Predicting ideal spinopelvic balance in adult spinal deformity

Clinical article

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Object. Spinopevic balance is based on the theory that adjacent segments of the spine are related and inuenced by one another. By understanding the correlation between the thoracolumbar spine and the pelvis, a concept of spinopelvic balance can be applied to adult deformity. The purpose of this study was to develop a mathematical relationship between the pelvis and spine and apply it to a population of adults who had undergone spine deformity surgery to determine whether patients in spinopelvic balance have improved health measures.

Methods. Using values published in the literature, a mathematical relationship between the spine and pelvis was derived where pelvic incidence (PI) was divided by the sum of the lumbosacral lordosis (LL; T12–S1) plus the main thoracic kyphosis (TK; T4–T12). The result was termed the spinopelvic constant (r): r = PI/(LL + TK). This was performed in patients in 2 age groups previously defined in the literature as “adult” (18–60 years of age) and “geriatric” (> 60 years). The equation was then constructed to relate an individual’s measured PI to his or her predicted thoracolumbar curvature (LL + TK), based on the age-specific spinopelvic constant: (LL + TK)r = r/PI. A retrospective review was then performed using cases involving patients who had undergone spine deformity surgery and were enrolled in our spinal deformity database. Sagittal balance, PI, and the sum of the main thoracic and lumbar curves were measured. The difference between the predicted sum of the regional curves (LL + TK)p, based on the individual’s measured PI and the age-specific spinopelvic constant, and the measured sum of the regional curves (LL + TK)m was then calculated to determine the degree of spinopelvic imbalance. Health status measures were then compared.

Results. Using the formula r = PI/(TK = LL) and normative values in the literature, the adult spinopelvic constant was calculated to be –2.57, and the geriatric constant –5.45. For the second portion of the study, 41 patients met inclusion criteria (13 classified as nongeriatric adults and 28 as geriatric patients). Application of these constants found a statistically significant decline in almost all outcome categories when the spinopelvic balance showed at least 10° of kyphosis more than predicted. While not statistically significant, the trend was that better outcomes were associated with a spinopelvic balance within 0 to +10° of the predicted value. The final analysis compared and separated out patients to be considered in sagittal balance, they must be within ± 10° of predicted spinopelvic balance. Patients in both sagittal and spinopelvic balance have statistically significant better outcomes than those in neither sagittal nor spinopelvic balance. Except for the mean SF-12 PCS (12-Item Short-Form Health Survey Physical Component Summary), there were no significant differences between those that were either in sagittal or spinopelvic balance, but not the other.

Conclusions. Restoring a normative relationship between the spine and the pelvis during adult deformity correction may play an important role in determining surgical outcomes in these patients independent of sagittal balance.

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Key Words • spinopelvic balance • sagittal balance • spinal deformity • thoracic deformity • lumbar deformity

The concept of spinopelvic balance utilizes the theory that the shape and orientation of the adjacent segments of the spine are related to and influenced by one another.1 These segments must orient in a way to achieve balance of the body’s center of gravity over a narrowly constrained range. The pelvis, with its static morphology, serves as the base of the spine and articulates with it through the sacrum and sacroiliac joints. The morphology of the pelvis determines the position of the sacrum. The mobile spine adapts to the sacral position, adjusting the degree of curvature to achieve a mechanically efficient posture.2 Since pelvic morphology is constant or at least relatively static after adolescence for each individual, the morphology of the pelvis can be considered the foundation on which the rest of the spine derives its sagittal orientation. In a normal, asymptomatic state, a balance occurs between the spine and the pelvis; spinopelvic balance. This term was first introduced by Vaz et al.,3 as a means of describing the relationship between pelvic morphology and the curvature of the spine.

Radiographically, pelvic morphology is best described through measuring the pelvic incidence (PI). The
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PI is defined as the angle from a line perpendicular to the midpoint of the sacral endplate and a line connecting this point to the center of the femoral heads. First described by Duval-Beaupère et al., PI is an individualized posture-independent measurement of pelvic morphology.\(^3\) PI is also equal to the sum of the sacral slope and the pelvic tilt, 2 posture-dependent measurements used to describe pelvic orientation.

Multiple studies have shown a strong correlation between PI and lumbar lordosis in nonpathological states.\(^1\),\(^9\),\(^11\) While predicting ideal lumbar lordosis is important, broadening the concept to include the thoracic spine in an adult spinal deformity population is important since these patients often have constructs that are carried into the thoracic spine to stabilize the deformity and achieve sagittal balance. By understanding the relationship between this thoracolumbar spinal unit and pelvic morphology, a concept of spinopelvic balance can be applied to adult spinal deformity.

The purpose of this study was 2-fold: 1) to develop an age-related spinopelvic constant that can be used to preoperatively understand and plan for an appropriate relationship between the pelvis and the spine; and 2) to apply this spinopelvic constant to a postoperative adult spinal deformity population to determine whether postoperative patients in spinopelvic balance have improved health status.

Methods

Using normative values published by Kuntz et al.\(^6\) a mathematical relationship between the spine and pelvis was derived by the author. The mean PI was divided by the sum of mean total lumbosacral lordosis (LL) in degrees (T12–S1) plus the main thoracic kyphosis (TK) in degrees (T4–12). The result was termed the spinopelvic constant (r): 

\[
 r = \frac{\text{PI}}{\text{LL} + \text{TK}}
\]

By deriving a spinopelvic constant, relative instead of absolute values could be used to correlate pelvic morphology and the sagittal curvature of the spine. Avoiding absolute values was felt to better represent the compensatory nature of the spine. This was performed in patients from 2 age groups, defined as “adult” (18–60 years of age) and “geriatric” (> 60 years). This age division was chosen to coincide with age groupings found in the literature. The same mathematical equation could then be arranged to relate the PI to the sum of the thoracolumbar curves: 

\[
 (\text{LL} + \text{TK}) \sim \text{PI} / r
\]

A review of a separate database containing standing lateral scoliosis radiographs obtained in asymptomatic individuals who were younger than 40 years of age and who had no spinal deformity was then conducted in an attempt to correlate the values calculated from the literature to those measured. This review yielded 12 radiographs (8 obtained in men, 4 in women) that allowed the visualization of both femoral heads and the occiput. The average age was 29.9 years (range 24–39 years). The average PI was +54° and the average sum of the TK and LL (+41° plus −62°) was −21°. Dividing the PI by the sum of the regional curves (+54°/−21°) resulted in a spinopelvic constant (r) of −2.57 for the nongeriatric adult population. For the geriatric population, the average PI was +60° and the sum of the TK and LL (+49° plus −60°) was −11°. Dividing the PI by the sum of the regional curves (+60°/−11°) resulted in a spinopelvic constant (r) of −5.45 for the geriatric population. With an individual’s measured PI and the age-specific spinopelvic constant, the formula (LL + TK) = PI/r is used to calculate an ideal thoracolumbar curvature that is balanced to the pelvis.

Radiographic Results

For the second portion of the study, 41 consecutively reviewed patients (29 women and 12 men) who met inclu-
sion criteria were included in the study. The average duration of follow-up was 0.99 years (range 0.12–3.09 years), representing the time period between surgery and when the latest clinical outcome measures and radiographic results were obtained. The average age was 61.71 years (range 32.2–80 years). There were 13 patients in the non-geriatric adult classification (age 18–60 years) and 28 patients in the geriatric classification (> 60 years).

Six patients underwent fusions from the upper lumbar spine (L1–3) to the sacrum, one of whom had pelvic fixation. Twenty patients underwent instrumentation from the lower thoracic spine (T10–12) to the sacrum, of which 18 had pelvic fixation. Ten patients had instrumentation placed from the upper thoracic spine (T2–5) to the sacrum. All of these patients had pelvic fixation. The remaining 5 patients had various thoracolumbar instrumentations that did not extend to the sacrum or pelvis.

The overall postoperative average PI was 50.62° (range 27.2° to 74.2°). The overall postoperative average PT was 22.95° (range 1.5° to 45.5°). In the non-geriatric adult population, the average PI was 50.71° (range 34.3° to 65.9°), while in the geriatric population it was 50.56° (range 27.2° to 74.2°). The average PT in the nongeriatric adult population was 21.56° (range 4.9° to 41.3°), while in the geriatric population it was 23.6° (range 1.5° to 45.5°). The overall postoperative average sagittal balance was +25.32 mm (range -102.3 to +132.4 mm). In the nongeriatric adult population, the average sagittal balance was +33.38 mm (range -37.6 to 92.4 mm), while in the geriatric population it was +21.59 mm (range -102.3 to +132.4 mm). The overall postoperative average spinopelvic imbalance was +8.05° (range -23.33° to +32.23°). In the nongeriatric adult population, the average spinopelvic imbalance was +4.08° (range -23.33° to +25.01°), while in the geriatric population it was +10.1° (range -11.13° to 32.23°).

**Postoperative Health Status**

For postoperative health status, the SRS-30 total score, ODI score, and SF-12 PCS score were evaluated. The first measurement evaluated was PT. Using the values from the literature, a normal PT for the adult population was 13° (± 3°) and for the elderly population was 18° (± 3°). Overall, 8 (19.5%) of the 41 patients had postoperative PT measurements that were considered normal for their age group. Two (15.3%) of the 13 adult patients and 6 (21.4%) of the 28 geriatric patients had a normal PT. When evaluating postoperative PT measurements with postoperative health status, the population was divided into those with a normal age-specific PT (8 patients) and those with an abnormal age-specific PT (33 patients). There were no significant differences in mean SRS score (normal 3.85, abnormal 3.53, p = 0.08), ODI score (normal 21.66, abnormal 31.75, p = 0.14), or SF-12 PCS (normal 40, abnormal 37.04, p = 0.51) health status measures.

For evaluation of these outcome measures in terms of sagittal balance, the population was broken down into 5 categories: 1) < -25 mm (4 patients), 2) -25 to 0 mm (3 patients), 3) 0 to +25 mm (13 patients), 4) > +25 to +50 mm (10 patients), and 5) > +50 mm (11 patients). The categories were chosen in an attempt to conform to literature standards and to group similar data in a small patient population. There were no significant differences in mean SRS or SF-12 PCS health status measures across the sagittal balance groups (p = 0.071 for SRS, Fig. 1A; p = 0.069 for SF-12 PCS, Fig. 1C; Table 1). There was a significant difference in mean ODI score across the sagittal balance groups (p < 0.001; Fig. 1B). However, when comparing outcomes for the first 4 individual categories to outcomes in patients who had a sagittal balance greater than 50 mm, there was a statistically significant difference seen across all outcome measures except in the 0 to +25 mm and +25 to +50 mm groups with respect to SF-12 PCS scores, in the > +25 to +50 mm groups with respect to the SRS total score, and in the < -25 mm group with respect to ODI.
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<table>
<thead>
<tr>
<th>Sagittal Balance</th>
<th>SRS</th>
<th>p Value</th>
<th>ODI</th>
<th>p Value</th>
<th>SF-12</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; -25 mm</td>
<td>3.93 ± 0.26</td>
<td>0.0241</td>
<td>21.0 ± 9.61</td>
<td>0.053</td>
<td>43.33 ± 3.27</td>
<td>0.0101</td>
</tr>
<tr>
<td>&lt; -25 to 0 mm</td>
<td>3.87 ± 0.19</td>
<td>0.0122</td>
<td>13.87 ± 1.94</td>
<td>&lt;0.0001</td>
<td>43.03 ± 3.51</td>
<td>0.0143</td>
</tr>
<tr>
<td>0 to +25 mm</td>
<td>3.77 ± 0.18</td>
<td>0.0287</td>
<td>25.79 ± 4.61</td>
<td>0.0245</td>
<td>39.44 ± 3.72</td>
<td>0.0752</td>
</tr>
<tr>
<td>&gt; +25 to +50 mm</td>
<td>3.61 ± 0.17</td>
<td>0.088</td>
<td>27.80 ± 4.88</td>
<td>0.0485</td>
<td>36.94 ± 3.03</td>
<td>0.1440</td>
</tr>
<tr>
<td>&gt; +50 mm</td>
<td>3.17 ± 0.19</td>
<td>NA</td>
<td>43.82 ± 6.14</td>
<td>NA</td>
<td>29.80 ± 3.66</td>
<td>NA</td>
</tr>
</tbody>
</table>

* Mean values and SEs are given for the SRS total score, ODI overall score, and SF-12 PCS score. The p values are for comparison with the > +50 mm group. Abbreviation: NA = not applicable.

These findings likely represent a continuum where outcomes were best when a person’s sagittal balance was between −25 and +25 mm and as sagittal balance became more positive, outcomes were worse.

For evaluation of spinopelvic balance, the population was broken down into 4 categories: 1) < −10° (8 patients), 2) −10° to 0° (12 patients), 3) 0° to +10° (10 patients), and 4) > +10° (11 patients). The categories were chosen to achieve approximately equal numbers in each group given the lack of a literature standard in which to go by. There were significant differences in mean total SRS scores, mean ODI score, and mean SF-12 PCS score across all categories (p = 0.003, p = 0.005, and p < 0.001, respectively; Fig. 2). Comparison of postoperative health status showed a statistically significant difference in almost all outcomes categories when the spinopelvic balance was 10° of kyphosis more than predicted. While not statistically significant, the trend was that better health status measurements were associated with a spinopelvic balance 0° to +10° from the predicted balance (Table 2).

The final analysis performed was to separate sagittal balance from spinopelvic balance and compare outcome measures with respect to these 2 variables. For a patient to be considered in sagittal balance, he or she must be ± 50 mm from neutral. For a patient to be considered in spinopelvic balance, he or she must be ± 10° from the predicted spinopelvic balance. Four categories were compared: 1) in sagittal and spinopelvic balance (17 patients), 2) in sagittal balance but not in spinopelvic balance (11 patients), 3) in spinopelvic balance but not in sagittal balance (5 patients), and 4) in neither sagittal nor spinopelvic balance (8 patients). There were significant differences in mean SRS, mean ODI overall score, and mean SF-12 PCS score across all categories (p = 0.014, p = 0.003, and p < 0.001, respectively; Fig. 3). According to the results of this analysis, patients who are in both sagittal and spinopelvic balance have statistically significant better health status measurements than those who are in neither sagittal nor spinopelvic balance. Except for the mean SF-12 PCS score, there were no significant differences between patients who were either in sagittal or spinopelvic balance, but not the other (Table 3).

**Illustrative Cases**

**Case 1—Patient in Sagittal and Spinopelvic Balance**

This 57-year-old woman underwent a T4–pelvis pos-
terior spinal fusion with multilevel Smith-Petersen osteotomies (Fig. 4). Her PI was 45°. Postoperatively, her sagittal balance was +3.4 cm. Using the adult spinopelvic constant, the predicted sum of her TK + LL (PI/r = 45°/−2.57) should be −17.5°. The actual measured sum of her TK + LL was −25.1°, resulting in a spinopelvic imbalance (actual − predicted = −25.1° − (−17.5°)) of −7.6°. This patient is in both sagittal and spinopelvic balance.

Case 2—Patient in Sagittal but not Spinopelvic Balance

This 63-year-old woman underwent a T11–pelvis posterior spinal fusion with multilevel Smith-Petersen osteotomies (Fig. 5). Her PI was 55.2°. Postoperatively, her sagittal balance was +1.33 cm. Using the geriatric spinopelvic constant, the predicted sum of her TK and LL (PI/r = 55.2°/−5.41) should be −10.2°. The actual measured sum of her TK and LL was +4.5°, resulting in a spinopelvic imbalance (actual − predicted = +4.5° − (−10.2°)) of +14.7°. This patient is in sagittal balance but not in spinopelvic balance.

Case 3—Patient in Spinopelvic but not Sagittal Balance

This 61-year-old man underwent a T4–pelvis posterior spinal instrumentation with pedicle subtraction osteotomies at T-10 and L-2 (Fig. 6). His PI was 36.3°. Postoperatively, his sagittal balance was +13.2 cm. Using the geriatric spinopelvic constant, the predicted sum of his TK and LL (PI/r = 36.3°/−5.41) should be −6.8°. The actual measured sum of his TK and LL was +1.9°, resulting in a spinopelvic imbalance (actual − predicted = +1.9° − (−6.8°)) of +8.7°. This patient is in spinopelvic balance but not in sagittal balance.

Case 4—Patient in Neither Spinopelvic nor Sagittal Balance

This 57-year-old woman underwent an L1–S1 posterior spinal fusion with multilevel Smith-Petersen osteotomies (Fig. 7). Her PI was 50.1°. Postoperatively, her sagittal balance was +6.8 cm. Using the adult spinopelvic constant, the predicted sum of her TK and LL (PI/r = 50.1°/−2.57) should be −19.5°. The actual measured sum of her TK and LL was +4.2°, resulting in a spinopelvic imbalance (actual − predicted = +4.2° − (−19.5°)) of +23.7°. This patient therefore is in neither spinopelvic nor sagittal balance.

**Discussion**

In this study, we have used normal values from the literature to derive a mathematical relationship between the morphological characteristics of the pelvis and the

<table>
<thead>
<tr>
<th>Spinopelvic Balance</th>
<th>SRS</th>
<th>p Value</th>
<th>ODI</th>
<th>p Value</th>
<th>SF-12</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; −10°</td>
<td>3.68 ± 0.17</td>
<td>0.018</td>
<td>28.70 ± 6.85</td>
<td>0.0663</td>
<td>38.14 ± 4.61</td>
<td>0.0708</td>
</tr>
<tr>
<td>−10° to 0°</td>
<td>3.57 ± 0.22</td>
<td>0.1255</td>
<td>25.94 ± 5.76</td>
<td>0.0139</td>
<td>38.56 ± 3.53</td>
<td>0.0176</td>
</tr>
<tr>
<td>0° to +10°</td>
<td>3.98 ± 0.20</td>
<td>0.0009</td>
<td>20.60 ± 5.80</td>
<td>0.0018</td>
<td>47.67 ± 2.03</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>&gt; +10°</td>
<td>3.2 ± 0.09</td>
<td>NA</td>
<td>43.09 ± 3.31</td>
<td>NA</td>
<td>29.26 ± 1.09</td>
<td>NA</td>
</tr>
</tbody>
</table>

* The p values are for comparison with the > +10° group.

**Fig. 3.** Bar graphs showing the mean SRS, ODI, and SF-12 scores relative to sagittal and spinopelvic balance. All 3 graphs show improved scores for patients in both sagittal and spinopelvic balance compared with patients who are in neither. With the exception of the SF-12 measurement, there was no difference between those patient in either sagittal or spinopelvic balance. Nml = normal; Sag Bal = sagittal balance; SPB = spinopelvic balance.
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<table>
<thead>
<tr>
<th>Category</th>
<th>SRS p Value</th>
<th>ODI p Value</th>
<th>SF-12 p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>nml SPB &amp; sag bal</td>
<td>3.84 ± 0.15</td>
<td>22.19 ± 3.77</td>
<td>41.61 ± 2.67</td>
</tr>
<tr>
<td>no SPB, nml sag bal</td>
<td>3.55 ± 0.14</td>
<td>30.15 ± 4.66</td>
<td>35.88 ± 2.95</td>
</tr>
<tr>
<td>nml SPB, no sag bal</td>
<td>3.48 ± 0.45</td>
<td>28.00 ± 13.29</td>
<td>49.05 ± 0.85</td>
</tr>
<tr>
<td>no SPB, no sag bal</td>
<td>3.19 ± 0.12</td>
<td>46.50 ± 4.55</td>
<td>28.69 ± 2.79</td>
</tr>
</tbody>
</table>

* The p values are for comparison to the group in both spinopelvic and sagittal balance ("nml SPB & sag bal"). There was a statistically significant difference in health status measurements between the group in both sagittal and spinopelvic balance and the group in neither. Abbreviations: nml SPB = normal spinopelvic balance; sag bal = sagittal balance.

Thoracolumbar spine: the spinopelvic constant. By using the formula \((LL + TK) = PI/r\) to determine the ideal predicted sum of the thoracolumbar curves and subtracting this value from the measured sum of the thoracolumbar curves, we can determine the degree of spinopelvic imbalance. Applying postoperative health status measurements to the degree of spinopelvic imbalance, we found that there is significant improvement in these health status measurements when a patient is within ±10° of their ideal spinopelvic balance. When correlating this with sagittal balance, the data suggest that spinopelvic balance may play a synergistic role with sagittal balance in optimizing the postoperative health status of adult patients who undergo surgery for spinal deformity.

Sagittal balance has been shown to be the single most important factor affecting outcome for adults undergoing spinal deformity surgery. Global sagittal plane correction is most reliably calculated using the tangent function as described by Ondra et al. This technique allows the conversion of the distance of correction needed to an angle that can be used to determine the size of the osteotomies required. On most radiology systems, this can easily be performed by drawing a C-7 plumb line and a sagittal vertical line from the posterior sacral promontory to the center of the C-7 vertebral body. This angle represents the overall degree of sagittal plane correction needed for the patient to be in sagittal balance. Once this angle is known, preoperative planning of osteotomies can then be performed. Placing osteotomies more caudally has a greater effect on sagittal balance as opposed to more cephalad placement. The goal is to place the appropriate type, size, and number of osteotomies so that sagittal plane alignment can occur.

While clinically effective, one of the shortcomings of the sagittal balance concept is that it does not address how balance should be achieved. The end result of how the C-7 plumb line falls in relationship to the sacrum is obtained within the framework that there should be a “normal” amount of lordosis in the lumbar spine and kyphosis within the thoracic spine. Cumulative normal values and ranges, while beneficial, do not address the specific needs of the individual. This challenge was addressed by Kim et al. in a study to determine the ideal lumbar lordosis in adult spinal deformity patients who underwent thoracolumbar fusion to either L-5 or S-1. They concluded that statistically significant risk factors for suboptimal sagittal balance included a greater than 45° difference from the sum of the PI and TK compared with the LL, and less than a 20° difference between TK and LL.

This is where the concept of spinopelvic balance impacts adult spinal deformity surgery. Spinopelvic balance is not the same as sagittal balance; the latter describes the overall sagittal plane relationship between spine and the pelvis while the former describes how the components of the sagittal plane, the regional curves, affect and relate to each other. One can be achieved without achieving the other. By first understanding the continuum between the spine and the pelvis in healthy, asymptomatic individuals, insight into what is normal can be gained. Quantifying this in terms of relative (not absolute) values makes it possible to then apply the concept to patients with spinal deformities. The constant is the individual’s pelvic morphology, which is best measured through the PT. The mechanics of how the pelvis affects the spine have been described by Vaz et al., who note that the PI is constant and unchanged, while lumbar lordosis, thoracic kyphosis, sacral slope, pelvic tilt, and knee position are all variable. PI, the constant in each individual, dictates the position of the sacrum, which is balanced by the degree of lumbar lordosis, which then impacts the amount of thoracic kyphosis—an open linear chain where the shape and orientation of one segment influence the adjacent segment.

Recently, Schwab et al. reported on the role of the pelvis, particularly the pelvic tilt, in adult patients with spinal deformities. In this paper, the authors acknowledge the role that PI plays in determining the degree of LL and support a formula based on the work of Duval-Beaupère et al., where \(LL = PI + 9^\circ (\pm 9^\circ)\). Pelvic tilt is thought to reflect the pelvic compensation for the presence of spinal deformity. In reviewing 125 cases involving adults (mean age 57 years) with spinal deformity, they found a significant correlation between quality-of-life measures and pelvic tilt. A high pelvic tilt is indicative of pelvic retroversion in an attempt to compensate for sagittal-plane deformity. While pelvic tilt is an important parameter and does correlate with the findings of outcome studies, it should also be remembered that pelvic tilt is a posture-dependent measurement. Thus, its greatest asset—that is, its ability to change and compensate with posture—can make it effort-dependent on the part of the patient. In our study, a normal PT did not correlate with a significant improvement in postoperative health status measures.

The question raised by our study is whether spinopelvic balance is an academic exercise in the asymptomatic patient or whether it has a clinical effect on outcome in the adult spinal deformity patient. In this small study, our results echo those of Glassman et al. in that patients who
Fig. 4. Case 1. Postoperative radiograph showing an example of a patient in both spinopelvic and sagittal balance. The patient had undergone a T4–pelvis posterior spinal fusion with multilevel Smith-Petersen osteotomies. The sagittal balance was +3.4 cm; the spinopelvic imbalance was calculated to be −7.6°.

Fig. 5. Case 2. Postoperative radiograph showing an example of a patient who is in sagittal balance but not in spinopelvic balance. The patient had undergone a T11–pelvis posterior spinal fusion with multilevel Smith-Petersen osteotomies. The sagittal balance was +1.33 cm; the spinopelvic imbalance was calculated to be +14.7°.
Fig. 6. Case 3. Postoperative radiograph showing an example of a patient who is in spinopelvic balance but not in sagittal balance. The patient had undergone a T4–pelvis posterior spinal fusion with pedicle subtraction osteotomies at T-10 and L-2. The sagittal balance was +13.2 cm; the spinopelvic imbalance was calculated to be +8.7°.

Fig. 7. Case 4. Postoperative radiograph showing an example of a patient in neither spinopelvic nor sagittal balance. The patient had undergone an L1–S1 posterior spinal fusion with multilevel Smith-Petersen osteotomies. The sagittal balance was +6.8 cm; the spinopelvic imbalance was calculated to be +23.7°.
have a C-7 plumb line that falls within 50 mm of the posterior sacral promontory have better outcomes than those who have a positive sagittal balance greater than +50 mm. What this study suggests is that patients who have more than 10° of predicted kyphosis within their thoracolumbar spine based on their pelvic morphology have statistically poorer outcomes than those who do not. Furthermore, patients who are in both sagittal and spinopelvic balance have better outcomes than those who are in either one or the other, and significantly better than those who are in neither. Spinopelvic and sagittal balance appear synergistic in achieving better outcomes. In addition to achieving sagittal balance, the surgeon should attempt to achieve regional balance of the thoracic and lumbar spine based on pelvic morphology: spinopelvic balance.

A final aspect of this study is the issue of how to simultaneously apply the concepts of spinopelvic and sagittal balance. In an adult spinal deformity patient, there are many variables that are known. The PI is a constant and does not change from pre- to postoperative measurements unless a sacral osteotomy is performed. The combined preoperative thoracic kyphosis and lumbar lordosis can then be measured: \( (\text{TK} + \text{LL})_\text{pi} \). Using the patient’s PI and the age-specific spinopelvic constant, the formula \( (\text{TK} + \text{LL})_\text{pi} = \text{PI}/r \) is then applied to calculate the ideal sum of the TK and LL. Subtracting the ideal sum of TK and LL from the preoperative measured sum of TK and LL gives the degree of correction needed to achieve spinopelvic balance. If the deformity does not require extension of the correction or instrumentation into one of the spinal regions, then the amount of correction needed to achieve spinopelvic balance can be focused into the other region. This can allow preoperative planning directed at achieving ideal lumbar lordosis and ideal thoracic kyphosis.

Knowing the degree of correction required to achieve spinopelvic balance and whether it should be applied in the lumbar or thoracic spine, one can calculate and then compare these data to the degree of correction that is required to achieve sagittal balance. The degree of correction of sagittal imbalance depends on not only the size of the osteotomy, but also where it is placed along the spine, since the more caudally the osteotomy is placed, the more effect it will have on the position of the C-7 vertebral body. Given that the concept of spinopelvic balance creates a degree of needed correction that is relatively fixed, it therefore makes this variable a constant relative to sagittal balance. The variable then becomes where along the spine in the operative region the degree of correction that achieves spinopelvic balance can be applied to achieve sagittal balance. Knowing that the degrees required to achieve spinopelvic balance may not always correspond to that needed for sagittal balance, the surgeon should opt for achieving sagittal balance over spinopelvic balance, since sagittal balance has proven outcomes over a large patient population.

Another variable to be considered is the effect that performing interbody grafting, such as in ALIF (anterior lumbar interbody fusion), DLIF/XLIF (direct lateral interbody fusion/extreme lateral interbody fusion), or TLIF/PLIF (transforaminal lumbar interbody fusion/posterior lumbar interbody fusion), will have on the creation of lordosis. The impact of osteotomies on sagittal and spinopelvic balance should be taken into consideration before they are performed. These techniques were not specifically considered in our manuscript.

The major weaknesses of this study lie in the use of pooled normative data from the literature as a basis for developing a spinopelvic constant and the size of the study. While a relatively small validation study was carried out and showed results consistent with the constant that was applied, an ideal study would derive a spinopelvic constant that is gender specific at multiple age ranges through a collective database of normal anatomy to ensure consistency of the data. The distinction between “adult” and “geriatric” is arbitrary and based solely on what could be derived from the literature as one of the largest pooled data sources available. Ideally, a large normative population could be established, thereby allowing a linear regression analysis to be performed to better define the relationship of the spine and pelvis over various ages in a continuum. This would allow for a more tailored preoperative plan for the restoration of spinopelvic balance based on the individual’s age and sex. Application of this idea to a larger study group would allow for multiple data points that would better characterize the optimal range that an individual’s deviation from the predicted spinopelvic balance could lie within and still result in acceptable outcomes.

Conclusions

Spinopelvic balance is based on the concept that there exists a normal, harmonious relationship between the pelvis and the spine. Restoring this relationship during adult spinal deformity correction may play an important role in determining the surgical outcomes of these patients, independent of sagittal balance. Spinopelvic balance also provides a valuable check on sagittal alignment decisions. This may affect the surgical decision on osteotomy type and location, as well as how and where correction is achieved along different segments of the spine. Nevertheless, this was a small pilot study, and the results should be confirmed in a larger patient population before generalized conclusions can be made.

Disclosure

Dr. Koski consults for Medtronic and has taught courses for DePuy and Stryker, for which he has received honoraria. Drs. Neal and Ondra are employees of the US government. This work was prepared as part of his official duties, and as such there is no copyright to be transferred. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the US Army, US Navy, or the Department of the Defense.

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