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Innominate asymmetry and lower limb static alignment in adult females

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Pelvic alignment is recognized as the cornerstone of overall skeletal alignment. Yet, there is lack of knowledge that supports the functional chain effect of different pelvic alignment on the lower extremities. The purpose of the study was to compare the lower limb's static alignment (anteversion angle, quadriceps angle, and navicular drop) bilaterally and between groups of different pelvic alignments. Fifty females with different pelvic alignments in the sagittal plane participated in the study. They were assigned into two groups; group (1) with anterior innominate rotation and group (2) control. Mixed design MANOVA revealed that the mean values of the right anteversion angle and the right quadriceps angle were significantly higher ($p<0.05$) in females with anterior innominate rotation compared with the control group but there was a non-significant difference in the mean values of navicular drop between groups ($p>0.05$). Moreover, the mean values of the anteversion angle and the quadriceps angle of the right side were significantly higher than the left side in the anterior innominate rotation group while the difference observed between the two tested sides of the control group was not statistically significant. Alteration in the sagittal plane pelvic alignment is a predictor for changes in proximal lower extremity alignment. Additionally, bilateral symmetry of the lower extremities should not always be assumed in healthy adult females.

Keywords: Pelvic asymmetry, anterior innominate rotation, Lower Limb Static Alignment, Functional chain, Bilateral asymmetry.

INTRODUCTION

Human body is recognized as a kinetic chain. The kinetic chain refers to the link system of the body, in which the links are made up of a series of joints that connect bones to one another, with articulation of the joints provided by muscle action. The body consists of three main support structures; the neck and shoulders, the trunk, and the pelvis, hips and knees. Forces are transmitted between the links of this chain in such a way that problems arising in one system can affect other systems (Schamberger W., 2002).

Postural problems may originate in any part of the body and cause increased stresses and strains throughout the musculoskeletal system. Kendall et al., (2005) stated that deviation from normal alignment of one or two body segments causes changes in other segments and increases the amount of energy required to maintain erect standing posture. Evaluators of posture need to identify the deviation and determine the cause of the deviation.

Pelvic alignment is recognized as the cornerstone of overall skeletal alignment. Proper or neutral pelvic alignment allows for efficient execution of movement and effective muscle recruitment [2]. The influence of proximal stability on lower extremity structure and pathology remains largely unknown. Bouisset, (1991) initially proposed that stabilization of the pelvis and trunk is necessary for all movements of the extremities.

One asymmetry that can be commonly associated with disturbed stress patterns, is unequal innominate bone inclination in the sagittal plane (Levangie & Norkin, 2011). Pelvic asymmetry (PA) is a common phenomenon which is often described in association with various pathological processes affecting the locomotor system. It is not only associated with pathology, but it can also be observed in healthy individuals with no evidence of any dysfunction. Since PA is observed in such a large percentage of healthy individuals, it is probably more appropriate to perceive it as a physiological phenomenon which is associated with, for example, absorption of routine mechanical load exerted on the lumbo-pelvic-hip complex (Krawiec et al., 2003).

Performance of a static examination on the lower extremity is critical in order to comprehend and predict an individual's dynamic movements of the lower extremity during functional activities and before injury. Therefore, the main goal of the current study was to compare the lower limb's static alignment (LLSA) bilaterally and between groups of females with different pelvic alignments in the sagittal plane. The LLSA was assessed by measuring the anteversion angle, quadriceps angle (Q-angle), and navicular drop of both sides in the two tested groups.

MATERIALS AND METHODS

Design

This study involved a cross sectional design in which each participant was assessed at one time. Participants were assigned into an experimental (Exp) group and control group, according to the degree of pelvic inclination in the sagittal plane.

Participants

Fifty females volunteered to participate in this study. Their mean ± SD age, body mass, and height were 21.8 ± 4.3 years, 55.7 ± 10.2 kg and 1.62 ± 0.04 m respectively. They were assigned into two equal groups of 25 (Exp. and control). The Exp. group included participants with a symmetrical pelvis with bilateral difference greater than one degree (anterior innominate rotation). The control group involved participants with neutral pelvis (pelvic tilt less than or equal to six degrees) and symmetrical pelvis (bilateral difference less than or equal to one degree).

Participants were excluded from the study if they had any previous history that would affect the alignment or the motion of lower extremity joints such as fractures, surgery, significant joint laxity or instability. Participants were also excluded if they had fixed deformity or low back / sacroiliac joint pain, and true leg length discrepancy. The LLSA were measured for all participants in both groups by the same examiner.

Instrumentations

The PALM inclinometer (Performance Attainment Associates, Saint Paul, MN, USA) was used for measuring the pelvic angle and static innominate rotation of ipsilateral anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). The baseline standard goniometer stainless steel model (Baseline evaluation instrument 12-1028, USA) was used for assessing the femoral anteversion angle and the Q-angle. The straight edge ruler was used for assessing the navicular drop.

Procedure

Before starting the procedures, a pilot study was conducted to determine the appropriate sample size. Power analysis was done at a significance level of 5% and a test power of 80% using G-power. It was revealed that a minimum of 18 participants for each group were required and the total required sample size was 36. In the current study, the total assessed number of participants was 75. Then, 25 participants, who didn't meet the inclusion criteria, were excluded from the study. Only fifty participants met the inclusion criteria and completed the study. This sample size achieved 93% power of significance. Prior to the clinical assessment, the nature of the study, aims, and procedures were explained to each participant to be familiar with the study. All participants provided written consent.

Pelvic angle was measured from a bilateral stance while the participant was standing and bearing equal weight on both lower limbs using a modified technique described by Gilliam et al., (1994). The participant's anterior thigh was snug against a table while she was looking at a fixed point at the wall in front to reduce postural sway. The inferior prominence of the ASIS and the most prominent portion of the PSIS were palpated, and the tips of the inclinometer were placed on these landmarks (Figure 1).

Figure (1): **Measurement of pelvic tilt angle using PALM inclinometer**

The angle formed by a line from the ASIS to the PSIS relative to the horizontal plane was measured with the inclinometer (Performance Attainment Associates, St Paul, MN) on both sides. The difference in innominate rotation between the right and left sides was calculated by subtracting the left side mean from the right side mean. This method of measurements has a high intra-tester reliability (ICC = 0.77 -0.99) (Shultz et al., 2006).

Lower limb static alignment assessment

The femoral neck anteversion (FNA) was measured using the Craig's test. With participant lying prone, the knee was flexed to 90 degrees. The examiner palpated the greater trochanter while passively rotating the hip until the most prominent part of the greater trochanter reached its most lateral position**.** The angle between the true vertical (vertical axis from the table) and the shaft of the tibia (line drawn from the tibial tuberosity to the bisection of the medial and lateral malleolus) was measured using the standard goniometer (Figure 2 a).This method of measurement has been reported to have an interclass correlation co-efficient (ICC) of 0.77 to 0.97 for intra-tester reliability (Shultz et al., 2006).

The Q-angle was measured in the frontal plane from a standing position as the angle between a line passing from ASIS to the center of the patella and another line from the patellar center to the tibial tuberosity using the standard goniometer. The central axis of the goniometer was placed over the center of the patella. Then, the proximal tibia was palpated and the lower goniometer arm (movable arm) was aligned along the patellar tendon to the tibial tubercle. The upper arm of the goniometer (stationary arm) was pointed directly at the ASIS (Figure 2 b).Using a standard goniometer in measuring Q-angle has a high reported intra-tester reliability (ICC = 0.89 – 0.98) (Shultz et al., 2006).

The navicular drop indicates the amount of foot pronation. Subtalar joint pronation, when measured in a weight bearing (WB) position, is a combination of calcaneal eversion with adduction and plantar flexion of the talus (Reichert, 2011). Navicular tuberosity was defined by tracking the tibialis posterior tendon in the distal direction. Navicular drop was determined as the difference in height of the navicular tuberosity from the floor during sitting and standing. Navicular drop was calculated as the difference between the two measurements in millimeter (mm) (McKeon & Hertel, 2009). An initial measurement was taken while the participant seated with her knees and hips at 90° angles, both feet were on the floor, un-weighted, and in subtalar neutral position. The un weighted navicular position is the distance from the floor to the marked point on the navicular tuberosity measured using a straight edge ruler. The participant was then asked to stand and to keep equal pressure on both feet while the measurement was repeated(Figure 2 c).

(a

(b)

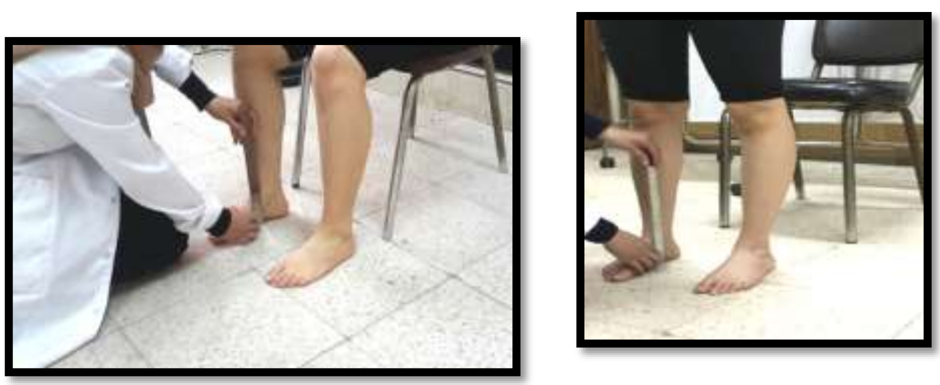

Figure (2): (a) Measurement of FNA by Craig's test using baseline standard goniometer. (b) Measurement of Q-angle from standing using baseline standard goniometer. (c) Measurement of navicular height using straight edge ruler.

Outcome

Values of the right and left anteversion angle, Q-angle, and navicular drop were the measured outcomes of the current study obtained by the standard goniometer and straight edge ruler. For each outcome, a mean of three trials was taken.

Statistical analysis

All statistical measures were performed using the Statistical Package for Social Sciences(SPSS) version 20.Data exploration was done to assess normality. This was conducted through assessing for the presence of significant Kolmogorov-Smirnov and Shapiro-Wilks normality tests in addition to the presence of skewness and kurtosis and extreme scores .Once data were found not to violate the normality assumption, parametric analysis was used. Two-way Mixed Design MANOVA was used to differentiate between the tested groups and the tested sides. Multiple pairwise comparison tests with subsequent Bonferroni adjustment to alpha level were conducted afterwards to detect the source of significance for each of the dependent variables. The alpha level was set at 0.05.

RESULTS

Results revealed that the right anteversion angle and Q-angle were significantly higher in participants with anterior innominate rotation than with the control group ($p<0.05$). On the other hand, there was no statistically significant difference in the mean values of left anteversion angle and Q-angle between groups ($p>0.05$). Additionally, there was no statistically significant difference in the mean values of the right and left navicular drop between groups ($p>0.05$).

Moreover, the mean values of right anteversion angle and Q-angle were significantly higher than the left side in participants with anterior innominate rotation ($p<0.05$) but there was no statistically significant difference in the mean values of navicular drop between the two tested sides ($p>0.05$). However ,the difference observedin the mean values of the measured alignment between the two tested sides of the control group was not statistically significant ($p>0.05$) as represented in tables1, 2, and 3.

Table 1. Descriptive statistics and multiple pairwise comparison tests of the anteversion angle between the two tested sides in both tested groups

Anteversion angle Mean ± SD (in degrees)			
EXP group		**Control group**	
Rt=16.03±3.29	Lt=13.53±3.95	Rt =13.15±3.10	Lt =13.03±2.74
Multiple Pairwise Comparison tests			
EXP Vs CNT		Rt	P= 0.007*
		Lt	P= 1.000
Rt Vs Lt		EXP	P = 0.000*
		CNT	P = 0.791

***Significant at alpha level < 0.05**

Table 2. Descriptive statistics and multiple pairwise comparison tests of the Q-angle between the two tested sides in both tested groups

Q-angle Mean ± SD (in degrees)			
Exp group		**Control group**	
Rt=15.61±3.98	Lt=13.53±4.13	Rt =12.92±2.13	Lt =12.73±1.58
Multiple Pairwise Comparison tests			
Exp Vs control		Rt	P= 0.008*
		Lt	P= 1.000
Rt VS Lt		Exp	P = 0.000*
		Control	P = 0.63

***Significant at alpha level < 0.05.**

Table 3. Descriptive statistics and multiple pairwise comparison tests of the navicular drop between the two tested sides in both tested groups

Navicular drop Mean ± SD (in mm)			
Exp group		**Control group**	
Rt=0.63±0.28	Lt=0.66±0.32	Rt =0.62±0.31	Lt =0.64±0.34
Multiple Pairwise Comparison tests			
Exp Vs control		Rt	P= 1.000
		Lt	P= 1.000
Rt Vs Lt		Exp	P = 0.706
		Control	P = 0.753

DISCUSSION

The significant increase in the anteversion angle of the right side of the anterior innominate rotation group is suggested to have resulted from the right anterior presentation of most of the participants in this study. It is suggested that anterior tilt of the innominate rotates the acetabulum antero-inferiorly on the anterior femoral head, which pushes the femur into internal rotation (Nguyen & Shultz, 2009).One-sided malposition of innominate have the tendency to be connected and coupled with internal rotation of the hip joint (Duvalet al., 2010). This was based on a previous study which reports that an anterior tilt of one innominate results in changing the orientation of the acetabulum, causing the femur to internally rotate on the pelvis (Deleo et al., 2004). The findings of the present study are confirmed by those reported by Bagwell et al. (2016). On the other hand, the findings are contradictory with those reported by Nguyen and Shultz (2007) whom reported that femoral anteversion was not related to the other anatomic alignment characteristics. These contradictions might be due to different tested population (as they assessed both males and females). Additionally, those researchers measured lower extremity alignment in subjects with a pelvic inclination angle ranges (from -1 to 17 degrees) which means that some individuals had symmetrical pelvis with anterior and posterior tilt.

Regarding the Q-angle, it is suggested that when the Q-angle is measured in a weight-bearing position, greater anterior tilt of the innominate would change the spatial orientation of the anatomical landmarks. The patella would displace medially and the tibial tuberosity would displace laterally increasing the Q-angle (Levangie & Norkin, 2011).

The findings of the current study are confirmed by those reported by Nguyen and Shultz (2007) who found a strong positive relationship among greater anterior pelvic angle, quadriceps angle, and tibiofemoral angle (relative valgus alignment).However, the results of current study are contradictory with the findings reported by Nguyen et al., (2009).Those authors reported that increased anterior tilt of the pelvis would result in rotational changes in the femur and tibia displacing the patella medially and the tibial tuberosity laterally, which do not seem to be sufficient to alter the frontal plane landmarks used in the measurement of Q-angle. The controversy difference between the findings of the previous study and the current study may result from different tested population. Those authors assessed the lower extremity alignment in healthy males and females without identifying the degree or the type of pelvic inclination.

Concerning the navicular drop, the results of the current study showed a non-significant difference in the mean values of navicular drop between groups. It is suggested that pelvic angle was independent of a pronated alignment factor (Nguyen & Shultz, 2009). Hertle et al., (2004) suggested that increased anterior innominate tilt is associated with increased anteversion and hip internal rotation, it contributes to a compensatory increase in knee external rotation. Because of the tight fit of the talus into the ankle joint mortise, transverse plane motion of the talus (subtalar joint supination) must accompanies the lower leg external rotation. So, with internal rotation of the femur, the tibia undergoes external rotation, and the subtalar joint is reoriented so that the calcaneus is passively forced into further inversion on weight-bearing (Schamberger, 2002).

The findings of present study were confirmed by the findings reported by Nguyen and Shultz (2009) who studied relationships among lower extremity alignment characteristics. On the other hand, the findings of present study are contradicted with those reported by Kamis and Yizhar (2007). Their main outcome was that an anterior pelvic tilt occurring simultaneously with induced calcaneal eversion, through a mediating effect of the shank. The researchers used wedges to induce hyperpronation then measured changes in pelvic alignment and lower extremities using computerized motion analysis system. It should be noted that exposing normal subjects to induced hyperpronation emphasizes the immediate effect on normal inter-segmental relationship and not necessarily a prolonged adaptive effect.

Regarding the difference between the two tested sides, the findings of the current study reported a difference between the two tested sides in the control group but this difference was not significant. Minor bilateral differences in the mean values of LLSA could be explained as a result of normal variation or minor errors in measurement. For example, any bilateral difference in the Q- angle has to necessarily be due to a relative alteration of the three bony points used to measure it. This variability can then be attributed due to a relative alteration in the positions of the center of the patella and the tibial tuberosity (Messier et al., 1997). Also, 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 (Shultz and Nguyen, 2007). These findings are supported by those of Messier et al. (1997) who studied etiologic factors associated with patellofemoral pain.

On the other hand, the findings of the present study are in disagreement with a study on Nigerian adults by Jaiyesimi and Jegede (2009) which revealed a significant contralateral difference of Q-angles in both males and females, recommending the documentation of both right and left angles in the clinics and research reports. These contradictions might be attributed to different tested sample as values for different population could not be applicable for the Egyptian population.

Presenters of the present study revealed that the mean values of the anteversion angle and the Q-angle of the right side were significantly higher than the left side in the anterior innominate rotation group. The observed increase in the mean values of the right limb is because of the right anterior presentation (right innominate is tilted more anterior than the left innominate) found in most of the participants. As a result of a one-sided dysfunction, a cause and effect chain, appears in that lower extremity (the same side of malaligned pelvis). Schamberger (2002) stated that the asymmetrical orientation of the lower extremities seen with the malaligned pelvis is one of the major factors contributing to the asymmetry of lower limb biomechanical function. As a consequence of anterior rotation of the right innominate bone, the origin and the insertion of the gluteal muscles are separated. This position lengthens and weakens the gluteal muscles resulting in greater hip internal rotation and increases the anteversion angle (Gnat and Saulicz, 2008). Also, Anterior rotation of the innominate approximates the rectus femoris origin and insertion, inhibiting muscle spindle firing and thereby decreasing tension and hence the strength of the contraction that the muscle can produce. Vastus medialis could be affected secondarily because of its connection with rectus femoris thus increasing the Q-angle (Schamberger, 2002). Findings of the current study are in disagreement with those of Raveendranath et al., (2011) who measured Q-angle while the participant was in supine position. Participants in their study had symmetrical pelvis.

CONCLUSION

. It can be concluded that alteration in the sagittal plane pelvic alignment is a predictor for changes in proximal lower extremity alignment. Additionally, bilateral lower extremity symmetry should not always be assumed in healthy adult females.

Future researches about the effect of pelvic alignment on dynamic posture using 2D or 3D motion analysis are needed to cover the gap in this area.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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University Human Ethics Committee approved this study. Participants gave written informed consent before data collection began.

AUTHOR CONTRIBUTIONS

Noha Khaled Shoukry: wrote the manuscript and conducted the practical part, Abeer Farag Hanafy: conducted the statistical part, Ahmed Atteya Ashour: reviewed the manuscript, Ahmed Salama Yamany: reviewed the manuscript), Naglaa Mohamed Elhafez: reviewed the manuscript, Salam Mohamed Elhafez: reviewed the manuscript. All authors read and approved the final version

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