb variables have the potential to differ substantially from side to side will assist both clinicians and researchers in determining the extent to which the uninjured limb may serve as a surrogate for the injured limb after injury, or whether a single limb versus both limbs should be measured in preseason screenings and prospective study designs. Hence, our purpose was to quantify absolute side-to-side differences in a collection of lower-extremity anatomic characteristics in a cohort of adult males and females, and to compare the magnitude of left-right differences observed with the absolute measurement error for each variable.

METHODS

One-hundred subjects (50 male, 50 female; 22.8 ± 3.3 years, 170.9 ± 9.8 cm, 74.0 ± 15.5 kg) free of current injury to the lower extremity, as well as any previous history that would affect the alignment or motion of the lower-extremity joints, participated. Because 40 subjects is considered sufficient for method-comparison studies, this study was sufficiently powered.[25] Before participation, subjects read and signed a consent form that had been approved by the university's institutional research board for the protection of human subjects.

Fourteen anatomic variables were measured using clinical measurement methods on both the left and right lower limbs (the first side measured was counterbalanced). Pelvic angle, hip anteversion, standing quadriceps angle, supine quadriceps angle, tibiofemoral angle, anterior knee laxity, genu recurvatum, tibial torsion, femur length, tibia length, and navicular drop were measured, as previously described by Shultz et al.[26] Standing rearfoot angle was measured as the angle formed between the longitudinal midlines of the distal third of the lower leg and the calcaneus, as described by Picciano et al.[27] The difference between the angle formed in subtalar joint neutral and relaxed stances was recorded. Total leg length was measured, both as the distance from the ASIS to the floor and as the distance from the superior aspect of the greater trochanter to the floor. Both lengths were measured to the nearest millimeter using a sliding anthropometric caliper that was equipped with bubble levels to ensure that the caliper remained parallel to the frontal and sagittal planes during measurements. For all standing measures, the subject stood in a standardized stance, with the feet positioned biacromial width apart and the toes facing forward.

All measures were taken three times on each side, and the average value of the three measurements for each side was used for bilateral comparisons. Side-to-side differences were examined using 68% and 95% limits of agreement (LOA).[25,28] The value on the left was subtracted from the value on the right, and 68% (± 1 SD) and 95% (± 1.96 SD) confidence intervals were constructed around the mean difference. All measures were taken by a single investigator, who established excellent test-retest reliability ($ICC_{2,k}$ range 0.82-0.99) on 16 subjects using identical testing methods. With the exception of total leg length, these values have been reported previously.[26,29] From these data, 95% LOAs for day-to-day differences in scores are reported in Table 1, which strictly calculates the absolute measurement error of test-retest differences within individual subjects. These data were then compared with the mean absolute left-right differences recorded within each subject for each anatomic measurement, to discern the extent of true left-right differences. Data were analyzed using the SPSS statistical software version 14.0 (SPSS, Inc.). We chose to not separate these data by sex because preliminary analyses had revealed no sex differences in mean difference scores (R-L), and because the measurement error against which these asymmetries were compared represents a combined sample of males and females (one that was too small to separate by sex).[26]

TABLE 1. Absolute Test–Retest Measurement Error for Each Anatomic Characteristic

Variable	Intratester 95% LOA
Leg length (ASIS to floor) (cm)	−0.2 ± 1.2
Leg length (greater trochanter to floor) (cm)	−0.5 ± 2.7
Pelvic angle (degrees)*	−0.3 ± 2.0
Hip anteversion (degrees)*	−0.8 ± 3.9
Standing Q angle (degrees)*	−1.0 ± 2.7
Supine Q angle (degrees)*	−0.9 ± 2.3
Tibiofemoral angle (degrees)*	−1.1 ± 1.9
Anterior knee laxity (mm)*	−0.2 ± 1.1
Genu recurvatum (degrees)*	0.3 ± 1.8
Femur length (cm)*	0.5 ± 1.0
Tibia length (cm)*	0.2 ± 1.5
Tibial torsion (degrees)*	0.5 ± 3.0
Rear foot angle (degrees)	0.0 ± 2.5
Navicular drop (mm)*	−0.2 ± 1.4

N = 16.
*Reliability data previously reported in Shultz et al.[26]

RESULTS

Table 2 lists the descriptive statistics and absolute left-right differences for each of the 14 measures. As expected, mean values for the left and right sides for the total sample were quite similar (columns 1 and 2). Further, the mean left-right difference was close to zero in all cases (columns 3 and 4), revealing no appreciable systematic differences between sides. However, when examining the 68% and 95% LOA (columns 3 and 4), the range and magnitude of left-right differences for each subject varied considerably, depending on the measure. Left-right differences in pelvic angle, tibial torsion, and navicular drop exceeded the measurement error in at least 32% of the cases (68% LOA). Left-right differences for hip anteversion, standing and supine quadriceps angle, tibiofemoral angle, anterior knee laxity, genu recurvatum, and femur length exceeded the measurement error in at least 5% of the cases (95% LOA). For many of these measures, the 68% LOA for left-right differences was comparable with 95% LOA for absolute measurement error, suggesting that anywhere from 5% to 32% of the cases had true left-right differences. Figure 1 provides a graphic comparison of the 95% LOAs for measurement error versus the 95% LOAs for left-right differences. Figure 2 presents Bland-Altman plots for those measures where left-right differences exceeded the measurement error in at least 32% of the cases (pelvic angle, tibial torsion, and navicular drop) as well as an example of a measure where the 68% LOA for the left-right difference was comparable with the 95% LOA for absolute measurement error (anterior knee laxity).

TABLE 2. Mean ± SD for Measurements Obtained on the Right and Left Sides (Columns 1 and 2) and the 68% and 95% Limits of Agreement for Right–Left Differences (Columns 3 and 4)

	(1) Right Side		(2) Left Side		(3)		(4)	
Variable	Mean	SD	Mean	SD	Mean Difference	68% LOA	Mean Difference	95% LOA
Leg length (ASIS to floor) (cm)	94.9	± 6.6	94.8	± 6.6	0.1	± 0.7	0.1	± 1.3
Leg length (greater trochanter to floor) (cm)	89.9	± 5.8	90.1	± 5.8	−0.2	± 0.8	−0.2	± 1.6
Pelvic angle (degrees)	10.4	± 5.1	10.2	± 4.5	0.2	± 2.9*	0.2	± 5.7†
Hip anteversion (degrees)	13.4	± 7.6	12.9	± 7.3	0.6	± 3.5	0.6	± 6.9†
Standing Q angle (degrees)	10.9	± 4.8	11.0	± 4.7	−0.1	± 2.8	−0.1	± 5.4†
Supine Q angle (degrees)	9.6	± 4.8	9.5	± 4.8	0.2	± 3.0	0.2	± 6.0†
Tibiofemoral angle (degrees)	9.4	± 2.8	10.2	± 2.5	−0.8	± 1.7	−0.8	± 3.2†
Anterior knee laxity (mm)	7.0	± 2.1	7.2	± 2.1	−0.2	± 1.0	−0.2	± 2.0†
Genu recurvatum (degrees)	4.0	± 3.7	4.4	± 3.9	−0.4	± 1.6	−0.4	± 3.2†
Femur length (cm)	43.5	± 2.8	43.6	± 2.8	0.0	± 0.8	0.0	± 1.5†
Tibia length (cm)	36.9	± 3.0	36.7	± 2.9	0.2	± 0.6	0.2	± 1.2
Tibial torsion (degrees)	19.7	± 6.7	19.2	± 7.0	0.5	± 5.1*	0.5	± 10.0†
Rear foot angle (degrees)	5.1	± 1.8	5.4	± 1.8	−0.3	± 1.4	−0.3	± 2.7
Navicular drop (mm)	6.6	± 3.1	7.0	± 3.4	−0.4	± 1.9*	−0.4	± 3.8†

N = 100.
* and † indicate right–left differences that exceed the absolute measurement error in at least 32% and 5% of the cases, respectively.

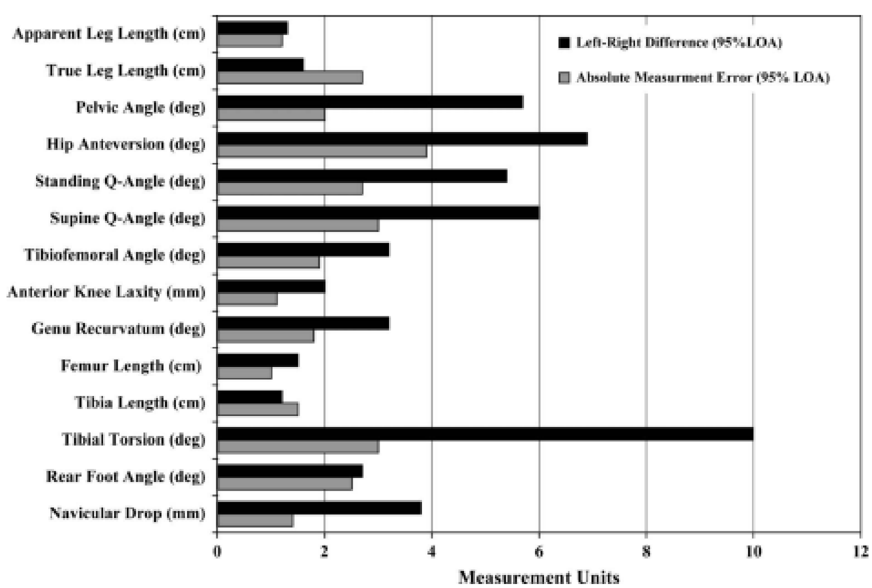

FIGURE 1. Comparison of the 95% limits of agreement for measurement error (Table 1) and left–right differences (Table 2, column 4).

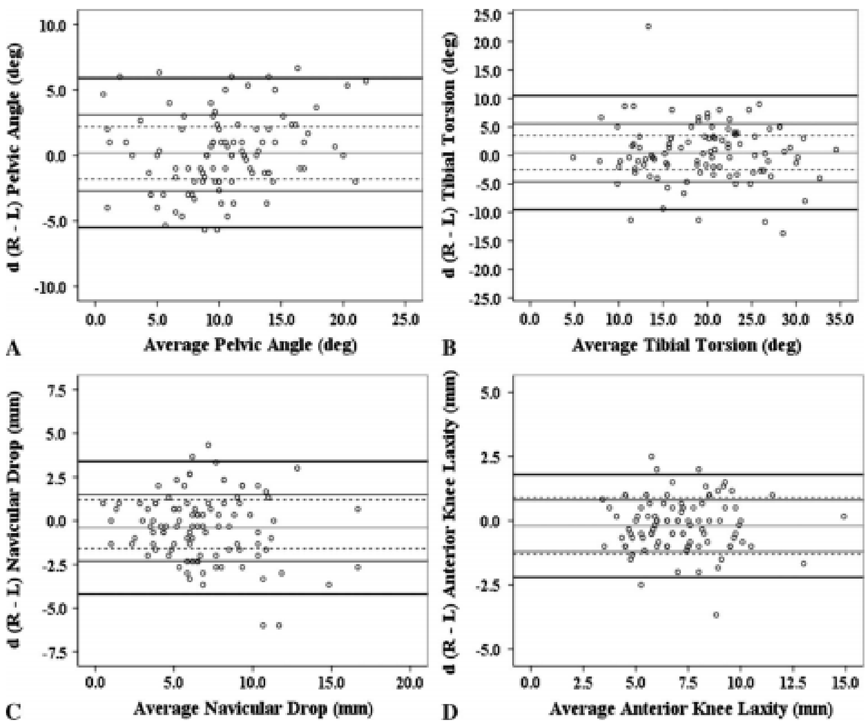

FIGURE 2. Bland–Altman plots displaying the difference scores between sides (R–L) against the average of the right and left scores for pelvic angle, tibial torsion, navicular drop, and anterior knee laxity. In each graph, the central gray line indicates the mean difference score, the dashed lines indicate the 95% limits of agreement (LOA) for the absolute measurement error, and the light and heavy black solid lines indicate the 68% LOA and 95% LOA of the left–right difference scores, respectively.

DISCUSSION

Our primary finding is that bilateral asymmetries were noted in 10 of the 14 measures, with left-right differences exceeding what would be expected simply because of measurement error. True left-right differences tended to be smallest for the four limb-length measures and were on the order of or less than the expected measurement error. However, bilateral asymmetries for pelvic angle, hip anteversion, standing and supine quadriceps angle, tibial torsion, tibiofemoral angle, anterior knee laxity, genu recurvatum, and navicular drop were more apparent, with left-right differences well exceeding their respective measurement errors.

As previously noted, comparisons of our findings with previous clinical studies of healthy individuals are limited. Our observed left-right differences for standing quadriceps angle and rearfoot angle are somewhat lower than those previously reported by Livingston and Mandigo,[15,17] with 50% and 20% of healthy subjects (N = 50) having left-right differences in standing quadriceps angle greater than 4 and 8 degrees, respectively, and 58% and 14% of asymptomatic subjects (N = 75) having left-right differences in rearfoot angle greater than 4 and 7 degrees, respectively. Comparing our left-right differences with previous work for anterior knee laxity, the differences seem lower.[10,22] Whereas we found that 95% of cases had left-right differences less than 2 mm, Daniel et al [10] have reported that only 88% of 120 healthy subjects had left-right differences less than 2 mm, and Sernert et al [22] report that 95% had left-right differences less than 3.2 mm. However, compared with the current study, which measured anterior displacement of the tibia relative to the femur with a 134-N force, they measured anterior displacement at 89 N; it is unknown whether larger differences may have been observed at 134 N. Further, the 95% LOA for left-right differences reported by Sernert et al 22 were similar to their absolute measurement error for the left (2.6 mm) and right (3.4 mm) knees. Thus, the greater left-right difference they observed may partly reflect greater measurement error compared with the current study. With the exception of Sernert et al,[22] none of the other aforementioned studies have reported measurement errors along with their data, so it is difficult to determine the extent to which differences in measurement reliability may have affected the differences in the magnitude of the left-right differences they observed.

A strength of the current study is that we compared left-right differences with what would be expected simply because of test-retest measurement error, on the basis of data acquired from the same examiner. When considering measurements taken on the left and right sides, it is expected that at least some of this difference may be related to measurement error. This is because many anatomic measurements require accurate identification of bony landmarks, with the examiner changing position and hand placements from one side to the other. Hence, it is not realistic to think that the magnitude of the left-right difference is completely attributable to true differences. By comparing our data with the expected measurement error, we could be 68% and 95% confident that true left-right differences were present if they exceeded one and two standard deviations of the absolute measurement error, respectively. This was not the case for limb-length measures. Although leg-length inequalities are thought to be prevalent in the adult population, there is little agreement as to how much of a difference is clinically meaningful, and the accuracy and usefulness of clinical measurement methods in identifying these differences have been questioned.[30] Our results reinforce these concerns in that somewhere between 5% and 32% of the subjects had left-right differences in leg length that exceeded 1.0 cm. Although these differences are in line with two reviews summarizing the findings on the prevalence of leg-length inequalities,[30,31] we cannot conclude from our data whether these differences represent true asymmetries.

In summary, there remains a need for large-scale retrospective and prospective study designs to clarify the relationship between lower-limb anatomic characteristics and knee injury risk. Designs of this type are time intensive, and the magnitude of data generated can be overwhelming. Therefore, it is prudent to gain a good understanding of the variability in the measures (in regard to both true physiological differences as well as those attributable to measurement error) to ensure the most efficient and valid collection of the risk factors of interest. Our findings reveal that in more than 32% of the cases for pelvic angle, tibial torsion, and navicular drop, and in 5% to 32% of the cases for hip anteversion, standing and supine quadriceps angle, tibiofemoral angle, anterior knee laxity, genu recurvatum, and femur length, the left side could not be substituted for the right side, because left-right differences well exceeded the measurement error. On the basis of these findings, we recommend that both extremities be measured when these variables are included in preseason screenings and prospective study designs, to ensure valid comparison. However, depending on the research question, clinical judgment may dictate whether the left-right difference observed is large enough to have clinical meaning and, therefore, whether bilateral measurements are warranted. In cases where measurement error is greater than or equal to the expected left-right difference (eg, leg-length measures), there would seem to be little value in measuring both sides. Hence, clinicians and researchers should carefully consider both the measurement accuracy of the examiner and the magnitude of the expected difference when deciding whether one or both sides should be measured in prospective studies, and whether the uninjured limb can serve as an appropriate surrogate for the injured limb.

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