Are Measurements of Sacral Slopes Reliable?

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Abstract **Background:** Malpositioning during total hip arthroplasty may cause dislocation, pain, and other complications. To evaluate the potential of sacral slope (SS) as a reliable parameter of pelvic flexion. **Methods:** We developed a model of pelvic flexion to determine the intraobserver and interobserver variability and reliability of SS measurements by lateral radiography by three independent observers. **Results:** Measurement error was 1.2° and the intraobserver reliability was moderate to substantial (Interclass correlation coefficient: 0.31 to 0.66). Based on the Spearman-Brown formula, the measurement is reliable if it is done at least seven times by two observers, and four times by three observers. **Conclusions:** The data suggest that measurement of SS of pelvic flexion is a clinically useful parameter for the optimization of THA conditions.

Keywords: *anterior pelvic plane, lateral radiograph, total hip arthroplasty, sacral slope, pelvic flexion angle, accuracy*

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1. Introduction

Malpositioning of the acetabular and femoral components in total hip arthroplasty (THA) may cause impingement of these components and subsequently result in dislocation, pain, and acceleration of polyethylene wear [1,2,3]. There have been many reports arguing for a safe zone in THA [4,5,6]. Combined anteversion, the sum of the anteversion of the acetabular and femoral components, has recently been shown to be important [4,5,6]. However, pelvic positioning is not static; it is dynamic during standing, lying, sitting, and other daily activities. For this reason, most commonly the tilt of anterior pelvic plane (APP), which is defined as the bilateral anterior superior iliac spine and the pubic symphysis, or sacral slope (SS) are used as the reference for characterizing the patient's orientation of the pelvis and for estimating the angle of implantation of the acetabular component based on lateral radiograph of the pelvis in the supine position [7,8]. Further, it has been clearly demonstrated that pelvic flexion substantially affects acetabular cup orientation [9,10,11,12]. Therefore, a constant anteversion angle of the acetabular component is not recommended, and surgeons may have to know precise pelvic tilt to insert the acetabular component into the proper position.

There are 2 methods for measuring pelvic tilt, one using lateral radiographs [13,14,15] and the other using three-dimensional (3D) measurement by computed tomography (CT) scan [12,16,17]. While 3D measurement allows alignment parameters to be determined with 1 degree and 1 mm accuracy [18], the required CT scan involves a high cost and also requires the software for analysis. Several reports in the literature have demonstrated that pelvis tilt from lateral radiographs is easily measured, convenient, and inexpensive [14,15,19].

The relationship between the spine and hip joint has been discussed as related to hip-spine syndrome [20,21,22,23]. In these studies, SS was considered as one of the important parameters related to hip-spine syndrome. However, few studies have examined the accuracy of SS. Some reports evaluated the accuracy of the pelvic flexion angle measured by manually identifying the locations of bilateral anterior superior iliac spine and the pubic symphysis by using synthesized lateral pelvic radiographs from a CT-based surgical navigation system [14,24]. They found both intra- and inter-observer error to be small and the results to be highly correlated. The difference in APP has been reported to be at least 3–5° between standing and supine positions by 3D measurement [16,17]. For that reason, the measurement of SS requires approximately 3° of accuracy.

The aim of this study was therefore to investigate the accuracy of SS measurement from lateral radiographs using a synthesized pelvic model configured for pelvic flexion angle, lateral tilt, and external rotation of the pelvis. We also sought to investigate factors contributing to the measurement error.

2. Subjects and Methods

2.1. Subjects

The pelvis model was developed from the CT scans of a 35-year-old woman who visited our institution for detailed examination of femoroacetabular impingement, however, abnormal findings were not observed. There were no

abnormalities of the lumber spine visible in anteroposterior and lateral radiographs. The Institutional Research Board at Niigata University Medical and Dental Hospital approved the study and informed consent was obtained from this patient.

2.2. Synthesizing the Pelvis Models

The pelvis model was synthesized using Zed Hip® (Lexi, Tokyo, Japan) a software that has been used in the past to assess 3D pelvis and lower extremity alignment from CT scan [18,25,26]. We recorded the 3D pelvic positions and orientation, which were used as control measurements in this study. One of us (NI) synthesized the pelvic models. Preliminary 3D measurements were conducted at our institution on 52 patients to determine the range of APP angles that should be included in our model. At least 90% of patients suffering from osteoarthritis have an APP angle between -20–20° (positive values represent flexion, negative extension) and less than ±6° lateral tilt in a standing position. Based on this, we initially restricted the APP angle in the pelvis model to ±20°, ±10°, ±5° (Figure 1), and 0°, where 0° is parallel to the vertical. Lateral tilt (Lt) and rotation (R) were then assigned to the pelvis models which have 7 different APP angles. Seven different Lt and R combinations were used: Lt0°-R0° (parallel to APP), Lt3°-R0°, Lt6°-R0°, Lt0°-R3°, Lt0-R6°, Lt3°-R3°, and Lt6°-R6°(Figure 2). Therefore, a total of 49 configurations were synthesized for the model.
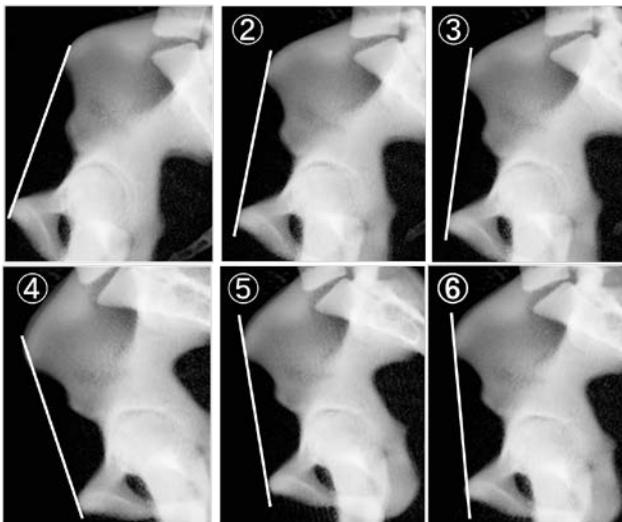
Figure 1. The restriction of APP angle (APP angle was restricted ① -20˚, ② -10˚, ③ -5˚, ④ +5˚, ⑤ +10˚, ⑥ +20˚, respectively)

Figure 2. The restriction of lateral tilt and rotation (Lt and R combinations were used: e.g. ① Lt6°-R0°, ② Lt0-R6°, ③ Lt6°-R6°)

2.3. True Value of SS

SS was measured by NI 5 times in the sagittal plane which presents the center of the sacrum when the APP angle was 0° (Figure 3). The mean angle was $45.0 \pm 0.14°$ (range 44.8–45.2°), therefore, we defined the true value of SS was 45° when APP was 0°. Based on this true value, consequently, the APP angles of 20°, -10° -5°, 0°, +5°, +10°, and +20° are converted to SS values of 25°, 35°, 40°, 45°, 50°, 55°, 65°, respectively.
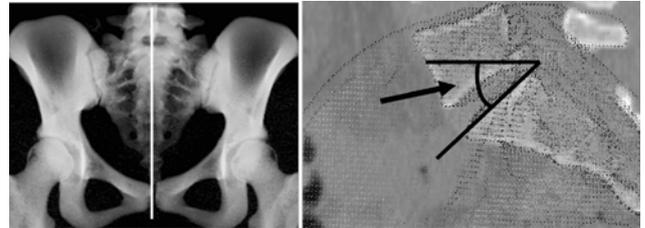
Figure 3. a) Anteroposterior radiograph of pelvis. The white line shows the plane which is through the center of the sacrum with the APP angle being 0°. b) Sagittal plane which is through the center of the sacrum with the APP angle being 0°. The true SS angle, which was measured in this plane, is shown by an arrow

2.4. Measurements

To investigate the accuracy of SS measurement from lateral radiographs by using a synthesized pelvic model, three orthopedic surgeons (HS, RT, YH), who are referred to as observers A, B, and C, independently measured SS angle. Data collection and analysis were performed by an independent evaluator (NI) who was not one of the observers. The observers measured SS from 49 shuffled lateral radiographs. All of the images were arranged in different sequences in three different sets and were re-evaluated by each of the three observers at 1-week intervals. SS was defined as the angle between the line parallel to the superior end plate of sacrum and vertical (Figure 4). Measurement error was determined by the difference between the true SS value and the measurement value [14]. Absolute value was determined with the numerical value without regard to its sign.
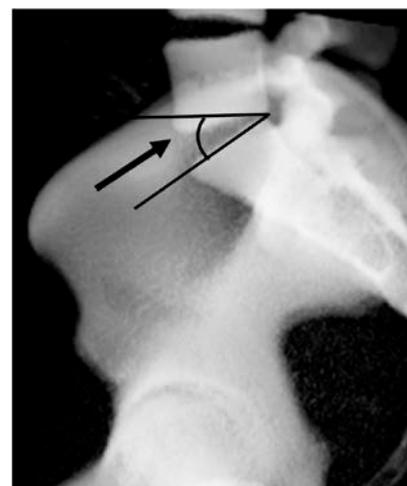
Figure 4. Lateral radiograph of pelvis showing SS measurement. (SS angle (shown by an arrow) was defined as the angle between the line parallel to the superior end plate of sacrum and horizontal line)

2.5. Statistical Analysis

SPSS statistical software (SPSS version 16.0, Inc, Chicago, IL) was used for all statistical analysis. Intra-

rater and inter-rater reliability were assessed using the interclass correlation coefficient (ICC). We determined that the number of required repeat measurements for highly reliable ICC was more than 0.8 using the Spearman- Brown formula (27): $\kappa = \rho2 \cdot (1-\rho1) / \rho1 \cdot (1-\rho2)$, where κ is the number of times the observer repeats the measurement, $\rho1$ is the actual value of ICC, and $\rho2$ is the target value of ICC (defined here as 0.8 to achieve high reliability). Multiple regression analysis was performed to analyze the relationships between factors (such as rotation and lateral tilt). $p < 0.05$ was considered statistically significant.

3. Results

3.1. Measurement Variability

The first set of analysis evaluated the variability in SS measurements made by each observer and the variability between the measurements done by the three observers (inter-observer variability). The three observers reported an overall SS range of -8.2° to +8.4°. The mean measurement error was 1.20° and mean absolute value of measurement error was 2.85°. Between the observers, 0.8° (A and C) – 3.5° (B and C) differences were observed (Table 1).

Table 1. Results for SS angle measurement and analysis for 3 observers

	Total	Observer A	Observer B	Observer C
Difference from true value (measurement value)*	1.20 ± 3.46°	1.04 ± 2.68°	-1.68 ± 2.71°	1.84 ± 2.68°
Range	-8.2°-8.4°	-8.2°-7.0°	-8.0°-7.4°	-4.8°-8.4°
Difference from true value （absolute value)*	2.85° ± 1.97°	2.49 ± 1.57°	2.42 ± 1.85°	3.63 ± 2.21°
Range	0°-8.2°	0°-8.0°	0°-8.0°	0°-7.4°
ICC (single measure)	0.542	0.660	0.459	0.313
95% CI	0.446-0.720	0.520-0.776	0.288-0.622	0.137-0.497
ICC (average measure)	0.761	0.853	0.718	0.578
95% CI	0.617-0.837	0.765-0.912	0.548-0.832	0.323-0.747
p value	<0.001	<0.001	<0.001	<0.001

*: mean±Standard deviation, SS: sacral slope, ICC: interclass correlation coefficient, CI: confidential interval.

Multiple regression analysis showed that both lateral tilt (odds ratio [OR]: 2.127, 95% confidence interval [CI]: 1.328-3.408) and rotation (OR: 1.772, 95% CI: 1.004-3.130), were significant risk factors for measurement error. (Table 2) It also showed that lateral tilt was more correlated with measurement error than rotation.

Table 2. The results of multiple regression analysis

	Odds ratio	95% CI
R	1.772	1.004 ~ 3.130
Lt	2.127	1.328 ~ 3.408

CI: confidential interval.

3.2. Reliability

We calculated interclass correlation coefficient (ICCs) and two-sided 95% CIs for each pairing of assessors using a weighted calculation (Table 3). The ICC scores were all below 0.8 (0.313 – 0.660), and varied significantly between observers, and observer combinations. The best ICC score was obtained when three observers conducted the SS measurements (0.761). Based on the Spearman-Brown formula, an ICC of 0.80 is identified as a highly reliable parameter (see Methods section).

Table 3. Intra- and inter-rater reliability interclass correlation coefficient results

Observer(s)	A	B	C	A and B	B and C	C and A	All
Difference from true value (measurement value)*	1.04 ± 2.68°	-1.68 ± 2.71°	1.84 ± 2.68°	-0.64±2.69˚	0.16±3.58˚	0.80±2.51˚	1.20 ± 3.46°
ICC	0.660[†]	0.459[†]	0.313[†]	0.583	0.373	0.682	0.542
95% CI	0.520－0.776	0.288－0.622	0.137－0.497	0.269-0.783	0.198-0.667	0.354-0.834	0.441-0.841
p value	<0.001	<0.001	<0.001	0.001	0.013	<0.001	<0.001
κ	2.1	4.7	8.9	2.9	6.8	1.9	3.3

＊: mean±Standard deviation, ICC: interclass correlation coefficient, CI: confidential interval, †single measure

Accordingly, we calculated kappa value and the number of measurements required by each observer to raise the ICC score above 0.8 varied between three to nine times for one observer, two to seven times for two observers, and four times for three observers. Altogether, these data suggest that SS measurements of pelvic tilt would represent a reliable parameter for the optimization of THA conditions when three surgeons participate in the measurements.

4. Discussion

In recent years, computer-assisted navigation systems for performing THA have become common. This seems to have improved acetabular component positioning, which otherwise is often insufficient with mechanical acetabular guides for implant orientation [7]. Some investigators have found combined anteversion of acetabular and femoral components to be important in preventing impingement [5,6,7]. Optimal positioning of acetabular and femoral components have been demonstrated with computer modeling [6,7]. However, the components may become malpositioned, even when the acetabular component is placed ideally relative to the bony anatomy, if the pelvic flexion angle of the patient is not considered [9,11,12]. Therefore, surgeons should be aware of the precise pelvic flexion angle.

In this current study, we demonstrated that the accuracy of SS from lateral radiograph was approximately 3°. However, measurement by only one observer is not recommended because differences up to 8° in once and 3.5° in average may be expected if the surgeon does use SS to measure the pelvic flexion angle. Therefore, we recommend that the measurement should be done at least seven times by two observers or at least four times by three observers for a high reliability (ICC > 0.8).

Consequently, this method can be considered clinically useful to know the variation of pelvic flexion angle.

Moreover, we demonstrated that lateral tilt and rotation of the pelvis led to measurement error and lateral tilt had a greater effect on measurement error than did rotation. We believed that the superior endplate of sacrum appears more dome-shaped with lateral tilt than rotation. Consequently, it may be difficult for observers to identify the line parallel to superior endplate of sacrum. Legaye [15] reported on measurement of SS by 7 different observers from lateral radiographs. He demonstrated that the standard deviation of SS when the superior plate of sacrum was dome-shaped was approximately 4 times larger than when the radiograph appeared normal. The measurement of SS is dependent only on the line of the upper end plate of sacrum, and this may not be linear in all cases. Moreover, the upper end plate of sacrum often appears dome-shape according to the particular rotation and lateral tilt. Consequently, this dome-shaped end plate seems likely to produce measurement error and dispersion. However, when the lateral tilt and rotation were reduced while performing the radiographic examination, the measurement error was also reduced because both lateral tilt and rotation of the pelvis were significantly likely to cause measurement error.

One limitation to the current study was the use of synthesized images for measurement, rather than actual X-rays. In actuality, we frequently experienced that superior end plate of sacrum was difficult to distinguish because of fragile bones, image density, or soft tissue noise. Therefore, the images that we used may reduce measurement error compared with measurement by using actual lateral radiographs. However, we could use the true value of SS to evaluate the measurement error strictly, and this is a strong point of this study.

5. Conclusion

Measurement of SS using lateral pelvic radiographs was considered as a clinically useful parameter for optimization of THA. However, if the surgeon does use SS to measure the pelvic flexion angle, we recommend rotation and lateral tilt of the pelvis should reduce at the time of the examination of lateral radiographs. Further, we recommend that the measurement should be done at least seven times by two observers or at least four times by three observers. Measurement by only one observer is not recommended because differences up to 3.5° in average may be expected.

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