Relationships Between Spinal Landmarks and Skin Surface Markers

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This investigation determined relationships between coronal vertical alignment (CVA) and sagittal vertical alignment (SVA) variables calculated from radiographs and surface markers representing bony landmarks. Biplanar radiographs were taken on 28 subjects (standing) after 2 metallic surface markers were placed on the skin superficial to C7 and S2. The CVA-R and SVA-R were measured on the radiographs. Similar variables were calculated from the surface markers (CVA-P-R, SVA-P-R). Correlation between CVA-R and CVA-P-R was 0.894 ($p < 0.000$), and between SVA-R and SVA-P-R was 0.946 ($p < 0.000$). Results lead to three recommendations: (1) obtain surface marker data when radiographs are taken to establish relationships between the two sets of data, (2) take care in providing instructions to the subjects if measures are to be taken at different times, and (3) observe caution in interpreting results when simultaneous x-ray and surface marker data were not recorded.

Keywords: spinal reconstructive surgery, radiographs, surface markers

Two common measures taken from the long cassette radiographs of patients with spinal deformity to assess spinal balance are the coronal vertical alignment (CVA-R) and sagittal vertical alignment (SVA-R) (Lenke et al., 1993). The CVA-R is the horizontal distance from the midsacral line to a vertical line dropped from the midpoint of the C7 body as measured from a coronal plane radiograph. The SVA-R is the horizontal distance from the posterior-superior tip of S1 to a vertical line dropped from the midpoint of the C7 body as measured from a sagittal plane radiograph.

In our previous work, we have defined similar measures (CVA-P and SVA-P) calculated from surface markers placed on the skin superficial to C7 and S2 using video motion capture (Lenke et al., 2001). The CVA-P was defined to be the horizontal distance from the centroid of the S2 surface marker to a vertical line passing through the centroid of the C7 surface marker in the coronal plane during standing. The SVA-P was a similar measure except that it was measured in the sagittal plane.

A goal of our previous work (Lenke et al., 2001) was to demonstrate a strong relationship between the radiographic spinal balance measures (i.e., CVA-R and SVA-R) and our video motion capture measures (i.e., CVA-P and SVA-P). Despite using the same instructions when collecting the video motion capture data as those given to the patients when the radiographs were taken, our correlations did not...
indicate a strong relationship between the respective variables. Of course, the major limitation of the correlation was that the radiographic and video motion capture data were not taken at the same instant in time. Even though the patients received the same instructions at both data collection sessions, they may not have assumed identical positions.

Gaining insight into the surface marker–bony landmark relationship is important from both a clinical and research perspective. From a clinical perspective, we believe that the existence of a strong relationship could be a step toward reducing the number of radiographs required for these patients. We speculate that, occasionally, simple photographs could be used instead of radiographs to calculate the CVA and SVA. From a research perspective, we would like to understand relationships between surface markers and the underlying landmarks they are representing not only for standing, but also for gait and other range of motion activities. The purpose of this investigation was to determine whether there were strong relationships between CVA and SVA variables calculated from radiographs of both spinal bony landmarks and surface markers representing those landmarks.

**Methods**

Thirty-four subjects were recruited for this investigation (25 females, 9 males, mean age 34 ± 18 years, range 14–77). They were recruited during regular clinic visits to one of two spinal surgeons (KB, LL). The only inclusion criteria were that they had been diagnosed with a spinal deformity and were willing to have surface markers placed on their spine during their regular spinal radiographs. Data from 28 of these subjects were used in the analysis (21 females, 7 males, mean age 34 ± 19 years, range 14–77). Data from six subjects were not used owing to obscured surface markers or bony landmarks (n = 3) or lost films (n = 3). All subjects signed a written consent form approved by the Washington University Human Subjects Committee.

Prior to taking standard coronal and sagittal plane long cassette radiographs, subjects had two metallic surface markers placed on the skin superficial to C7 and S2 by research assistants experienced in placing markers (Lenke et al., 2001; Engsberg et al., 2003). It should be noted that S2 was used instead of S1 because it is easier to identify using palpation than S1. Standard coronal and sagittal plane long cassette radiographs were then taken (Figure 1).

The CVA-R and SVA-R were measured on the radiographs, as described above, by two research assistants experienced in taking these measures. The typical method of using the edge of the radiographic film as the vertical was employed. Two different research assistants experienced in processing surface marker data calculated the variables (i.e., CVA-P-R and SVA-P-R) from the surface markers seen in the radiographs. The center of each surface marker was estimated and marked on the radiograph and a vertical line was drawn from the center of C7 down to the center of S2. The horizontal distance from S2 to the C7 line was measured in both the coronal and sagittal planes. Pearson product–moment correlation coefficients were used to determine relationships between the respective radiographic and surface marker variables (i.e., CVA-R vs. CVA-P-R and SVA-R vs. SVA-P-R). The amount of

Figure 1 — Anterior-posterior (left) and lateral (right) radiographs of a subject showing the C7 and S2 surface markers. Note that the surface markers in lateral radiograph have been enhanced to improve clarity because image quality was lost from the original.
explained variance expressed as a percentage was determined by squaring the correlation coefficient and multiplying by 100. Linear regression was used to determine the equation for predicting the bony landmark variables from the surface marker variables (Equations 1 and 2). Ninety-five percent confidence interval upper and lower bounds were also calculated.

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\begin{align*}
CVA-R &= C_1 \times CVA-P-R + C_2 \\
SVA-R &= C_3 \times SVA-P-R + C_4
\end{align*}
\]

Results

The result for the correlation between the CVA-R and CVA-P-R variables was 0.894, explaining 80% of the variance, and was significant at \( p < 0.000 \) (Figure 2). The linear regression coefficients used to predict CVA-R from CVA-P-R and the 95% confidence interval upper and lower bounds (Figure 2) are presented in Table 1. For example, if a subject had a CVA-P-R value of 0 mm, the predicted CVA-R value would be −1.96 mm. The 95% confidence interval upper bound would be 1.8 mm and the lower, −5.8 mm. The 95% confidence interval bandwidth is 3.8 mm. With a CVA-P-R of 20 mm, the bandwidth increased to 7.9 mm.

The result for the correlation between the SVA-R and SVA-P-R variables was 0.946, explaining 89% of the variance, and was significant at \( p < 0.000 \) (Figure 3). The linear regression coefficients used to predict SVA-R from SVA-P-R and the 95% confidence interval upper and lower bounds (Figure 3) are presented in Table 1. For example, if a subject had a SVA-P-R value of 0 mm, the predicted SVA-R value would be −12.0 mm. The 95% confidence interval upper and lower bounds (Figure 3) are included.

### Table 1 Linear Regression Coefficients Used to Predict Radiographic Variables from Video Variables and the 95% Confidence Interval Upper and Lower Bounds

<table>
<thead>
<tr>
<th>Prediction coefficient</th>
<th>CVA-P-R coefficient ( (C_1 \text{ of Eq. 1}) )</th>
<th>CVA Constant ( (C_2 \text{ of Eq. 1}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVA-R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper bound</td>
<td>1.231</td>
<td>1.838</td>
</tr>
<tr>
<td>Mean</td>
<td>1.024</td>
<td>−1.958</td>
</tr>
<tr>
<td>Lower bound</td>
<td>0.817</td>
<td>−5.754</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SVA-P-R coefficient ( (C_3 \text{ of Eq. 2}) )</th>
<th>SVA Constant ( (C_4 \text{ of Eq. 2}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper bound</td>
<td>1.169</td>
</tr>
<tr>
<td>Mean</td>
<td>1.004</td>
</tr>
<tr>
<td>Lower bound</td>
<td>0.838</td>
</tr>
</tbody>
</table>

Figure 2 — The CVA-R variable plotted against the CVA-P-R variable indicating a strong relationship between the two variables; 95% confidence intervals are included.

Figure 3 — The SVA-R variable plotted against the SVA-P-R variable indicating a strong relationship between the two variables; 95% confidence intervals are included.
interval upper bound would be −5.8 mm and the lower, −18.2 mm. The 95% confidence interval bandwidth is 6.2 mm. With a CVA-P-R of 20 mm, the bandwidth increased to 14.4 mm.

**Discussion**

The purpose of this investigation was to determine whether there were strong relationships between CVA and SVA variables calculated from radiographs of both spinal bony landmarks and skin markers representing those landmarks. Our results indicated very strong correlations between similar CVA and SVA variables taken from bony landmarks and skin surface markers when the data were collected simultaneously. These results were in contrast to our previous work indicating no correlation between the variables when they were taken at two different points in time (Lenke et al., 2001), despite the subjects receiving the same instructions for how to stand. Similar work has been conducted by Marks and colleagues (Marks et al., 2003), for whom the primary purpose was to investigate the effects of different body positions on the SVA. They recruited 15 healthy female adolescents without spinal deformity. Although not the major focus of the work, they reported differences of within 1 cm for an SVA value calculated from C7 and S1 from a sagittal plane radiograph and an SVA value (SVA′) calculated from surface markers placed superficial to those landmarks. They did not report a standard deviation for understanding variability or a correlation indicating the strength of the relationship.

The results from the regression analysis demonstrated the potential usefulness in a clinical setting as the radiographic variables (i.e., CVA-R and SVA-R) can be calculated from the surface marker variables (i.e., CVA-P-R and SVA-P-R) using Equations 1 and 2, respectively. The methods used in the present investigation could be easily modified such that only a still camera could be used to collect the data. Data could be collected in an exam room along with other standard information such as height and weight. Also encouraging are the 95% confidence intervals. The bandwidths seem reasonable to permit some assurance in such a prediction. Additional work in this area is required to further demonstrate efficacy. Additional work is also required to further understand sources of variability and how to minimize them. For example, it is unlikely that the thickness of the soft tissue had a profound influence in the CVA relationship. However, soft tissue thickness could have a strong influence on the SVA relationship. A soft tissue measure such as body mass index might be helpful in this regard.

The present investigation is adding to the body of knowledge in this area by reporting the strength of the relationships between the SVA-R and SVA-P-R, and between the CVA-R and CVA-P-R variables for subjects with a spinal deformity, and by demonstrating how the method could be used in a clinical setting to possibly reduce the number of radiographs taken from a patient.

The results of this investigation lead to three research recommendations and one clinical. The first research recommendation is that, if possible, obtain surface marker data when radiographs are taken to establish the relationship between the two sets of data. The surface markers could remain on the subject if additional data, outside the radiographic suite are necessary (e.g., in a gait laboratory). The second research recommendation is that great care must be taken in providing instructions to the subjects if these measures are to be taken at different times. The third research recommendation is that caution should be observed in interpreting results when simultaneous x-ray and surface marker data have not been taken and the inference is that the data will be highly correlated with each other. The clinical recommendation is that continued development of a method that may reduce the number of radiographs that patients need to have is a worthy endeavor. The methods proposed in the present investigation may be helpful in this regard.

**References**


