Sex differences in the pattern of innominate motion during passive hip abduction and external rotation

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\textbf{A B S T R A C T}

The objective of the study was to evaluate sex differences in the pattern of innominate motion about the sacroiliac joint (SIJ) during hip movement. Although the magnitude of intrinsic SIJ motion is influenced by joint congruence and ligament elasticity sex differences in pelvic joint kinematics are under-investigated. Forty healthy and active males and females between the ages of 18 and 35 were recruited. 3D motion of the innominate bones and femur were recorded with a magnetic tracking device as the hips were loaded in standardised increments of 10° in 3 positions – external rotation (ER), abduction (AB), and combined external rotation and abduction (AB + ER). While females had greater overall innominate motion, two distinct sex dominant patterns emerged. Patterns of innominate motion also differed when load was applied to the dominant rather than non-dominant limb. As the main motion within the pelvis is intrinsic, the results of the present study point to a differing viscoelastic response and different movement strategies to passive load between the sexes. In addition, careful attention to limb dominance should be considered when testing SIJ motion.

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1. Introduction

The amount of passive motion that develops at a joint can be influenced by intrinsic factors such as articular shape, congruence, and capsular and ligamentous laxity. Due to the requirements of pregnancy and childbirth, the female pelvic joints (both SIJ’s and symphysis pubis) are thought to be more lax than their male counterparts (MacLennan et al., 1986; Kristiansson et al., 1996). However, differences in the pelvic joints of males and females extend beyond the hormonal influences. Vleeming et al. (1990) determined that the articular surfaces of the female sacroiliac joint (SIJ) are smoother than the male SIJ and have a lower coefficient of friction, allowing the surfaces to slide more easily on one another. Furthermore, the articular surfaces of the female SIJ are shorter and more angled than the male SIJ (Brunner et al., 1991). Thus, there are inherent sex differences in pelvic joint kinematics. While research has shown that the range of motion between males and females is significantly different (Sturesson, 1997) no research could be found that investigated sex differences in the pattern of motion through successive incremental hip displacements.

There is a strong link between the mobility of the hip/pelvis and low back pain (LBP), and studies have shown that participants with LBP also tend to have significant bilateral differences in the magnitude of internal to external rotation of the hip (Friberg, 1983; Offierski and White, 1983; Mellin, 1988; Barbee-Ellison et al., 1990; Chesworth et al., 1994; Combatto et al., 2006). Further, there are differences in the range of lateral rotation of the hip between male and female LBP sufferers (Combatto et al., 2006). As asymmetry of hip abduction and external rotation was previously reported in patients with inflammation of the sacroiliac joints (LeBan et al., 1978) Cibulka et al. (1998) investigated the association between LBP and SIJ involvement to determine whether there was a distinguishable difference in hip motion symmetry. They found that patients without SIJ involvement showed greater external and reduced internal hip rotation in both left and right sides whereas those with SIJ involvement had greater hip external rotation than internal rotation, on only one side (Cibulka et al., 1998).

The purpose of the present study was to determine whether sex differences exist in motion of the left and right innominate bones when one hip is incrementally moved into increasing amounts of axial rotation, abduction, or a combination of axial rotation and abduction. Based on the background research, we hypothesized that (i) women would have greater overall innominate range of
motion (ROM); (ii) innominate motion would increase with hip rotation but patterns would differ between males and females; and (iii) that there would be no bilateral asymmetry within each sex.

2. Methods

2.1. Subjects

Forty healthy and active subjects between the ages of 18 and 35 volunteered for this study approved by the University of Otago Human Ethics Committee. Subjects were 21 females (25.0 ± 3.1 yrs) with a mean BMI of 20.7 ± 2.0 kg/m² and 19 males (23.3 ± 4.3 yrs) with a mean BMI of 22.5 ± 2.7 kg/m². All subjects participated in an average of 8.9 h (± 4.1) of vigorous activity per week. At the time of data collection, they were all free from hip or low back disorders and gave informed consent for their participation. This study incorporated a randomized block design of three load conditions with subjects allocated to three random-order blocks ([1 2 3], [2 3 1], [3 1 2]), such that all subjects completed all conditions, but in a different order.

2.2. Procedure

Kinematic data were collected with a magnetic tracking device\(^3\), consisting of a transmitter, four receivers, a digitizer and a systems electronics unit. Measurement error of the system in the x, y and z coordinates of each of the 4 pelvic points was 0.02 mm (SD 0.84 mm) on the x-axis, 0.07 mm (SD 0.82 mm) on the y-axis and -0.03 (SD 0.99 mm) on the z-axis. The global average value of imprecision in the measurement of a point for intra-observer reliability was 0.80 mm (SD 1.47 mm). A global coordinate system was established by mounting the transmitter to a rigid wooden support. The receivers were mounted to thermoplastic frames and secured firmly to the thighs and over the S1 spinous process with double-sided tape and Velcro\(^\circ\) support straps. An anatomically relevant reference system for identifying the hip joint centre was defined with a predicative method based on each subject’s pelvic and lower limb anthropometrics (Bush and Gutowski, 2003).

A hip rotation frame (as described in Bussey et al., 2009) was used to standardize the rotational increments applied to the femurs in three anatomical hip positions: external rotation - ER, abduction – AB, and a combination of external rotation and abduction called ER + AB. By standardizing the femur rotation we were capable of standardizing the external load applied to the innominate, although the internal load may vary due to individual anatomical differences in muscle and ligament stiffness. A maximum of six incremental rotations (10° each) for both ER and AB were used, for each participant.

A palpation and digitizing technique known to accurately and reliably measure innominate motion (Bussey et al., 2009) was used to calculate motion of the innominate bones in reference to their initial static positions. This technique required the palpation and digitizing (using the tracking stylus) of the anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS) at each incremental rotation. Each palpated landmark was digitized several times in the reference position (hip at 0°); the leg was passively rotated in 10° increments and the procedure repeated. The results of the measurement test-retest reliability analysis conducted for the present study are in Table 1. The motion of the innominate in the sagittal and transverse planes of the pelvis reference system was calculated as angular displacement between the reference position and each subsequent 10° hip rotation (of ER, AB and ER + AB) (Bussey et al., 2009).

2.3. Kinematics

Using anatomically relevant local coordinate axes derived from digitized bony landmarks data were reduced using standard matrix transformations to determine the rotational matrix of the femur with respect to the pelvis and the pelvis with respect to the lumbar spine.

Innominate bone motion was defined by the angular displacement of the innominate bones from a neutral position. Sagittal plane motion was calculated as a composite angle between innominate rotating about the sagittal-horizontal axis of the pelvis (described in Bussey et al., 2009). Transverse plane motion was calculated as absolute displacement of left and right bones individually about the vertical axis. For this calculation the innominate on the same side as the hip being moved is referred to as loaded while the innominate on the contralateral (fixed) side referred to as unloaded. Thus SJ motion is described in three angles of innominate movement, Loaded, Unloaded (in the transverse plane) and Sagittal (in the sagittal plane).

2.4. Data analysis

Data reduction was undertaken with a purpose-written Matlab\(^0^4\) routine and analysis consisted of computations of the mean and standard deviation of the innominate bone and hip range of motion measured across all participants for each trial. To evaluate the patterns of innominate motion between males and females we described each participant’s innominate angles as a function of hip rotation. Each participant’s data were evaluated to determine the best polynomial fit (either a first or second order).

All statistical analyses were performed in SAS v9 (SAS Institute, Cary NC). The non-independent data of this repeated measures design were accommodated using linear mixed models (Fitzmaurice et al., 2004). The outcome variables were the three innominate angles: loaded, unloaded, and sagittal. We considered the following factors in our models: hip position (ER, AB and ER + AB); side (left, right); sex (male, female) and incremental rotations (six 10° steps). Exploratory analyses accepted these rotations as continuous variables with good data fit allowing computation of linear models. Random coefficient models were used with intercept and rotation as effects, allowing each participant’s angles to have their own linear trajectory as a function of rotation. We began with full models including all interactions, and used backwards selection to choose a final model. Estimates of sex differences were then calculated from these models. To avoid type I errors we used a cutoff value of α = 0.01 for interaction terms.

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\(^{3}\) Polhemus 3Space Fastrack\(^\circ\), 40 Hercules Drive, P.O. Box 560, Colchester, VT 05446.

\(^{4}\) The MathWorks, Inc., Natick, MA.
3. Results

The means and standard deviations of the mean maximal innominate and passive hip range of motion in each position of ER, ABD and ABER are presented in Table 2. Mean hip rotation ranged from 10° to 53° of ER and 9.8° to 56° of ABD. Both sexes were capable of greater ROM in the ABER condition with abduction ranging from 10° to 58° and external rotation ranging from 50° to 75°. Further, while we made every effort to limit the amount of coupled rotation of the hip using the standardization frame, there was still some evidence of coupled rotation. For example, ER was coupled with hip flexion (maximal 9°), and ABD was coupled with some ER of the hip (maximal 15°). We consider this motion coupling is inevitable to allow for maximal ROM without physiological disruption at the joint.

We evaluated each individual’s innominate motion as a function of hip rotation to determine whether the pattern was best estimated as linear (first order polynomial) or non-linear (second order polynomial). Overall the first order polynomial was the most reasonable fit to the raw data, as shown in Fig. 1. From this analysis, we made several generalizations, which may be observed in Fig. 1: first, it is clear from the positive slopes of the linear line estimates for ER and ABD that innominate angles increase with hip rotation but do not in the ER + AB position. Second, for all hip positions mean sagittal innominate angles were greater then loaded and unloaded angles for both sexes. Third, that for all hip positions the female line estimates for both loaded and sagittal are above the males, suggesting that females have greater mean innominate angles than males. Finally, that there is little difference between males and females in unloaded innominate angles.

Some of our observations were confirmed as statistically interesting by the linear mixed model. First, it was apparent that the slopes of the lines for the loaded angles are statistically significantly different between the sexes (Table 3). Female loaded angles appear to increase at a greater rate than males. From Fig. 1 it appeared that magnitudes of sagittal innominate angles are greater for women, however, the slope estimates were not statistically distinguishable from the males (Table 3). This means that while females may have greater initial sagittal angles, the rate at which their angles increase is no different from the rate of increase in males. Yet our statistical analysis revealed a sex by side interaction effect, which says that there is a difference in sagittal angles between males and females but it is dependent upon the side (Table 3).

Upon further investigation, we found that females had larger sagittal angles on the left and males had larger sagittal angles on the right (Table 2). It appeared that male and female innominate bones responded differently depending on which hip was under load. The women tended to experience larger loaded angles coupled with smaller sagittal angles when the right leg was stressed but larger sagittal angles coupled with smaller loaded angles when the left leg was stressed (Table 2). In males, load applied to the right leg resulted in greater sagittal angles but made no difference in loaded angles (Table 2).

In order to explore the nature of the difference(s) in innominate bone motion between males and females we compared the direction of the load side (same side as the stressed limb) and non-load side (contralateral to stressed limb) innominate bones. Firstly, we isolated the sagittal angle or rotation about the sagittal-horizontal axis. Both males and females displayed similar patterns of motion about the sagittal-horizontal axis in that the innominate bones were found to rotate reciprocally, rotating in opposite directions about the axis (Fig. 2B) under load. However, when the motion about the vertical axis was isolated, it appeared the males and females had different strategies for achieving maximal rotation. In almost all hip positions and on both sides, males experienced reciprocal rotation about the vertical axis, where, for example, when the left hip was stressed the left (loaded) innominate experienced counter clockwise rotation and the right (unloaded) innominate experienced clockwise rotation about the vertical axis (Fig. 2A). Conversely, in maximal hip positions, females experienced a unilateral rotation of the innominate bones about the vertical axis, particularly on the right side, where both the loaded and unloaded innominate bones rotated in a clockwise direction about the axis (Fig. 2A).

4. Discussion

Our results support the hypothesis that women have a greater overall innominate ROM and are in agreement with Sturesson and colleagues who found that male SIJ ROM was 30–40% less than female SIJ ROM (Sturesson and Uden, 1989; Sturesson, 1997; Sturesson et al., 2000a, 2000b). However, these researchers never postulated as to why males and females differed in SIJ ROM. In the present study, the methods we used cannot explain the disparity in ROM between sexes since both males and females were placed in the same position with the pelvis unloaded in a neutral posture, and both groups were stressed with the same magnitude and direction of external force. The only way that the method would have influenced the outcome was if the structural differences in the pelvis and hip gave one group a mechanical advantage over the other. Due to the passive nature of the study, we assume that muscle activity cannot account for changes in joint stiffness. Therefore, the results of the present study point to differing viscoelastic responses in the pelvic ring between sexes.

Based on the understanding that males and females differ in SIJ geometry and possible ligament elasticity (Vleeming et al, 1990;...
Bechtel, 1998), we hypothesized that applying a passive load to the hip in the same manner, would result in different patterns of motion between sexes. Indeed, we found that females experienced a greater rate of increase in the loaded innominate motion, which suggests females and males differ in their viscoelastic response to load directed about the vertical axis. Further, the female SIJ appear to be less stiff about the sagittal-horizontal axis as females had slightly greater initial sagittal angles but similar sagittal slope estimates as males. Thus, females experience a greater range of motion initially but after the initial rotation, the rate of change in innominate angle is the same as in males, and viscoelastic responses do not differ when load is directed about the sagittal-horizontal axis. Therefore, it appears that a more likely explanation for the sex disparity is the combination of differing articular surface geometry (Bechtel, 1998) and viscoelastic behaviour resulting in differing responses to the standardised load applied in the present research.

There also appears to be a great deal of individual variation in the pattern of motion of the innominate bones as load increased. The deformation about the vertical axis was expected to be characterized by both the loaded and unloaded innominate bones moving unilaterally in the direction of applied load since it was hypothesized in a previous study (Bussey, 2004) that this pattern was most likely to reduce the dislocation torque on the pubic symphysis when placed under large deformation load. However, the pattern of innominate motion tended to be sex-dependent. Females tended to experience external and posterior rotation of the load side innominate bone accompanied by internal and neutral or anterior rotation of the unloaded side innominate bone (namely a unilateral pattern of motion about vertical axis and a reciprocal pattern about the sagittal-

### Table 3

<table>
<thead>
<tr>
<th></th>
<th>Sex</th>
<th>mean</th>
<th>95% CI for the difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loaded (degrees)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1.63</td>
<td>(0.093, 0.60)</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Unloaded (degrees)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1.24</td>
<td>(-0.12, 0.29)</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em><em>Sagittal</em> (degrees)</em>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female left</td>
<td>3.08</td>
<td>(0.26, 1.72)</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>Male left</td>
<td>2.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female right</td>
<td>2.31</td>
<td>(-0.88, 0.57)</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Male right</td>
<td>2.47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p-value for sex × side interaction < 0.0001.

Fig. 1. Male and female pelvic displacement angles displayed as a linear function of hip rotation for each of the ER, AB and ER + AB positions. Note only 50° of rotation are shown to standardize the graphs because not all positions had participants who reached 60° of rotation.
horizontal axis). Males, on the other hand, tended to experience external and posterior rotation of the load side innominate bone accompanied by external and anterior rotation of the unloaded side innominate bone (thus a reciprocal pattern about both the vertical and sagittal-horizontal axes). We feel that the unilateral pattern of the female innominate allowed them greater end range of motion about the vertical axis by reducing the stress on the pubic symphysis.

Previous research has suggested that bilateral asymmetry in hip external rotation and abduction is associated with LBP (Barbee-Ellison et al., 1990; Chesworth et al., 1994; Gombatto et al., 2006). Therefore, we did not expect bilateral asymmetry to occur within this healthy population. Indeed, the present study found no significant differences in hip range of motion between left and right sides. However, there were some bilateral effects in the innominate range of motion. In female’s passive rotation of the right limb led to a greater innominate ROM about the vertical axis, whereas rotation of the left limb led to a greater innominate ROM about the sagittal-horizontal axis. Males displayed a slightly different pattern under right limb rotation having greater innominate ROM about the sagittal-horizontal axis. These findings point to differing dominant axes for each innominate but further differing dominant axes according to sex.

The idea that there might be a different dominant axis for each innominate bone has previously been proposed (Lavignolle et al., 1983; Plochocki, 2002) but has not been demonstrated. The motion of the innominate bones is unique within the body, as they are connected in a three link closed kinetic chain, where motion about one axis occurs in conjunction with/or at the expense of motion about another axis. For this reason, some researchers have used a dominant three-dimensional axis (a helical axis) to describe the motion of the innominate bones (Sturesson and Uden, 1989; Jacob and Kissling, 1995). However, while helical axes are probably a more superior way to describe the 3D rotation of the innominate bones, they also require greater precision in measurement and are more difficult to interpret clinically.

5. Conclusions

Males and females appear to have different load transfer patterns across the pelvic ring, although further research is required to explore their significance in low back and pelvic pain and injury. Asymmetry in innominate bone motion occurs when passively displacing either the dominant or non-dominant leg, at least in these healthy individuals. Further, these findings suggest that clinicians should at least recognise limb dominance when testing SIJ mobility and specifically before labelling a joint dysfunctional due to hypo- or hyper-mobility. Further research on LBP patients is required to determine if and how the pattern of innominate motion is affected by pain and how the patterns of innominate motion relate to the motion of the hip in injured individuals.

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