Standing Balance and Sagittal Plane Spinal Deformity
Analysis of Spinopelvic and Gravity Line Parameters

Virginie Lafage, PhD,* Frank Schwab, MD,* Wafa Skalli, PhD,† Nicola Hawkinson, NP,* Pierre-Marie Gagey, MD,‡ Stephen Ondra, MD,§ and Jean-Pierre Farcy, MD*

Study Design. Prospective study of 131 patients and volunteers recruited for an analysis of spinal alignment and gravity line (GL) assessment by force plate analysis.

Objective. To determine relationships between GL, foot position, and spinopelvic landmarks in subjects with varying sagittal alignment. Additionally, the study sought to analyze the role of the pelvis in the maintenance of GL position.

Summary of Background Data. Force plate technology permits analysis of foot position and GL in relation to radiographically obtained landmarks. Previous investigations noted fixed GL-heel relationships across a wide age range despite changes in thoracic kyphosis. The pelvis as balance regulator has not been studied in the setting of sagittal spinal deformity.

Methods. The 131 subjects were grouped by sagittal vertical axis (SVA) offset from the sacrum: sagittal forward (>2.5 cm), neutral (–2.5 cm ≤ SVA ≤ 2.5 cm), and sagittal backward (SVA < –2.5 cm). Simultaneous spinopelvic radiographs and GL measure were obtained. Offsets between spinopelvic landmarks, heel position, and GL were calculated. Group comparisons were made for all offsets to determine significance.

Results. Aside from the offset T9-GL and GL-heels, all other offsets between spinopelvic landmarks and GL revealed significant differences (P < 0.001) across the 3 subject groups. However, with increasing SVA, the GL kept a rather fixed location relative to the feet. A correlation between posterior pelvic shift in relation to the heels with increasing SVA in this study population was confirmed (r = 0.8, P < 0.001).

Conclusion. Increasing SVA in standing subjects leads to a posterior pelvic shift in relation to the feet. However, no significant difference in GL-heel offset is noted with increasing SVA. It thus appears that pelvic shift (in relation to the feet) is an important component in maintaining a rather fixed GL-Heels offset even in the setting of variable SVA and trunk inclination.

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The aging process and deformity of the spinal column can lead to altered sagittal plane alignment. To date, optimal spinal balance remains poorly defined. However, a number of radiographic parameters have been developed as guides of sagittal alignment. Values of thoracic kyphosis by Cobb measurements, and lumbar lordosis are commonly used to assess regional alignment. Global spinal alignment is commonly assessed by a plumbline method drawn onto full-length radiographs. More recently, pelvic parameters have also been examined to improve evaluation of sagittal plane balance. Although ranges of normal values and series of patients with specific pathology such as spondylolisthesis have been published, the correlation between these radiographic parameters and standing balance is not yet fully understood.

Although radiographs permit an evaluation of vertebral alignment and pelvic landmarks, current standard techniques using 36° cassettes do not capture foot position. Analysis of spinal and pelvic offsets from standing foot position can be captured through forceplate analysis; a forceplate device is made of pressure sensors distributed across a level surface and permit detailed analysis of foot position and pressures of a subject that stands on such a platform. Given that a freestanding person must be balanced over a small area between the feet to avoid requiring support (or falling over), it would appear that spinal imbalance or misalignment must lead to compensatory mechanisms to maintain a center of force [gravity line (GL)] in close relation to the feet.

It has been reported that normal global balance in adults by radiographic plumbline falls within a narrow range from the pelvis (sacrum, or S1). Jackson has reported values in asymptomatic adults with a mean sagittal vertical axis [SVA (distance form a plumbline drawn form C7 and the posteriorsuperior corner of S1)] offset of 0.5 cm (SD ± 2.5 cm). According to these data, offset greater than 2.5 cm anteriorly or posteriorly are considered beyond the normal range.

The purpose of this study was to evaluate the impact of SVA offset on pelvic parameters and spinopelvic position relative to the feet in standing subjects. This study also sought to analyze the effects of SVA offset on GL position. Enrollment was limited to adults without significant coronal deformity or imbalance. A hypothesis of this study was that healthy volunteers and patients (even in the setting of marked sagittal plane deformity) maintain a GL within a fixed area relative to the feet. Furthermore, changes in pelvic location (translation and orientation) associated with SVA offset were hypothesized to occur.
Materials and Methods

Patient Selection
This is a prospective, institutional review board approved study including 131 adult volunteers (66 asymptomatic and 65 patients; age range, 18–93 years). Volunteers were recruited through paper advertisement and patients during office consultation. Exclusion criteria included previous spine surgery, frontal deformity (maximal Cobb angle greater than 20 degree or frontal imbalance greater than 5 cm), pregnancy, or history of a neurologic disorder. All subjects had radiographic spinal evaluation in the free-standing position with 36° cassette films. The sagittal vertical axis (SVA), which is the distance between the C7 plumbline and the posterosuperior corner of S1 in the sagittal plane, was used to subdivide the group of subjects (Table 1). According to SVA value, subjects were classified as sagittal backward (SVA > 2.5 cm), neutral (2.5 cm ≤ SVA ≤ 2.5 cm), or sagittal forward (SVA < −2.5 cm), meaning respectively that C7 plumbline falls behind, over, and in front of S1.

Balance Evaluation Protocol
For each subject, forceplate technology and radiologic measurements were combined to evaluate their frontal and sagittal balance. This published protocol is briefly presented hereafter. Subjects were asked to stand on a forceplate in a free-standing position, with elbows flexed at approximately 45 degrees and fingertips on the collar bones. This position was chosen as it has been shown to be a normal relaxed position that does not alter spinal posture and allows radiographic evaluation.

These measurements (Figure 1) aim to evaluate the position of anatomic components (feet, pelvis, and vertebrae) in relation to the GL at a moment in time. Although the subject kept his/her free-standing position, frontal and sagittal full length radiographs were obtained, which included femoral heads and C7 vertebra. Precise GL location at the time of radiographs was extracted from forceplate data based on a time stamp placed during film exposure. As previously reported, these measurements were postprocessed using a Matlab function in order to project the gravity line and the heel line (vertical line drawn from the midpoint between both heels) on each radiograph. This process permitted an analysis of offsets between spinopelvic structures and these 2 lines as described in the Table 2.

Radiologic Measurements
Each radiographic film was digitized through a Vidar scanner (Vidar Systems Corp., Herndon, VA) with 75 dpi resolution and 12 gray levels. Sagittal and frontal spinopelvic parameters were evaluated using Spineview software (Surgiview, Paris, France), a validated computer based tool, which enables quantitative measurements of the spine and pelvis. The spinal sagittal plane (Figure 2) was described by calculating the lumbar lordosis of each subject. The pelvic plane was described by calculating the pelvic incidence.

Table 1. Subjects Distribution Among Groups

<table>
<thead>
<tr>
<th></th>
<th>Sagittal Backward (Sb)</th>
<th>Neutral (N)</th>
<th>Sagittal Forward (SF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>43</td>
<td>51</td>
<td>37</td>
</tr>
<tr>
<td>Mean age ± 1 SD (yr)</td>
<td>35 ± 16</td>
<td>51 ± 18</td>
<td>68 ± 17</td>
</tr>
<tr>
<td>Male/female ratio</td>
<td>28/15</td>
<td>21/20</td>
<td>17/20</td>
</tr>
<tr>
<td>Mean SVA ± 1 SD (cm)</td>
<td>−4.5 ± 1.6</td>
<td>0.2 ± 1.3</td>
<td>8.0 ± 5.0</td>
</tr>
<tr>
<td>SVA range (cm)</td>
<td>[−9 to −2.6]</td>
<td>[−2.4 to 2.1]</td>
<td>[2.6 to 18.9]</td>
</tr>
</tbody>
</table>

Figure 1. Projection of anatomic landmarks, gravity line (dotted line), and heel line on digital radiographs. The gravity line and heel line are projected to evaluate offsets between these lines and radiologic landmarks.
bar lordosis, the thoracic kyphosis, the sagittal vertical axis (SVA), the global trunk inclination (defined as angle between the vertical and the best fit line across all vertebral centroids from C7 to S1) and the sagittal tilt of T1 or T9, which is the angle between the vertical plumb line and the line drawn from the vertebral body of T1 or T9 and the center of the bicoxofemoral axis. The sagittal pelvic morphology and orientation were described by the pelvic incidence, pelvic tilt, sacral slope, and the overhang (Figure 3).

**Statistical Analysis**

Data were statistically analyzed using SPSS software (SPSS, Chicago, IL). Significant differences between the 3 groups were investigated using t-test and then subjected to a simple linear regression analysis and Pearson correlation. The level of significance was set at 0.05.

### Results

**Radiologic Parameters**

According to the inclusion criteria, the SVA parameter was significantly different across the 3 groups ($P < 0.001$) as well as the T1 sagittal offset ($P < 0.001$) and the trunk global inclination ($P < 0.001$) which varied from −12 degree to −6 degree and +3 degree, respectively, for the sagittal backward, neutral, and sagittal forward group. Concerning the sagittal curves, the sagittal forward group seem to have a significant lower lumbar lordosis than the sagittal backward group and a significant greater thoracic T4–T12 kyphosis ($P < 0.005$) than the 2 other groups (Table 3).

No significant difference was observed for the sagittal T9 tilt among these 3 groups of subjects.

Several differences were noted across groups in terms of pelvic morphology and pelvic orientation (Table 4). No significant difference was found for the sacral slope, whereas it appeared to be slightly higher (38 degrees) for the sagittal backward group than for the sagittal forward group (35 degrees). However, the pelvic incidence, which is a morphologic parameter, was different among the groups: mean value was 52 degrees for the neutral group, lower (48 degrees) for sagittal backward group, and higher (56 degrees) for the sagittal forward groups. Consequently, the pelvic tilt was lower (10 degree) for

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**Table 2. Static Test Parameters Processed on the Frontal and Sagittal Plane**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4–GL</td>
<td>Distance between T4 vertebral body center and the gravity line</td>
</tr>
<tr>
<td>T9–GL</td>
<td>Distance between T9 vertebral body center and the gravity line</td>
</tr>
<tr>
<td>T12–GL</td>
<td>Distance between T12 vertebral body center and the gravity line</td>
</tr>
<tr>
<td>L3–GL</td>
<td>Distance between L3 vertebral body center and the gravity line</td>
</tr>
<tr>
<td>S1–GL</td>
<td>Distance between the anterosuperior S1 corner and the gravity line</td>
</tr>
<tr>
<td>FH–GL</td>
<td>Distance between the center of the bicoxofemoral axis and the gravity line</td>
</tr>
<tr>
<td>Heel–GL</td>
<td>Distance between the heels mid-point and the gravity line</td>
</tr>
<tr>
<td>Heel–S1</td>
<td>Distance between the anterosuperior S1 corner and the heels</td>
</tr>
<tr>
<td>Heel–FH</td>
<td>Distance between the femoral heads midpoint and the heels</td>
</tr>
</tbody>
</table>

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Figure 2. Sagittal spinal radiologic parameters. **A,** Thoracic kyphosis measured from the superior endplate of T4 to the inferior endplate of T12. Lumbar lordosis measured from the superior endplate of L1 to the superior endplate of S1. Sagittal vertical axis (SVA) defined as the horizontal offset from the posterosuperior corner of S1 to the vertebral body of C7. **B,** T1 sagittal tilt and T9 sagittal tilt defined as the angle between the vertical plumb line and the line drawn from the vertebral body of T1 or T9 and the center of the bicoxofemoral axis.
the sagittal backward group than for the neutral one (16
degree), and it was higher 21 degree in sagittal forward
group; these differences were significant ($P < 0.001$). In
summary, the sagittal backward group appears to
present a smaller pelvic incidence and a pelvic antever-
sion regarding the neutral group; in contrast, the sagittal
forward group revealed a greater mean pelvic incidence
and a pelvic retroversion regarding the neutral group.

**Forceplate**

A qualitative analysis of spine location regarding the heel
line and the gravity line (Figure 4) revealed that the GL
crossed the lumbar spine for the sagittal backward group
is in front of the entire spine for the neutral group and
crossed the cervical spine for the sagittal forward spine.

It is notable that aside for the distance between T9 and
and the GL (T9–GL) and the distance between the GL and
the heels (GL-Heel), all the other parameters revealed
significant differences ($P < 0.001$) across the 3 groups
(Table 5). When SVA increased, the GL kept a rather
fixed location relative to the feet, while all measured
anatomic components measured (excepted T9) moved
around this GL: as shown on Figure 4, T4 moved closer
to the GL, T9 kept its location, and the lower vertebrae
(T12, L3, and S1) moved away from the GL (toward the
heels). In addition to the spinal curvature changes mea-

Table 3. Spinal Radiological Parameters (Mean Value ±
1 Standard Deviation)

<table>
<thead>
<tr>
<th></th>
<th>Sagittal Backward (Sb)</th>
<th>Neutral (N)</th>
<th>Sagittal Forward (Sf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyphosis (deg)*</td>
<td>–41 ± 11</td>
<td>–42 ± 15</td>
<td>–51 ± 20</td>
</tr>
<tr>
<td>Lordosis (deg)†</td>
<td>63 ± 12</td>
<td>57 ± 11</td>
<td>50 ± 13</td>
</tr>
<tr>
<td>SVA (mm)†</td>
<td>–45 ± 17</td>
<td>0 ± 13</td>
<td>80 ± 50</td>
</tr>
<tr>
<td>Incl/C7/S1 (deg)†</td>
<td>–12 ± 3</td>
<td>–6 ± 2</td>
<td>3 ± 7</td>
</tr>
<tr>
<td>T1 Sagittal offset (deg)†</td>
<td>–8 ± 2</td>
<td>–5 ± 2</td>
<td>1 ± 5</td>
</tr>
<tr>
<td>T9 Sagittal offset (deg)†</td>
<td>–14 ± 3</td>
<td>–13 ± 4</td>
<td>–10 ± 6</td>
</tr>
</tbody>
</table>

*Significance differences ($P < 0.005$) between the sagittal forward group and
the 2 others.
†Significant difference ($P < 0.001$) between the sagittal forward group and
the sagittal backward group.
‡Significant differences ($P < 0.001$) among the 3 groups.
sured on radiographs, the current results suggest a rotation of the spine (sagittal trunk forward inclination) around the T9 vertebra.

Analysis of pelvic location regarding the heel line and GL (Table 5 and Figure 5) revealed that when SVA increased the pelvis shifted posterior towards the heels. The combination of the pelvic shift and pelvic retroversion lead to a decrease of the heel-S1 offset from 115 to 90 mm and 56 mm, respectively, for the sagittal backward, neutral, and sagittal forward (total translation = −58 mm) and to a decrease of the heel-FH offset from 127 to 109 mm and 84 mm (total translation = −43 mm).

The correlation analysis on the entire study group (all subjects) between forceplate parameters and radiologic parameters revealed a number of interesting relationships. An increase in SVA offset anteriorly was correlated with an increase of the S1–GL offset ($r = 0.762$) and FH–GL offset ($r = 0.622$): in simple terms, as C7 moves anteriorly the pelvis shifts posteriorly regarding the feet and gravity line. Conversely, a posterior displacement of C7 leads to an anterior pelvic shift.

The findings across the study group also revealed the T9 vertebra to have a rather fixed location regarding the gravity line; moreover, this T9–GL offset was highly correlated with the T9 sagittal inclination from the pelvis ($r = −0.706$).

### Discussion

The purpose of this study was to evaluate the impact of SVA offset on pelvic parameters and spinopelvic position relative to the feet in standing subjects. SVA offset was applied to define 3 subject groups given the wide use of this parameter in the radiographic analysis of spinal balance. Marked differences between groups were identified on a number of levels: regional and global spinal alignment, pelvic alignment, GL offsets from spinopelvic landmarks. Quite notably, however, the GL-heels and T9–GL offset remained surprisingly constant across the study groups.

SVA offset defined 3 groups in this study. This was based on a common notion that increasing SVA occurs with age and sagittal plane pathology. To limit confounding factors, and given the limited information on age effect on the spinopelvic relationship with GL offsets, adjustment to groups were made to eliminate significant differences in age means. In this additional analysis, subject numbers were limited but numerous differences between groups remained statistically significant. The findings of a constant GL-heel offset, a pelvic shift and retroversion between the sagittal backward and sagittal forward groups were maintained. Those parameters that lost significant difference (compared the initial total study group comparisons) may be attributable to sample size, although age related effects (CNS, muscle tension, force, mass . . .) cannot be dismissed. One can note that age appears to have only medium correlations with L3–GL, S1–GL, S1-heel, SVA, and pelvic tilt-overhang (all $<0.62$).

Although current standards in patient evaluation with radiographs can permit quantification of the plumbline

### Table 5. Static Test Parameters Among Groups (Mean Value ± 1 Standard Deviation)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sagittal Backward (Sb)</th>
<th>Neutral (N)</th>
<th>Sagittal Forward (Sf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4–GL (mm)*</td>
<td>109 ± 21</td>
<td>90 ± 26</td>
<td>61 ± 27</td>
</tr>
<tr>
<td>T9–GL (mm)</td>
<td>105 ± 26</td>
<td>101 ± 30</td>
<td>99 ± 32</td>
</tr>
<tr>
<td>T12–GL (mm)*</td>
<td>66 ± 27</td>
<td>74 ± 29</td>
<td>85 ± 39</td>
</tr>
<tr>
<td>L3–GL (mm)*</td>
<td>15 ± 23</td>
<td>31 ± 26</td>
<td>56 ± 35</td>
</tr>
<tr>
<td>S1–GL (mm)*</td>
<td>5 ± 20</td>
<td>23 ± 22</td>
<td>58 ± 28</td>
</tr>
<tr>
<td>FH–GL (mm)*</td>
<td>−5 ± 19</td>
<td>3 ± 20</td>
<td>30 ± 26</td>
</tr>
<tr>
<td>Heel–GL (mm)</td>
<td>120 ± 28</td>
<td>113 ± 23</td>
<td>114 ± 25</td>
</tr>
<tr>
<td>Heel–FH (mm)*</td>
<td>127 ± 30</td>
<td>109 ± 31</td>
<td>84 ± 32</td>
</tr>
<tr>
<td>Heel–S1 (mm)*</td>
<td>115 ± 35</td>
<td>90 ± 32</td>
<td>56 ± 38</td>
</tr>
</tbody>
</table>

*Significant differences among the three groups.
offset, position of the lower extremities and feet remains elusive. Most notably, the posterior pelvic shift in relation to the heels with increasing SVA in a patient population with spinal deformity has not been previously reported \((r = 0.6, P < 0.001)\). Group sagittal forward versus sagittal backward demonstrated significant differences \((P < 0.001)\) in the pelvic shift but also in the pelvic tilt. Thus, an increase of the SVA leads to a posterior shift of SI toward the heels and perhaps an increase of the pelvic tilt (retroversion). Findings presented in the current study are consistent with the ones focusing on an adult asymptomatic population, meaning the same global mechanisms of compensation take place in asymptomatic and patient population.

Analysis of data from this study revealed a higher pelvic incidence, a supposed fixed morphologic parameter, with higher SVA. This raises the question whether pelvic morphology can predispose to sagittal plane imbalance, whether changes can occur in the sacral endplate, or as suggested by Skalli et al sagittal imbalance can lead to compensatory motion in the sacroiliac joint.

It would appear that even wide variation in SVA can be tolerated so long as compensatory mechanisms come into play to maintain standing balance. It is evident from the data in this study that the role of the lower extremities and the pelvis are critical in understanding spinal balance as well as imbalance observed in pathologic states. As SVA offset increased a posterior shift of the pelvis occurred. This would require a change in the degree of hip flexion/extension given the noted posterior translation of the pelvis in relation to the feet with increasing SVA offset. Furthermore, changes in knee and ankle joint position may come into play to maintain a GL relationship to the feet.

This study confirms the role of pelvis as an equalizer (compensatory mechanisms) in the sagittal balance. It also underlines that the pelvis translation is a parameter as important as the pelvis rotation (measured by the pelvis tilt). Ideally, one should analyze our patients from head to feet or at least include the pelvis.

Although this study focused on the static aspects of the GL in relation to spinal and pelvic landmarks, force plate analysis also permits dynamic analysis of sway. Such investigation would permit quantification of GL movement patterns in standing subjects. Next steps in the comprehension of standing balance and compensatory mechanisms in the setting of spinal deformity should include work in the area of dynamic aspects of the gravity line.

**Conclusion**

This study analyzed the impact of SVA on spinopelvic radiographic parameters and force plate acquired GL and foot position in adult subjects. Three distinct subject groups were created by varying SVA values. Significant differences between groups were noted for a number of radiographic and GL parameters. Increasing SVA leads to a posterior pelvic shift in relation to the feet. Increasing pelvic incidence was also noted in the sagittal forward displaced SVA group. However, no significant difference in GL-heels offset is noted across the subject groups. It appears that pelvic shift is a key component in maintaining a rather fixed GL-heels offset even in the setting of variable SVA and trunk inclination.

**Key Points**

- Increasing SVA offset leads to a posterior pelvic shift in relation to the feet.
- No significant difference in GL-heels offset is noted across groups of varying SVA offset.
- Pelvic shift is a key component in maintaining a rather fixed GL-heels offset (GHO) even in the setting of variable SVA and trunk inclination.

**References**


