Variation in Pelvic Morphology May Prevent the Identification of Anterior Pelvic Tilt

STEPHEN J. PREECE, PhD¹, PETER WILLAN, PhD², CHRIS J. NESTER, PhD³, PHILIP GRAHAM-SMITH, PhD⁴, LEE HERRINGTON, MSc⁵, PETER BOWKER, PhD⁶

BACKGROUND

The angle of pelvic tilt in quiet standing describes the orientation of the pelvis in the sagittal plane. It is determined by the muscular and ligamentous forces that act between the pelvis and adjacent segments. A forward rotation of the pelvis, referred to as anterior pelvic tilt, is accompanied by an increase in lumbar lordosis and is believed to be associated with a number of common musculoskeletal conditions, including low back pain and anterior cruciate ligament deficiency. In addition, anterior pelvic tilt has been associated with a loss of core stability, and therefore the degree of pelvic tilt has been used to assess core strength.

A standard method of assessing the angle of pelvic tilt is depicted in Figure 1, which illustrates the angle between the horizontal and a line drawn from the anterior superior iliac spine (ASIS) to the posterior superior iliac spine (PSIS). Although this angle is determined by the balance of muscular and ligamentous forces that act between the pelvis and adjacent segments, it is also dependent on the relative position of the two bony landmarks (ASIS and PSIS) on the innominate bone. Therefore, the use of the ASIS-PSIS angle as a measure of pelvic tilt is in fact a combined measure of 1) the balance of muscular/ligamentous force and 2) pelvic morphology.

Anterior pelvic tilt and increased lumbar lordosis have been suggested to increase loading on the lumbar spine. As such, exercise programs are often prescribed to reduce anterior pelvic tilt. If the decision as to what constitutes anterior pelvic tilt is to be determined from palpation of the ASIS and PSIS, then it is important to understand the influence of pelvic morphology on the ASIS-PSIS angle. If this angle is significantly influenced by morphological variation, then it may not be possible to correctly identify anterior pelvic tilt.

A number of previous research studies have used the ASIS-PSIS angle to investigate differences in pelvic orientation between sufferers of pathology and healthy control subjects. In order to correctly interpret the findings of these

ABSTRACT: Pelvic tilt is often quantified using the angle between the horizontal and a line connecting the anterior superior iliac spine (ASIS) and the posterior superior iliac spine (PSIS). Although this angle is determined by the balance of muscular and ligamentous forces acting between the pelvis and adjacent segments, it could also be influenced by variations in pelvic morphology. The primary objective of this anatomical study was to establish how such variation may affect the ASIS-PSIS measure of pelvic tilt. In addition, we also investigated how variability in pelvic landmarks may influence measures of innominate rotational asymmetry and measures of pelvic height. Thirty cadaver pelves were used for the study. Each specimen was positioned in a fixed anatomical reference position and the angle between the ASIS and PSIS measured bilaterally. In addition, side-to-side differences in the height of the innominate bone were recorded. The study found a range of values for the ASIS-PSIS of 0–23 degrees, with a mean of 13 and standard deviation of 5 degrees. Asymmetry of pelvic landmarks resulted in side-to-side differences of up to 11 degrees in ASIS-PSIS tilt and 16 millimeters in innominate height. These results suggest that variations in pelvic morphology may significantly influence measures of pelvic tilt and innominate rotational asymmetry.

KEYWORDS: Pelvic Bones, Pelvic Tilt, Pelvimetry, Posture.

¹Research Fellow, Centre for Rehabilitation and Human Performance, University of Salford, Manchester, UK. ²Professor of Human Anatomy, Human Anatomy, University of Manchester, Manchester, UK. ³Senior Research Fellow, Centre for Rehabilitation and Human Performance Research, University of Salford, Manchester, UK. ⁴Lecturer in Sports Science, Centre for Rehabilitation and Human Performance Research, University of Salford, Manchester, UK. ⁵Lecturer in Sports Rehabilitation, Centre for Rehabilitation and Human Performance Research, University of Salford, Manchester, UK. ⁶Professor of Rehabilitation Research, Centre for Rehabilitation and Human Performance Research, University of Salford, Manchester, UK.

This work was supported by an EPSRC grant (UK), reference number GR/SS9710/01

Address all correspondence and requests for reprints to: Stephen J. Preece, s.preece@salford.ac.uk
studies, it is important to examine how much variability in the ASIS-PSIS angle might be attributable to differences in pelvic morphology. Too much variability has the potential to both weaken possible correlations and to hide true differences between subject groups.

As well as a measure of pelvic orientation, the side-to-side difference in ASIS-PSIS angles has been used to assess innominate rotational asymmetry. Given that there may be side-to-side differences in the relative position of these two bony landmarks on the two innominate bones, this measure may prevent the correct identification of innominate rotational asymmetry. Again, if decisions for clinical management are to be made based on the finding of rotational asymmetry, it is important to understand the potential influence of morphological variability. In a research setting, such variability has the potential to mask true relationships between rotational asymmetry and other clinical measures, such as leg length discrepancy.

There is a need to understand the influence of pelvic morphology on measures of pelvic orientation and on innominate rotational asymmetry. Therefore, a cadaver study was designed with three primary aims. The first was to investigate the variability in the ASIS-PSIS angle across a number of pelvis positioned in a fixed anatomical reference position. The second aim was to quantify side-to-side differences in the ASIS-PSIS angle, again across a range of pelvis in a fixed reference position. Finally, in order to compare with in vivo studies of pelvic asymmetry, we aimed to investigate the variability in pelvic asymmetry, quantified from side-to-side differences in pelvic height.

**Methods**

Thirty bony pelvises (20 male/10 female) were studied in the dissecting rooms at the University of Manchester, which were licensed for such study by the Human Tissue Authority (and before 2007 by licensing arrangements through H M Inspector of Anatomy). Each pelvis was positioned in the anatomical neutral position suggested by Kendall and McCreary in that both ASISs are aligned horizontally and the pubic symphysis and ASISs are in the same vertical plane.

Sinnatamby proposed an alternative pelvic anatomical neutral position to the method used by Kendall and McCreary. This is defined as the position in which the ischial spine and the pubic symphysis are in the same horizontal plane (Figure 1). We were interested in the influence of pelvic morphology on pelvic tilt; therefore, the angle between the horizontal and a line from the ischial spine to the pubic symphysis was measured for each pelvis positioned as described above. This measurement was obtained by placing a steel rule in contact with these two landmarks and then positioning the palmeter along the length of the rule. Again, measurements were taken from both the left and right sides of each pelvis. Measurements taken on five specimens, repeated after a week, gave an intra-tester reliability coefficient of ICC = 0.977 with a SEM = 1.1 degrees.

In order to answer our second research aim, the side-to-side difference between the ASIS-PSIS angle was calculated for each pelvis. In addition, as we were interested in the influence of morphology on pelvic asymmetry, we also used the side-to-side difference in the ischial spine-pubic symphysis angle to quantify pelvic asymmetry. In order to answer the final research aim, relating to pelvic asymmetry, the side-to-side difference in height of the left and right innominate bone was obtained. This was defined as the distance between the bottom of the ischial tuberosity and the top of the iliac crest. The palmeter was also used to measure this distance by positioning the arms in contact with the appropriate points on the pelvis and reading the measured distance. Measures were repeated after one week and intratester reliability coefficients calculated. These were found to be ICC = 0.94 with a SEM = 1.9 mm. This final measure of pelvic asymmetry was chosen as it allowed comparison with previously published data.

**Results**

With the pelvis fixed in the standard reference position, the ASIS-PSIS angle (calculated as the mean of both sides) was found to vary from 0 to 23 degrees...
with a mean of 13 degrees and standard deviation of 5 degrees. A Kolmogorov-Smirnov (K-S) test showed that the data were distributed normally. Analysis of the ischial spine-pubic symphysis angle gave a similar range of values (4 to 26 degrees) with a mean of 14 and standard deviation of 5 degrees. Again, a K-S test showed this variable to be normally distributed. The ASIS-PSIS measures for each specimen are given in Table 1 and the distribution of this angle shown with a histogram in Figure 3.

Although it has been suggested that the ASIS-PSIS angle in female pelves may be larger than that in male pelves11, an unpaired t-test showed there to be no significant difference in this angle (95% CI -2.8 degrees to 5.4 degrees). Similarly, with the ischial spine-pubic symphysis angle, there was also no significant difference in gender among the specimens (95% CI -2.3 degrees to 5.8 degrees).

The side-to-side differences in the ASIS-PSIS angle, taken as the difference between the left and right ASIS-PSIS angle, ranged from -6 degrees (left more anteriorly tilted) to 5 degrees (right more anteriorly tilted) with a mean of -1 degrees and standard deviation of 2 degrees. This result demonstrates that, on average, the location of the ASISs and PSISs was such that there appeared to be a relative anterior rotation of the left innominate bone relative to the right although the large range and standard deviation shows there was considerable variation between specimens (Table 1). This variation is clearly illustrated in the histogram of the side-to-side differences, shown in Figure 4. A similar variation was obtained using the ischial spine-pubic symphysis measure of tilt, which displayed a range of -3 degrees to 5 degrees and mean of 1 degree and standard deviation of 2 degrees. In con-

### TABLE 1

Left and right ASIS-PSIS angles, side-to-side differences, and mean angles for every specimen used in the study.

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Sex</th>
<th>ASIS - PSIS angle (right)</th>
<th>ASIS - PSIS angle (left)</th>
<th>Side-to-side difference</th>
<th>Mean ASIS - PSIS angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>f</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>f</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>f</td>
<td>8</td>
<td>9</td>
<td>-1</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>f</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>f</td>
<td>12</td>
<td>14</td>
<td>-2</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>m</td>
<td>14</td>
<td>13</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>m</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>m</td>
<td>15</td>
<td>21</td>
<td>-6</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>m</td>
<td>9</td>
<td>12</td>
<td>-3</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>m</td>
<td>15</td>
<td>16</td>
<td>-1</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>m</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>m</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>13</td>
<td>m</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>m</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>15</td>
<td>f</td>
<td>20</td>
<td>21</td>
<td>-1</td>
<td>21</td>
</tr>
<tr>
<td>16</td>
<td>m</td>
<td>20</td>
<td>21</td>
<td>-1</td>
<td>21</td>
</tr>
<tr>
<td>17</td>
<td>m</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>18</td>
<td>m</td>
<td>18</td>
<td>21</td>
<td>-3</td>
<td>20</td>
</tr>
<tr>
<td>19</td>
<td>m</td>
<td>13</td>
<td>17</td>
<td>-4</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>f</td>
<td>14</td>
<td>16</td>
<td>-2</td>
<td>15</td>
</tr>
<tr>
<td>21</td>
<td>m</td>
<td>12</td>
<td>14</td>
<td>-2</td>
<td>13</td>
</tr>
<tr>
<td>22</td>
<td>f</td>
<td>8</td>
<td>10</td>
<td>-2</td>
<td>9</td>
</tr>
<tr>
<td>23</td>
<td>f</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>m</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>m</td>
<td>5</td>
<td>7</td>
<td>-2</td>
<td>6</td>
</tr>
<tr>
<td>26</td>
<td>m</td>
<td>16</td>
<td>17</td>
<td>-1</td>
<td>17</td>
</tr>
<tr>
<td>27</td>
<td>f</td>
<td>20</td>
<td>19</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>28</td>
<td>m</td>
<td>23</td>
<td>22</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>29</td>
<td>m</td>
<td>9</td>
<td>11</td>
<td>-2</td>
<td>10</td>
</tr>
<tr>
<td>30</td>
<td>m</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

FIGURE 3. Histogram to show the distribution of the ASIS-PSIS angle across all the specimens. The left and right values have been considered separately for this representation of the data.

FIGURE 4. A similar variation was obtained using the ischial spine-pubic symphysis measure of tilt, which displayed a range of -3 degrees to 5 degrees and mean of 1 degree and standard deviation of 2 degrees. In con-

---

**TABLE 1.** Left and right ASIS-PSIS angles, side-to-side differences, and mean angles for every specimen used in the study.
measure the angle between the horizon
researchers used an inclinometer to
degrees in a cohort of 15 low back pain
jects and Levine and Whittle
ample, Kroll et al
ported with
30 pelves, values similar to those re
ASIS-PSIS angle of 23 degrees across the
investigation showed a range in the
ASIS-PSIS angle was measured in 30
cal reference position. The results of this
measurement again demonstrates the
large variability in asymmetry across the
different specimens.

Discussion

The first primary aim of this study was
to establish whether pelvic morphology
may significantly influence measures of
pelvic orientation. Following this aim,
the ASIS-PSIS angle was measured in 30
cadaver specimens fixed in an anatomical
reference position. The results of this
investigation showed a range in the
ASIS-PSIS angle of 23 degrees across the
30 pelves, values similar to those re
ported with in vivo studies\textsuperscript{1,12,13}. For ex-
ample, Kroll et al\textsuperscript{12} reported between 3–22 degrees of tilt in 54 normal sub-
jects and Levine and Whittle\textsuperscript{1} a mean of
11.3 degrees and SD of 4.3 degrees across 20 female subjects. Similarly, Gilliam et
al\textsuperscript{13} obtained a range of between 4–21 degrees in a cohort of 15 low back pain
patients. As with the present study, these
researchers used an inclinometer to
measure the angle between the horizon-
tal and the ASIS-PSIS line. Our findings
also agree with data reported by Deus-
inger\textsuperscript{14}, who measured the ASIS-PSIS
angle in 13 cadaver pelves and found a
variation of between –9 degrees (poste-
rior tilt) and 12 degrees (anterior tilt),
although it was unclear how he defined
a pelvic anatomical neutral position.

The similar findings to those re-
ported in in vivo studies\textsuperscript{1,12,13} suggest sig-
nificant potential for morphological
variation across pelves that could poten-
tially influence the standard clinical
measurement of pelvic tilt. It is possible
that differences of up to 23 degrees in the
ASIS-PSIS angle could reflect differ-
ces in morphology rather than differ-
ces in muscular and ligamentous
forces acting between the pelvis and ad-
jacent segment. This is best illustrated
using an extreme example. Figure 5
shows two pelves aligned in the standard
reference position, with an ASIS-PSIS
angle in the first specimen of 0 degrees
and in the second of 23 degrees. The ad-
tional finding of similar range (22 de-
grees) in the pubic symphysis-ischial
spine angle gives further support to the
idea that there is considerable morpho-
logical variation between pelves. Again,
this may have a significant influence on
associated measures of tilt.

Given the significant morphologi-
cal variability across different pelves, the
use of the ASIS-PSIS angle to quantify
pelvic tilt may result in weaker correla-
tions between pelvic tilt and other clini-
cal measurements than would be ob-
tained if muscle and ligament forces
could be measured directly. For ex-
ample, it is expected clinically that an in-
crease in lumbar lordosis would be ac-
companied by an increase in anterior
pelvic tilt. As such, a number of research-
ers have attempted to correlate the ASIS-
PSIS angle with a measure of lumbar
lordosis, which can be reliably measured
using a flexible draftman’s curve\textsuperscript{15,16}. Walker et al\textsuperscript{17} investigated this relation-
ship across 31 subjects but they found
only a very weak correlation (r=0.32).
Similar results were obtained by Kroll et
al\textsuperscript{12}, who studied 54 subjects and found a
correlation of r=0.33.

In addition to weakening potential
correlations, the significant variability in
pelvic morphology has the potential to
mask true differences in pelvic tilt be-
tween different groups of subjects. Given
that the standard deviation of the ASIS-
PSIS angle in our study was 5 degrees,
we would suggest that to have a strong
effect size (i.e., Cohen’s $d=0.8$), group
differences in the ASIS-PSIS angle
should be at least 4 degrees. This should
ensure that differences in the ASIS-PSIS
angle between groups reflects any true
differences in the muscular and liga-
mentous forces that act between the pel-
vis and adjacent segment and not just
differences in pelvic morphology.

Bullock-Saxton\textsuperscript{7} compared the
ASIS-PSIS angle between a group of
normal subjects ($n=25$) and a group of
low back pain sufferers ($n=30$) but found
no difference (P<0.05) in this measure-
ment of tilt (no values for the ASIS-PSIS
angle were reported in this paper). One
explanation for this finding could be
that a large variation in pelvic morphol-
ogy masked any differences in tilt. Her-
tel et al\textsuperscript{3} compared the angle of pelvic tilt
between a group of normal subjects
($n=20$) and a group of subjects with a
history of anterior cruciate ligament in-
jury ($n=20$). In contrast to the results of
Bullock-Saxton\textsuperscript{7}, they found a signif-
ificant difference in the angle of tilt with
the normal group having a mean of 1.7
degrees and the ACL group having a
mean of 3.2 degrees. Although this dif-
ference was statistically significant
(P<0.05), within the context of our re-
results, this difference represents only a
small effect size ($d=0.3$).

The second primary aim of this
study was to investigate whether side-
to-side differences in pelvic morphology
could influence clinical measures of in-
nominate rotational asymmetry. To ad-

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{histogram}
\caption{Histogram demonstrating the distribution of the side-to-side
difference in the ASIS-PSIS angle across all specimens. A positive value indicates
that the right side is more anteriorly
tilted than the left.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure_5}
\caption{Different values of ASIS-PSIS tilt. Two different pelves both
positioned in pelvic neutral according to Kendall and McCreary\textsuperscript{9}.}
\end{figure}
dress this aim, the difference between the ASIS-PSIS angle was noted for each specimen when positioned in a symmetric reference orientation. This study found a surprisingly large range in the side-to-side difference of the ASIS-PSIS angle: 11 degrees. This range is similar to the range of values reported in vivo by Krawiec et al. Given this similarity, our data would suggest that morphological variation between pelves will have significant influence on associated clinical measures of innominate rotational asymmetry.

Leg length discrepancy has the potential to cause innominate rotational asymmetry. As such, a correlation would be expected between innominate rotational asymmetry and leg length discrepancy. Krawiec et al investigated this relationship, quantifying asymmetric innominate rotation using the ASIS-PSIS angles but they found only a weak correlation (r=0.33). Again, a possible explanation for these findings is that morphological variation in the positioning of the ASIS and PSIS weakened what, otherwise, might have been a stronger correlation.

Significant pelvic asymmetry, due to variations in pelvic morphology, was also demonstrated using the ischial spine-pubic symphysis angle and the side-to-side difference in pelvic height. This latter finding is in agreement with Badii et al, who used radiographic techniques and defined a measure of innominate asymmetry using the distance from the iliac crest to the acetabuli. Such pelvic asymmetry has the potential to reduce the validity of using the height of the iliac crests as an indirect measure of leg length discrepancy. This was verified in a recent study by Petrone et al, who obtained values of ICC=0.76–0.78 for the validity of using this measure as an indirect estimate of leg length discrepancy.

Clinical Relevance

The ASIS–PSIS angle should not be used in isolation to assess pelvic orientation. Additional factors should also be taken into consideration, such as the depth of the lumbar lordosis and the hip joint angle in standing with neutral knee joint alignment. Assessment of innominate rotational asymmetry using the ASIS-PSIS landmarks must also be viewed with caution.

Conclusion

This study found significant variation in the ASIS-PSIS angle across 30 cadaver pelves all positioned in a fixed anatomical reference position. This variation may significantly influence clinical measures of pelvic tilt and has the potential to weaken any true correlations between tilt and other clinical measurements. The study also showed that significant side-to-side variability in the relative position of the ASIS and PSIS landmarks. Again, this variability has the potential to significantly influence clinical measures of innominate rotational asymmetry.

REFERENCES