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The Berbeo-Sardi Angle (BSA): An Innovative Method to Effectively Estimate Pelvic Retroversion in Anteroposterior Radiographs—A Correlation With Traditional Parameters

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Abstract

Study: Design: Diagnostic studies—concordance between diagnostic tests.
Objectives: The purpose of this study was to develop a novel spinopelvic parameter (Berbeo-Sardi angle [BSA], the angle formed at the intersection of a line that connects the inferior margin of the sacroiliac joint to the midpoint of a horizontal line joining both femoral heads) measurable in anteroposterior radiographs that indirectly estimates pelvic retroversion and correlates with traditional measurements like pelvic tilt (PT).
Summary: Sagittal balance appraisal and surgical planning rely on the interpretation of spinopelvic parameters. An increased PT reflects pelvic retroversion as a compensatory mechanism to limit sagittal imbalance and correlates with increased pain and disability. However, poor imaging techniques and incorrect patient positioning frequently hamper landmark identification in lateral radiographs, and with no measurable angles in anteroposterior radiographs, it is often impossible to determine PT and pelvic retroversion.
Methods: Whole-spine radiographs from 105 consecutive patients were used to retrospectively measure conventional spinopelvic parameters and the BSA. Intraclass correlation coefficient was used to assess a quantitative correlation between the PT and BSA as indirect measures of pelvic retroversion.
Results: Average values for pelvic incidence, lumbar lordosis, sacral slope, PT, and BSA were 46.5° (±10.23), 48.56° (±12.30), 29.97° (±9.77), 16.94° (±8.03), and 54.47° (±4.05), respectively. We encountered a moderately strong correlation ($r = -0.66$) between PT and BSA. Receiver operating characteristic plot analysis revealed that a BSA threshold of 46° has a sensitivity of 90% to identify pathologic PT values (>20°), whereas a BSA ⩾60° has a specificity of 90% to rule out pelvic retroversion using anteroposterior radiographs.
Conclusions: There is a moderately strong correlation between the BSA, an innovative spinopelvic parameter measurable in anteroposterior radiographs, and PT. BSA seems to show great promise in simplifying spinopelvic appraisal by easily estimating pelvic retroversion associated with sagittal imbalance, while avoiding image-quality issues often encountered in lateral radiographs.
Level of Evidence: Level III.

Keywords: Spine; Spinal deformity; Pelvic tilt; Pelvic retroversion; Sagittal balance

Introduction

Sagittal balance is now considered one of the most important predictors of surgical and health-related quality-of-life (HRQoL) outcomes [1-5]. The pelvis, which serves as foundation to the human spine, has been broadly studied because of its fundamental role in global alignment. Duval-Beaupere described pelvic incidence and its close relationship with lumbar lordosis in the early nineties [6]. This would set the grounds for others like Dubousset who years later would coin the term ‘‘pelvic vertebra’’ [7-9]. Several authors have since investigated spinopelvic parameters to define the ideal spinal balance for each individual. Pelvic incidence (PI), a fixed parameter, will determine ideal lumbar lordosis (LL) and reproduce the relationship of the

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sacrum to the pelvis [4,10]. It is defined by the sum of sacral slope (SS) and pelvic tilt (PT), dynamic parameters that change inversely proportional to one another in order to preserve the constant PI [5,11].

Independent of its cause, sagittal malalignment implies altered spinopelvic parameters to maintain an upright posture within the “Cone of Economy” [7,11]. One of the first changes that follow sagittal imbalance is pelvic retroversion. As the pelvis rotates backward, it counters the anterior displacement of mass caused by a positive sagittal vertical axis (SVA), thus keeping the C7 plumb line behind femoral heads [12-14]. This pelvic rotation about the hip axis will turn the sacral endplate into a more horizontal position, decreasing SS but proportionally increasing PT [5].

Increased PT can result from aging, trauma, congenital abnormalities, loss of LL, and augmented thoracic kyphosis—conditions also known to cause pelvic retroversion by recruitment of compensatory mechanisms [4,10]. These changes have been associated with deteriorating quality of life outcomes. Furthermore, surgical restoration of optimal spinopelvic parameters, especially achieving PT values below 20°, has been associated with improved functional status and walking tolerance [1,5,15-17].

Accurate evaluation of global alignment requires that all key radiographic landmarks be clearly visible in 36-inch standing scoliosis films. Nevertheless, it is not uncommon to find inadequate lateral radiographs due to poor imaging technique, flaws in patient positioning and uneven x-ray penetration at different spinal levels. These low-quality lateral radiographs often make it nearly impossible to measure PT and estimate pelvic retroversion, thus altering the reliability of spinopelvic parameters.

There are currently no universally accepted angular spinopelvic parameters that can be measured in anteroposterior (AP) spinal films in order to provide an alternative solution for pelvic version appraisal. In an effort to overcome image-quality issues associated with lateral radiographs and simplify spinopelvic analysis, the purpose of this study was to assess a possible correlation between PT and a novel spinopelvic parameter (ie, the Berbeo-Sardi angle [BSA], the angle formed at the intersection of a line that connects the inferior margin of the sacroiliac joint to the midpoint of a horizontal line joining both femoral heads) as an indirect measure of pelvic retroversion in anteroposterior radiographs.

Materials and Methods

Study design

This study was conducted at a University Hospital and all data were obtained from the databases of the Neurosurgery and Radiology departments. After institutional review board approval, medical records of all patients who had 36-inch standing scoliosis films performed during a two-year period were reviewed. Inclusion criteria were age greater than 13 years and a clinical or radiographic diagnosis of symptomatic spinal deformity, chronic low-back pain, neurogenic claudication, or radicular entrapment. Asymptomatic patients or those with a history of spinopelvic neoplasic disease or surgery were excluded.

Two experts queried the included radiographs to identify minimum radiographic standards defined by the *Spinal Deformity Study Group* [18]. Patients only qualified for inclusion if their images were deemed acceptable by consensus. All studies had to include AP and lateral projections taken with the patient in an upright position with their knees locked, feet apart at shoulder width, looking straight ahead and with less than 1 cm of pelvic asymmetry. Mandatory landmarks that had to be visualized were as follows: vertebral bodies from C2 to the sacrum, both femoral heads, the entire ribcage form right to left, and the sacroiliac joints [18,19]. Four hundred fifty-one consecutive radiographic studies practiced between April 2015 and September 2016 were retrospectively assessed before obtaining the 105 full-length spine radiographs needed for our study.

Radiographic parameters

Two experts independently measured all spinopelvic parameters using the image processing software OsiriX (open-source software; www.osirixviewer.com). The analysis focused on the following traditional parameters measured in lateral films (Fig. 1):

- SVA: Defined as the horizontal distance from the C7 plumbline to the posterosuperior corner of S1.
- PI: Angle between a line perpendicular to the midpoint of the sacral endplate and the line connecting this point to the center of the femoral heads.
- LL: Angle between the upper end plate of L1 and the superior end plate of S1.
- PT: Angle between a line connecting the center of the femoral heads to the midpoint of the sacral end plate and a vertical line from this point.
- SS: Angle between a horizontal line and the superior end plate of S1.

Left and right BSA were measured in AP films. For analysis purposes, we included individual values for each side, as well as their average (Fig. 2).

- BSA: Angle formed at the intersection of a line that connects the inferior margin of the sacroiliac joint to the midpoint of a horizontal line joining both femoral heads.

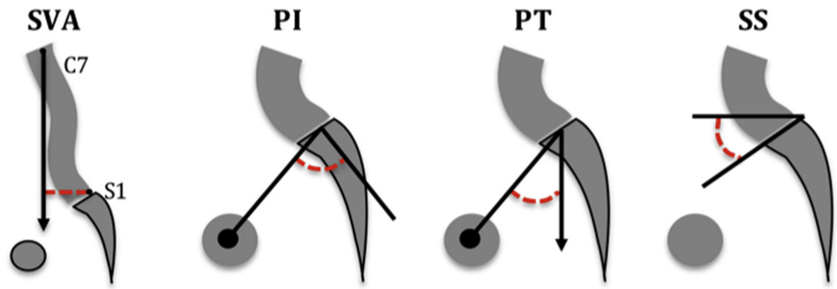

Fig. 1. Traditional spinopelvic parameters. SVA, sagittal vertical axis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope.

Statistical analysis

Using Bonett's formula for interrater reliability (precision of confidence interval around intraclass correlation coefficient) we determined that a total of 105 patients needed to be included in the study [20]. Statistical analyses were performed using Stata Statistical Software 13.1 (StataCorp Tx), and significance for all tests was set at $p < .05$ [21]. Descriptive statistics were performed to determine means and standard deviations for the different variables and spinopelvic parameters. Considering there is no gold standard to measure pelvic retroversion, but PT is accepted as the closest estimate, we aimed to determine the correlation between PT and BSA using a simple linear regression model. Intraclass correlation coefficient (r) with values between −1 and 1 was interpreted as poor when approaching 0 (below 0.3), fair from 0.3 to 0.5, moderate from 0.51 to 0.6, moderately strong from 0.61 to 0.8, and very strong if greater than 0.8 [22]. Negative values indicated an inverse relationship between variables.

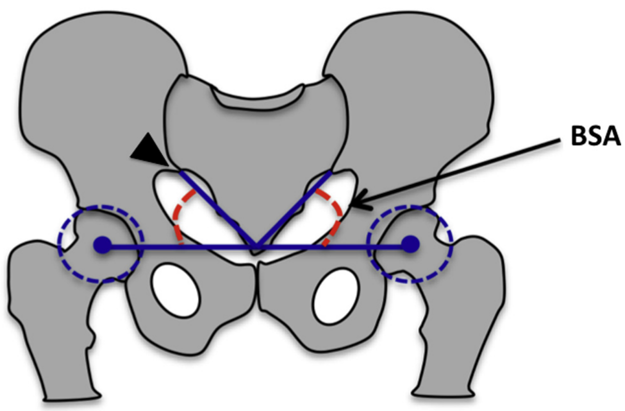

Fig. 2. BSA (arrow) defined as the angle formed at the intersection of a line (blue solid line) that connects the inferior margin of the sacroiliac joint (arrowhead) to the midpoint of a horizontal line joining both femoral heads (outlined by dashed blue lines). Note the geometrical symmetry between the left and right angles. BSA, Berbeo-Sardi angle.

Results

Sixty-four women and 41 men were enrolled. At the time radiographs were taken, the average age was 50.6 ± 21.6 years. The chief complaint warranting the radiographic study was axial low-back pain (88.6%), followed by radicular pain (42.9%) and neurogenic claudication (15.2%). When evaluating coronal alignment, 27 patients (25.7%) had some degree of scoliosis with a mean Cobb angle of 25.1° ± 11.77° (range 12°-56°). All demographic characteristics are shown in Table 1.

SVA values ranged from −8 to +22 cm. Sixty-one patients (58.1%) had sagittal malalignment defined as an SVA of less than −2.5 cm or greater than +2.5 cm. Average values for PI and LL were 46.5° ± 10.23° and 48.56° ± 12.30°, respectively. Mismatch between PI and LL ranged from −38° to +31°, with only 18.1% of patients having abnormal values greater than 10°. Average PT in the overall population was 16.94° ± 8.03°, with slightly higher values in men than in women. However, no statistically significant difference was observed in any of the spinopelvic parameters with regard to sex. Details of spinopelvic parameters are shown in Table 2.

Table 1
Demographic and baseline characteristics.

Patients, n (%)	
Males	41 (39)
Females	64 (61)
Total	105 (100)
Age, years, M ± SD (range)	
Total	50.6 ± 21.6 (14−86)
Females	55.3 ± 20.8
Males	43.3 ± 20.9
Body mass index	23.6 ± 3.7
Axial low-back pain, n (%)	93 (88.6)
Radicular pain, n (%)	45 (42.9)
Neurogenic claudication, n (%)	16 (15.2)
Coronal alignment	
No scoliosis: Cobb <10°, n (%)	78 (74.3%)
Scoliosis: Cobb ⩾10°, n (%)	27 (25.7%)
Average Cobb angle, M ± SD (range)	25.1° ± 11.77° (12°−56°)

SD, standard deviation.

Table 2
Spinopelvic measurements.

Parameter	Average (°)	SD (°)	Min (°)	Max (°)
Pelvic incidence (PI)	46.50	10.23	23.00	74.00
Females	46.54	10.36	23.00	74.00
Males	46.46	10.13	30.00	72.00
Pelvic tilt (PT)	16.94	8.03	3.00	39.00
Females	16.60	8.04	3.00	36.00
Males	17.50	8.08	5.00	39.00
Sacral slope (SS)	29.97	9.77	2.00	56.00
Females	29.88	9.65	9.00	56.00
Males	30.12	10.07	2.00	52.00
Lumbar lordosis (LL)	48.56	12.30	5.00	76.00
Females	48.70	10.08	26.00	75.00
Males	48.34	15.42	5.00	76.00
Berbeo-Sardi angle (BSA)	54.47	4.05	42.05	62.15
Females	54.33	4.29	42.05	62.15
Males	54.66	3.68	47.65	61.20
Left	56.03	4.73	39.9	65.2
Right	52.89	4.69	41.2	61.5

SD, standard deviation.

Average BSA was 54.47° ± 4.05°. Similar values among males (54.66° ± 3.68°) and females (54.33° ± 4.29°) were found, with no statistically significant difference between them ($p = .5975$). However, when discriminating sides, there was a statistically significant difference of 3° ($p < .0001$) between the left and right BSA.

Correlation analysis revealed a moderately strong correlation between BSA and PT ($r = -0.66$). When discriminating the correlation coefficients according to sex, we found a statistically significant difference ($p < .05$) between men ($r = -0.62$) and women ($r = -0.69$). We set the cutoff point for normal PT at 20° and found an abnormally increased value in 29.52% of patients, 11 men and 20 women. Subgroup analysis of these 31 patients showed a poor correlation between BSA and PT ($r = -0.29$).

Using a receiver operating characteristic (ROC) curve to display the trade-off between sensitivity and specificity, we

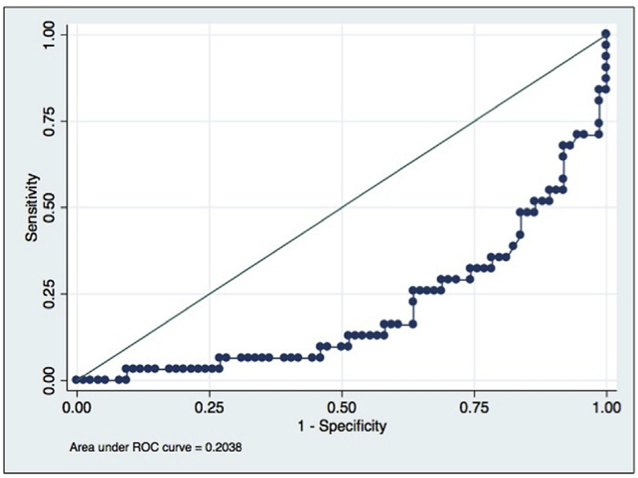

Fig. 3. Receiver operating characteristic curve for BSA/PT. BSA, Berbeo-Sardi angle; PT, pelvic tilt.

Table 3
Receiver operating characteristic table for BSA/PT.

Cutoff value	Sensitivity, %	Specificity, %	LR+	LR−
≤42.05	100	0.00	1.000	—
≤45.55	93.55	0.00	0.936	—
≤48.4	83.87	1.35	0.8502	11.9355
≤52.25	48.39	13.51	0.5595	3.8194
≤55	22.58	36.49	0.3555	2.1219
≤57.1	6.45	63.51	0.1768	1.4729
≤58.8	3.23	81.08	0.1705	1.1935
≥62.15	0.00	100.00	—	1.000

BSA, Berbeo-Sardi angle; LR+, positive likelihood ratio; LR−, negative likelihood ratio; PT, pelvic tilt.

found the optimal cut-off value for BSA to be 52°; however, such value had a very low sensitivity (48.39%) and specificity (13.51%). Nevertheless, we observed that a BSA ≤46° has a sensitivity of 90% to identify patients with pathologic PT (>20°). Figure 3 and Table 3 depict the ROC curve and its cut-off values.

Discussion

The interdependence among the axial spine, pelvis, and lower extremities is defined in terms of radiographic parameters [17]. Thirty-six-inch radiographs are, therefore, indispensable to assess global spinal balance and set proper surgical goals that fit individual spinopelvic angles. Although easily obtained, poor imaging technique or incorrect patient positioning frequently hamper accurate radiographic interpretation. During the enrollment process, we encountered a significant amount of inadequate films, and before obtaining the 105 patients needed for our study, we had to go over 451 radiographic studies—the vast majority of which failed to meet minimum quality standards.

We noticed that although boney structures could generally be recognized in AP projections, low-quality lateral films were usually responsible for radiographic study dismissal. The main obstacle encountered was failure to identify critical landmarks because of uneven x-ray absorption between spinal segments. This is consistent with previous reports where difference in tissue density between areas of the body has been shown to cause inadequate exposure and repeated examinations [23]. Authors have attempted to resolve this issue by implementing strategies like image digitalization, chassis, digressive screens, and attenuation filters, but with inconsistent results [24-27]. These measures can still fail to correctly show the position of the spine because of other factors that cause further image distortion such as x-ray diversion (parallax), patient's age, bone quality, and obesity [27]. The objective of this study was to develop a novel angular parameter measurable in AP radiographs that correlates with PT and estimates pelvic retroversion associated with sagittal imbalance.

To overcome problems associated with lateral radiographs, a relation between PT and coronal parameters have been investigated [25]. However, most studies were designed for patients undergoing hip arthroplasty, only tested linear measurements in pelvic radiographs, and none exhibited a strong correlation [25,28-33]. Spinopelvic parameters have been standardized as angular measurements because of a higher interobserver reliability while avoiding the radiographic calibration needed with linear ones [34]. Blondel et al. recently proposed the sacro-femoral-pubic angle (SFP) as an option to estimate PT in coronal radiographs [35,36]. And though some studies have shown good correlation between the SFP and PT, literature is inconclusive showing Pearson correlation coefficients ranging from −0.32 to 0.74 [35,37,38]. Furthermore, there is still a lack of reference data in age-matched healthy adolescents, and the conventional formula appears to work poorly on patients with scoliosis or with high PI; hence, whether the SFP is a suitable surrogate for PT is still to be determined [37,38].

The geometric theory behind the BSA is supported by the linear relationship that exists between PT and pelvic retroversion. Because the sacrum is virtually fixed to the pelvis, rotation about the hip axis will change the orientation of the sacral end plate and alter PT values according to the direction of the rotational vector. As the pelvis rotates backward (pelvis retroversion), the pelvic inlet seen in AP projections will tend to flatten, and in turn the BSA will lessen while PT increases. Thus, creating an inverse relationship between BSA and PT.

Pelvic tilt was chosen as the ideal target for the correlation because of its clinical and biomechanical implications. First, it can indirectly estimate compensatory pelvic retroversion caused by sagittal imbalance. To maintain upright posture, misaligned patients neutralize their plumb line by rotating the pelvis about the hip axis, increasing their PT. Because this temporary “alignment” demands a high-energy expenditure to maintain the body within the cone of economy, compensatory mechanisms will eventually fail, leading to pain and functional limitations [4,10]. Furthermore, the statistically significant correlation ($p < .0001$) between PT values and HRQoL outcomes, added to its dynamic nature, make it a strong parameter on which to rely and seek impact with surgery [2,4,5,17]. In fact, failure to achieve adequate PT goals with intersomatic fusions has been associated with negative surgical outcomes [39-41].

Linear regression analysis revealed a moderately strong correlation ($r = -0.66$) between BSA and PT as an indirect measure of pelvic retroversion. The negative sign of the correlation coefficient indicates an inverse relationship between both angles and supports the aforementioned biomechanical theory behind the authors’ hypothesis: the smaller the BSA, the greater the PT and the larger the rotational vector. There was a statistically significant difference ($p < .05$) between male and female coefficients that we believe is a result of the heterogeneous pelvic morphology amid both sexes. When compared to its female counterpart, male pelvic inlet tends to be narrower and could lead to slight variations in the BSA. However, pelvic types were not included within the variables, and further studies are needed to determine their impact over the correlation.

Normative PT values vary across the literature and range from −5° to 30°, but the most representative value that correlates with surgical, HRQoL, and pain outcomes is 20° [4,10,42]. Therefore, we adopted this value to divide patients between those with normal PT and elevated PT as a result of pelvic retroversion. Subgroup analysis of patients with abnormal PT values (>20°) revealed a poor correlation between BSA and PT ($r = -0.29$). However, this was not statistically significant consequence of a low sample size that only included 31 patients. Also, because all the patients included in our study were considered symptomatic, no correlation between BSA, pain, and increased PT was performed.

Anticipating possible asymmetries between left and right BSA resulting from inadequate x-ray angulation at the moment of the examination, their average was used for the correlation analysis to avoid discrepancies from altering the outcome. However, individual analysis of the right and left BSA was also performed and revealed a 3° difference between both sides. Angular measurements are subject to a certain degree of interobserver variability, and discrepancies of up to 5° are to be expected [43]. Therefore, the 3° difference though statistically significant ($p < .0001$) is clinically irrelevant, and allows for the angle to be measured indifferently in the right or left side without any real impact over the correlation.

Using ROC curve analysis, we found that a BSA of 52° was the “ideal” cut-off point to diagnose patients with an elevated PT and pelvic retroversion. Although this angle represented the optimal balance between sensitivity and specificity, their values were unsatisfactory and of no clinical worth. Nonetheless, because one of the main objectives pursued with the development of the BSA was to simplify recognition of sagittal imbalance by identifying pelvic retroversion, further analysis was done to establish other cut-off points that could serve such purpose. We found that a BSA threshold of 46° has a sensitivity of 90% to identify pathologic PT values (>20°), whereas a BSA equal to or greater than 60° has a specificity of 90% to rule out pelvic retroversion using anteroposterior radiographs. We consider that these values allow for a quick and easy assessment of sagittal imbalance using AP radiographs.

There were some limitations of the present study. In the absence of a gold standard parameter to objectively measure pelvic retroversion in plain films, a conformity analysis could not be performed and therefore only consistency was implemented. Also, although low-quality images were filtered beforehand, this was a retrospective study and we could not control the optimal technique when the radiographs were taken. Even though landmarks were clearly visible in all of the included images, we found that many of them did not comply with ideal parameters [18]. This could have weakened the correlation coefficient, particularly if the x-ray orientation regarding the pelvic inlet was not completely perpendicular in all patients. A prospective study in which imaging techniques are standardized and strictly controlled could reveal a stronger correlation and allow further research to establish an association among the SFP angle, BSA values, and HRQoL outcomes. However, radiographic studies analyzed were a direct representation of the image quality physicians encounter on a daily basis, and it is worth mentioning that even under suboptimal conditions there was a moderately strong correlation between PT and BSA, which supports its value in routine clinical settings.

Conclusions

This study found a moderately strong correlation between the BSA, an innovative spinopelvic parameter measurable in anteroposterior radiographs, and PT. BSA seems to show great promise in simplifying spinopelvic appraisal by easily estimating pelvic retroversion associated with sagittal plus-balance, while avoiding image quality issues often encountered in lateral radiographs. It remains to be investigated whether BSA values might be associated with HRQoL outcomes and if it reverses with the surgical correction of sagittal malalignment.

Key points

- Pelvic tilt (PT) reflects pelvic retroversion resulting from sagittal imbalance and has gained special importance for its strong association with pain and surgical outcomes.
- Poor imaging techniques frequently hamper landmark identification in lateral radiographs, and with no measurable angles in anteroposterior (AP) radiographs, it is often impossible to determine PT and pelvic retroversion.
- The Berbeo-Sardi angle (BSA) has a moderately strong correlation ($r = -0.66$) with PT and can be used to easily estimate pelvic retroversion associated with sagittal malalignment.

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