

# Influence of lower limbs discrepancy and pelvic coronal rotation on pelvic incidence, pelvic tilt and sacral slope

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## Abstract

**Purpose** Pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS) are important parameters in sagittal spine alignment evaluation. The measurements are a projection of the three-dimensional pelvis onto a two-dimensional radiograph and they may be influenced by orientation of the pelvis. The aim of this study was to assess the influence of pelvic rotation in the coronal plane (CPR) on radiographic accuracy of PI, PT, and SS measurements.

**Methods** Radiological evaluation of the CPR angle was performed on 1 radiological phantom. The radiographs were taken in 5° CPR increments over a range of 0°–45° (evaluated with a digital protractor). On each of the lateral radiograph, PI, PT, and SS were measured three times by three independent researchers. The lowest CPR that changed PI, PT, or SS by  $\geq 6^\circ$  (the highest reported error of measurement of these parameters) was considered as unacceptable. Next, CPR was calculated based on the distance between femoral heads (FHD). The agreement of the calculated and measured CPR was quantified by the intraclass correlation coefficient (ICC) and the median error for a single measurement (SEM), with value 0.75 considered as excellent agreement.

**Results** PI, PT and SS could be measured with an acceptable error of 6° on radiographs with up to 20° pelvic rotation. From 20° CPR onwards the S1 endplate was distorted, that makes the measurements of PI, PT and SS questionable. There was an excellent agreement between CPR measured with a protractor and calculated based on FHD with ICC of 0.99 and SEM of 1.1°.

**Conclusions** Rotation of the pelvis in the coronal plane during acquisition of radiographs influences PI, PT and SS measurements. Substantial error of PI, PT and SS measurements occurs with CPR of more than 20° which is equivalent to a lower limb discrepancy of 5.2 cm. CPR may be calculated while acquiring the radiograph. Further evaluation of the influence of CPR on spinopelvic parameters with a larger sample would be valuable.

**Keywords** Lower limbs discrepancy · Pelvic rotation · Pelvic incidence · Pelvic tilt · Sacral slope

## Introduction

Sagittal spinal balance is provided by reciprocal curves of thoracic kyphosis and lumbar lordosis and their relation to the pelvis [1]. In many diseases, lumbar lordosis is impaired by pathological process and one of the most important treatment aims is to restore physiological balance [1]. Patients with improperly restored spine sagittal balance demonstrate worse clinical outcomes than patients with sagittal spine parameters within normal values [1–3].

Several quantitative positional and anatomic parameters were distinguished to evaluate and predict the spinopelvic sagittal alignment [4]. Pelvic incidence (PI), first introduced by Duval-Beaupère et al. [5], is the most widely used anatomic parameter. Pelvic incidence becomes stable about

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the age of 10 years and remains constant in adolescence and adulthood [4, 6, 7]. Pelvic incidence is hypothesized to be the fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves and based on PI value geometry of physiological lumbar lordosis can be predicted [8], what is crucial in restoration sagittal balance in reconstructive surgery of the spine [1]. As an anatomic parameter, PI is reported to be independent of the position and orientation of the subject [4]. It is true when considering PI as the real anatomic three-dimensional parameter. However, projection of PI from the three-dimensional pelvis onto a two-dimensional radiograph may be influenced by position and orientation of the pelvis while acquiring the radiograph [9]. Tyrakowski et al. revealed that the PI measurements on radiographs are not reliable when the pelvis is rotated more than 30° in the axial plain [9]. However, to our knowledge no study assessing the influence of the coronal pelvic rotation (CPR) on the PI measurements exists.

The aim of this study was to assess the influence of pelvic rotation in the coronal plane (around the sagittal axis) on radiographic accuracy of PI, PT, and SS measurements.

## Methods

Evaluation of CPR was performed on one radiological phantom (Picker-Alderson Pelvic Phantom, Model B, Ser. No. 137) that was composed of normal mature human female pelvis with proximal femora with their heads centered in the acetabula as well as fourth and fifth lumbar vertebrae [9]. The bones were covered with fiber glass that had radiographic density of soft tissues. All of the bones were oriented as in standing position. The phantom was placed on a perfectly leveled stand. The stand enabled the phantom to rotate in coronal plane (around the sagittal axis) to the desired angle that could be established with screw spreader and measured by a digital protractor (82201B-00, GemRed Sensor Technology Co., Ltd, Guangxi, China) with an accuracy of 0.1°. A sphere with a diameter of 25 mm made of metal was placed and fixed in the middle of the superior surface of the phantom and served as a template to calibrate all of the distances measured on the radiographs (Fig. 1a, b).

A true anteroposterior radiograph (the phantom adhering with its whole posterior surface to the X-ray cassette; symmetric iliac wings and foramina obturata on the radiograph) was obtained (Fig. 1a). Next, the lateral radiographs were obtained in the following manner: the model was positioned on the stand with the left hip closer to the X-ray cassette; the X-ray beam was centered in the center of the phantom; and the radiograph showing perfect

overlapping of the femoral heads in the anteroposterior and proximal–distal directions was considered as 0° of rotation (Fig. 2a). Next, the model was rotated every 5° around the sagittal axis, at which point radiograph was obtained. In this manner, radiographs were obtained at a rotation ( $\beta$ ) of 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, and 45° (Fig. 2b–j, respectively).

All of the radiographs were obtained by use of the digital X-ray machine (General Electric Medical Systems, Advantx; General Electric Healthcare, Waukesha, WI, USA). The distance from the X-ray tube to the cassette was 100 cm for all of the radiographs. All of the radiographs were downloaded from the Centricity PACS system (General Electric Medical Systems, Centricity PACS Radiology RA1000 Workstation; General Electrics Healthcare, Barrington, IL, USA) as bitmap images and analyzed quantitatively in CorelDRAW Graphics Suite X6 (Corel Corporation, Ottawa, ON, Canada). The distance measured on each radiograph was calibrated by dividing the real diameter of the metal sphere of 25 mm by its diameter measured on that radiograph.

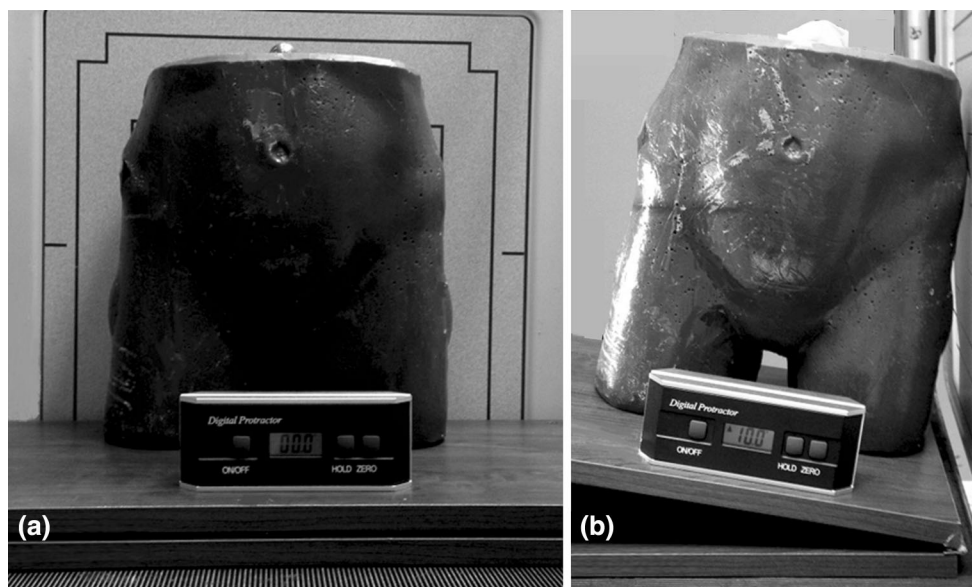
## Influence of pelvic coronal rotation on pelvic sagittal parameters measurements

On each of the lateral radiograph, three pelvic parameters were measured: PI, PT, and SS. PI was defined as the angle between the line joining the center of the bicoxofemoral axis and the center of the S1 endplate and the line orthogonal to the S1 endplate [5]. PI was measured in the following manner: a circle was drawn around the borders of each femoral head [10]. The midpoint of the line joining the centers of the circles surrounding femoral heads (the bicoxofemoral axis) was found automatically by the software. The S1 endplate was drawn as a straight line joining the superoposterior and superoanterior corners of S1 vertebral body. The midpoint of S1 endplate was found automatically by the software. The line joining the midpoint of S1 endplate and the midpoint of the bicoxofemoral axis as well as the line perpendicular to the S1 endplate was drawn. The angle between these two lines was measured automatically by the software and was considered PI (Fig. 2).

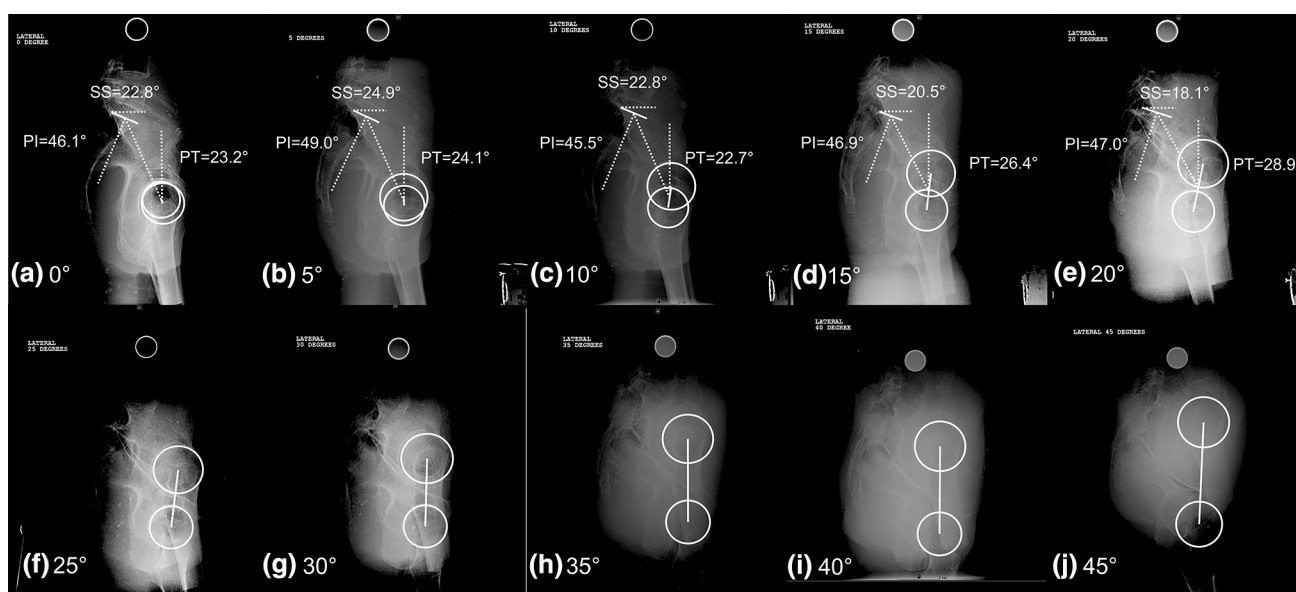
PT was the angle between the line joining the center of the bicoxofemoral axis and the center of the S1 endplate and the vertical line and was measured automatically by the software (Fig. 2).

SS was defined as the angle between the line parallel to the S1 endplate and the reference horizontal line and was measured automatically by the software (Fig. 2).

Three independent researchers (orthopedic spine surgeon with 7 years of experience, orthopedic spine surgeon with 9 years of experience and orthopaedic resident),



**Fig. 1** Phantom on the stand with the digital protractor during the radiographs acquisition **a** anteroposterior radiograph, **b** lateral radiograph with 10° of rotation in coronal plane



**Fig. 2** PI, PT and SS on the lateral radiographs of the pelvis obtained with various degree of pelvic rotation: **a** radiograph with 0° of rotation; **b** radiograph with 10° of rotation; **c** radiograph with 10° of rotation; **d** radiograph with 15° of rotation; **e** radiograph with 20° of

rotation; **f** radiograph with 25° of rotation; **g** radiograph with 30° of rotation; **h** radiograph with 35° of rotation; **i** radiograph with 40° of rotation; **j** radiograph with 45° of rotation. On the figure **f–j** the sacral slope could not be established

measured PI, PT and SS once on each of the lateral radiographs taken with CPR from 0° up to 45°.

For each researcher the values of PI, PT, and SS measured on the radiograph with 0° of rotation were considered as a reference. The lowest angle of CPR while acquiring the radiograph that changed PI, PT, or SS by 6° (the highest reported error of measurement of these parameters) or more was considered as unacceptable [2].

#### Method of calculating pelvic rotation angle based on anteroposterior and lateral radiographs

The calculations of the radiological parameters values were performed based on method proposed by Tyrakowski et al. [9].

On the anteroposterior radiograph, a circle was drawn around the borders of each femoral head. The centers of

these circles were found automatically by the software and the linear distance between the centers of the femoral heads (FHD) ( $A$ ) was measured (Fig. 3).

On each of the lateral radiographs, a circle was drawn around the borders of each femoral head, and the centers of the circles were found automatically by the software. The vertical linear FHD ( $B$ ) was measured (Fig. 4a–i). These distances were subsequently used to calculate the sinus of the angle ( $\alpha$ ) of rotation of the pelvis when the radiograph was obtained according to the trigonometric formula 1 (Fig. 5a, b):

$$\sin \alpha = B/A.$$

Thus, the angle of CPR ( $\alpha$ ) could be calculated according to the formula 2:

$$\alpha = \arcsin B/A.$$

All of the calculations of  $\alpha$  values were performed by use of formulas (ASIN, DEGREE) in the Microsoft Office Excel 2007 (Microsoft, Redmond, WA, USA).

The angles of pelvic rotation measured by the protractor while acquiring the radiographs ( $\beta$ ) and calculated according to formula 2 ( $\alpha$ ) were compared and their agreement was quantified by the intraclass correlation coefficient (ICC) and the median error for a single measurement (SEM) [11].

The measurements of the distances  $A$  and  $B$  and subsequently calculations of the angle of CPR were performed by the same researcher three times at 4-week intervals. The order of the radiographs in the second and third series of measurements was different and random. Two other independent researchers (orthopedic resident and orthopedic spine surgeon with 9 years of experience) performed

the same measurements and calculations once. Intraobserver reproducibility and interobserver reliability of the proposed method of calculating the angle of CPR were tested and quantified by ICC and SEM [11].

### Statistical analysis

The data were analyzed using the JMP 10.0.2 (SAS Institute Inc, Cary, NC, USA) statistical software. The ICC value of less than 0.40 indicated poor agreement, 0.40–0.75 indicated fair to good agreement, and values greater than 0.75 reflected excellent agreement [12].

## Results

### Influence of pelvic rotation on pelvic sagittal parameters measurements

The values of PI, PT, and SS measured on lateral radiographs are presented in Table 1.

PI, PT and SS could be measured with an acceptable error of  $6^\circ$  on radiographs with up to  $20^\circ$  pelvic rotation, Table 1. Thus, the maximum angle of pelvic rotation while acquiring a lateral radiograph without significantly influencing spinopelvic measurements was  $20^\circ$ , Table 1.

It is important to note that all researchers reported that from  $20^\circ$  of pelvic rotation in the coronal plane onwards, the S1 endplate was distorted and thus drawing the line parallel to the S1 endplate was impossible, Fig. 2. That makes the measurements of PI, PT and SS above  $20^\circ$  of CPR questionable.

### Method of calculating the pelvic rotation angle based on anteroposterior and lateral radiographs

FHD measured on the anteroposterior radiograph was 150.66 mm. The vertical FHD measured on the subsequent lateral radiographs with  $0^\circ$ ,  $5^\circ$ ,  $10^\circ$ ,  $15^\circ$ ,  $20^\circ$ ,  $25^\circ$ ,  $30^\circ$ ,  $35^\circ$ ,  $40^\circ$ , and  $45^\circ$  (Fig. 4a–i) are listed in Table 2. Comparison of the angles of rotation of the pelvis while acquiring the radiographs calculated ( $\alpha$ ) vs. measured by the protractor on the stand ( $\beta$ ) when the radiographs were taken is presented in Table 2.

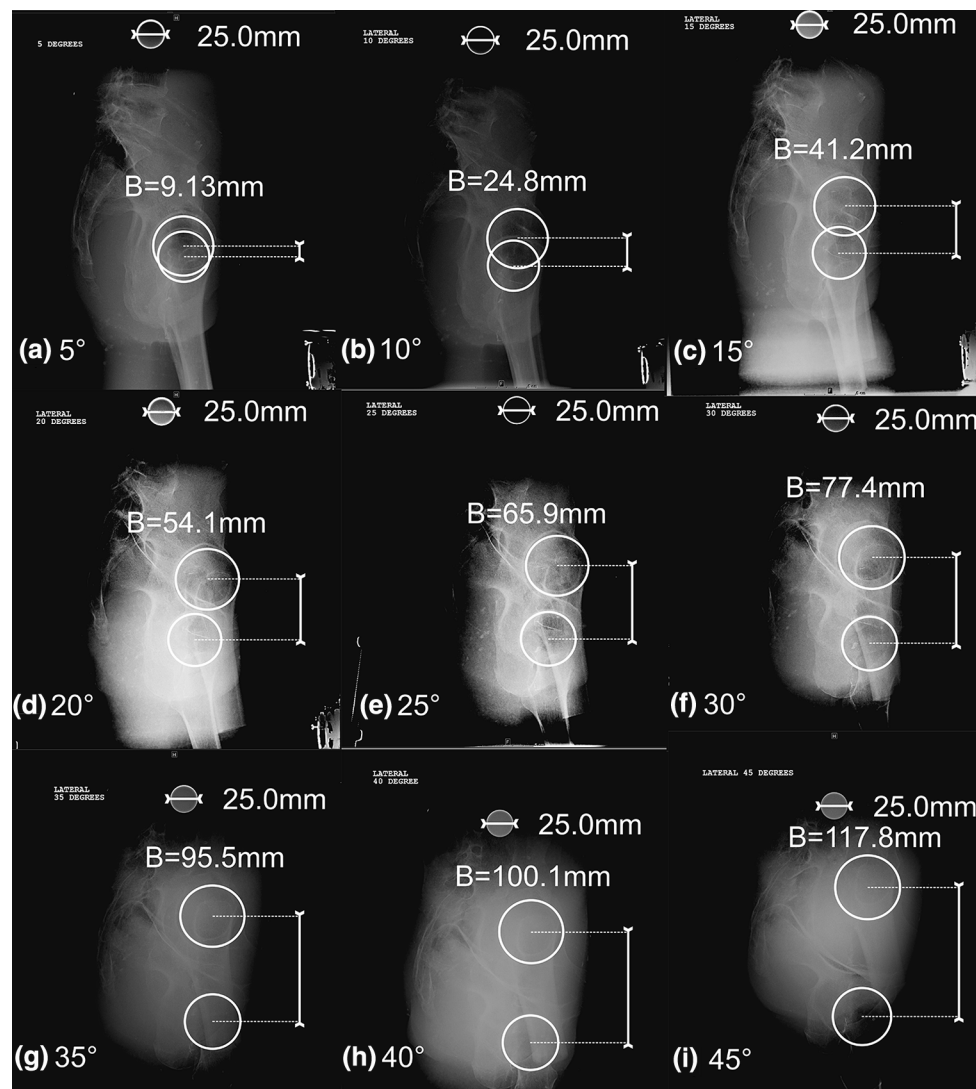
There was an excellent agreement between the angle of rotation of the pelvis measured by use of the protractor ( $\beta$ ) and calculated using our method ( $\alpha$ ) with ICC of 0.99 and SEM of  $1.1^\circ$ .

Excellent intraobserver reproducibility and interobserver reliability were demonstrated. The calculated rotation angle based on measured FHD on the lateral radiographs acquired in coronal rotation of the pelvis



**Fig. 3** Anteroposterior radiograph of the phantom with linear distance between the centers of the femoral heads





**Fig. 4** Lateral radiographs of the pelvis obtained with various degree of pelvic rotation: **a** radiograph with 5° of rotation; **b** radiograph with 10° of rotation; **c** radiograph with 15° of rotation; **d** radiograph with 20° of rotation; **e** radiograph with 25° of rotation; **f** radiograph with

30° of rotation; **g** radiograph with 35° of rotation; **h** radiograph with 40° of rotation; **i** radiograph with 45° of rotation. *B* indicates vertical distance between the centers of the femoral heads

demonstrated an ICC of 0.99 with SEM of 0.4° and an ICC of 0.99 with SEM of 0.6°, respectively.

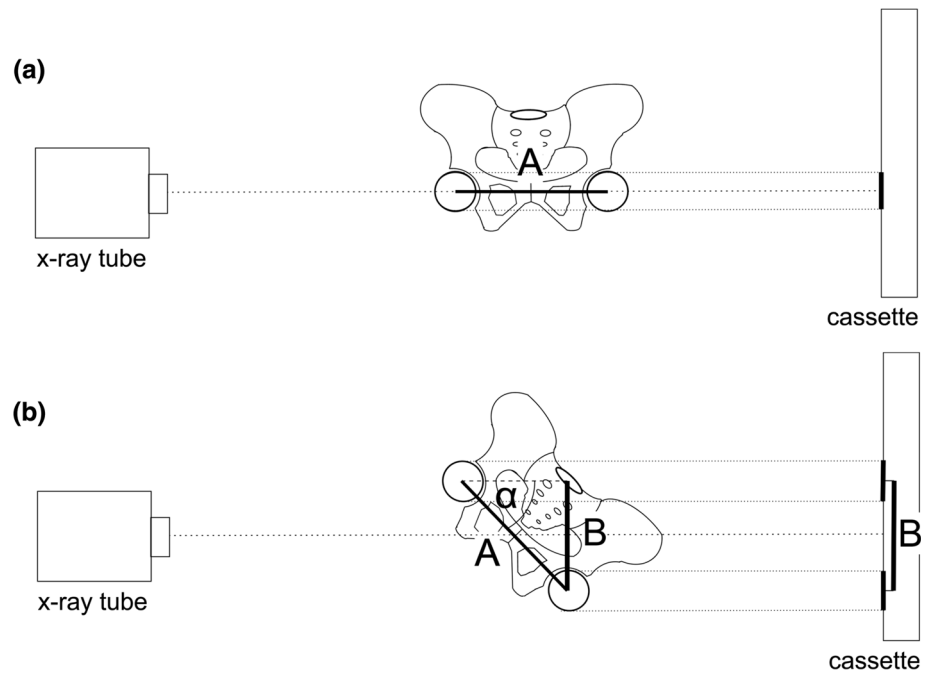
## Discussion

The purpose of this study was to draw attention to the potential problem and the possible influence of CPR on measurements of radiological spinopelvic parameters, namely PI, PT and SS. We believe that pelvic CPR is a common issue, which is underestimated and often unnoticed. If such an inadvertence is discovered the question of repeating radiographs and providing additional X-ray exposure to the patient arises. Thus, the knowledge about

the range of CPR providing reliable measurement of PI, PT, and SS on the lateral radiographs is important and need to be validated.

The reasons for pelvic rotation in coronal plane on the radiograph can be divided into apparent associated with X-ray source position (subsequent to divergent X-ray beam) and with true pelvis rotation [13]. Reasons for true pelvic rotation are lower limbs discrepancy (LLD), lumbar structural scoliosis, hip contractures, muscles contractures and their combinations [14]. One of the most common is LLD with its prevalence ranging from 4 to 40 % [15, 16]. In the populations without impairments LLD affects 4.0–8.0 % [15, 17]. Although, the LLD should be equalized to level the pelvis when acquiring the radiograph, it is

**Fig. 5** Diagram presenting the technique of obtaining lateral radiograph of the pelvis—view from the anterior direction: **a** ideal lateral radiograph obtained with no rotation of the pelvis in the coronal plane; **b** lateral radiograph obtained with  $\alpha$  rotation of the pelvis in the coronal plane *A*—linear distance between the centers of the femoral heads in the coronal plane (measured on the anteroposterior radiographs); *B*—vertical distance between the centers of the femoral heads in the sagittal plane (measured on the lateral radiographs)



**Table 1** Pelvic incidence, pelvic tilt, and sacral slope measured on the lateral radiographs acquired with the particular angle of pelvic rotation

Rotation $\beta$ (°)	Parameter					
	PI (°)	PI $\beta$ -PI0° (°)	PT (°)	PT $\beta$ -PT0° (°)	SS (°)	SS $\beta$ -SS0° (°)
0	46.1	0	23.2	0	22.9	0
5	49.0	2.9	24.1	0.9	24.9	2.0
10	45.5	-0.6	22.7	-0.4	22.8	-0.1
15	46.9	0.8	26.4	3.2	20.5	-2.4
20	47.0	0.9	29.0	5.8	18.1	-4.8
25	–	–	–	–	–	–
30	–	–	–	–	–	–
35	–	–	–	–	–	–
40	–	–	–	–	–	–
45	–	–	–	–	–	–

– S1 outline not (insufficiently) visible, *PI* pelvic incidence, *PT* pelvic tilt, *SS* sacral slope,  $\beta$  angle of pelvic rotation in the coronal plain while acquiring the radiograph measured by the protractor

not uncommon to assess the radiographs with pelvis unlevelled in everyday clinical practice. In this study we aimed to set X-ray source in a proper position to avoid the apparent CPR.

In our results the measurements of FHD could be performed for a wide range of CPR up to 45° and measurements of spinopelvic parameters were limited to CPR of 20°. When spinopelvic parameter values measured in 0° of coronal rotation were compared with measurements performed in subsequent degrees of coronal rotation, the cut-off point with substantial mistake of 6° for PI, PT and SS was not achieved up to the level of 20° of CPR. The observation that above 20° of CPR the contour of S1

proximal endplate is very difficult to distinguish was confirmed by all raters, Fig. 2. Thus, it was impossible to establish reliable values of PI, PT and SS for the angles of CPR of 25° and more. We expected that in some point of coronal rotation the outline of the S1 superior endplate could be difficult to distinguish, due to overlapping lumbar spine and pelvis bony structures and changes in the shape of S1 endplate that becomes eclipse-like when rotation increases. However, we did not assume that the outline of the S1 endplate could be impossible to set. What is more, additional distraction was provided by overlapping soft tissues, especially the shadow of the buttock could also be misleading when S1 endplate was determined, Fig. 2. With

**Table 2** Comparison of the calculated and the measured angles of pelvic rotation while acquiring the lateral radiographs

Rotation $\beta$ (°)	$B$ measured in rotation (mm)	$\sin \alpha = B/A$	Calculated $\alpha$ (°)	$\alpha - \beta$ (°)
0	0	0	0	0
5	9.13	0.0606	3.5	-1.5
10	24.84	0.1649	9.5	-0.5
15	41.24	0.2737	15.9	0.9
20	54.06	0.3588	21.0	1.0
25	65.91	0.4375	25.9	0.9
30	77.43	0.5139	30.9	0.9
35	95.54	0.6341	39.3	4.3
40	100.05	0.6641	41.6	1.6
45	117.84	0.7821	51.4	6.4

$A$  the distance between the centers of the femoral heads measured on the anteroposterior radiograph which is 150.66 mm,  $B$  vertical distance between the centers of the femoral heads measured on the lateral radiograph,  $\alpha$  calculated angle of pelvic rotation,  $\beta$  angle of pelvic rotation measured with protractor

CPR the femoral heads remain well visible, which was confirmed by good ICC results of the distance measurements.

When we compared our results with results of horizontal rotation published by Tyrakowski et al. the presented results for single measurement revealed lower degree of the pelvic rotation cut-off point for reliable measurements for PI and PT, and higher for SS [9]. When comparing FHD measurements and calculation of the rotation angle, our results are in-line with Tyrakowski et al. [9].

The distance between the centers of the femoral heads on the lateral radiograph reflects both the apparent and true CPR. Thus, when the X-ray source is set correctly, this distance is identical with true rotation of the pelvis and can be used to measure LLD. Based on this assumption the measured distance is the LLD value in mm (distance  $B$ , Table 2; Figs 2, 5). Taking into consideration, that the radiological phantom, used in this study reflects adult female pelvis, the presented LLD results reflecting subsequent rotation angles could be applicable in everyday practice (distance  $B$ , Table 2). However, FHD may vary in select patients and in these cases the reliable range of LLD should be calculated from the trigonometric formula. The distance between centers of the femoral heads can be measured on radiographs or CT scans and used to further calculations. Mullaji et al. revealed, that FHD on CT scans of the Indian population was around 16 cm with little influence by sex, body mass, or height [18]. Thus, for this distance of 16 cm, every 5° of the pelvic coronal rotation would reflect 13.94 mm of LLD. In our study the distance between the femoral heads measured on the anteroposterior radiograph was 150.66 mm. Thus, in our study 5° of CPR would reflect 13.13 mm of LLD. According to these data the PI, PT and SS measurements would not be affected by LLD up to 5.2 cm. This we find as an important clinical implication of our study. We also showed, that application

of trigonometric rules proposed by Tyrakowski et al. [9]. is a reliable method of calculating CPR. Thus, using these simple mathematical calculations we can make an important clinical decision regarding usefulness of a particular lateral radiograph of the spine for proper measurements of PI, PT and SS.

When applying the results of this study to clinical practice both true and apparent pelvic rotation should be taken into consideration. A combination of small LLD and improper patient positioning or focus of the X-ray source at improper level may result in radiographs which are not reliable for spinopelvic parameter measurements. It is therefore critical to achieve proper source positioning and apply standardized patient positioning with equalized LLD.

The apparent rotation in ordinary X-ray devices differs depending on many factors such a cassette size, distance from the X-ray source and source position. However, when new imaging techniques are applied, the apparent pelvic rotation seems to be negligible [19].

One of the limitations of this study is the fact, that all measurements were performed on one phantom. The phantom was designed to reflect normal anatomy and provide the best quality of radiographs. The use of the radiological phantom ensure the possibility of perfect positioning (much more precise than in assessment of patients) and performing large number of X-rays without harm of X-ray exposure. However, from the statistical point of view bigger sample size would be beneficial.

The strong side of this study is possible clinical application. The knowledge of the LLD cut-off point for reliable measurements may result in more accurate operative planning and may help to avoid to unnecessary radiograph repetition. The possibility of assessment of the combination of the apparent and the true rotation could be beneficial, especially for patients with coexisting LDD. These results

can be valuable in radiograph quality analysis for research projects concerning spinopelvic parameters.

## Conclusions

Rotation of the pelvis in the coronal plane during acquisition of radiographs influences PI, PT and SS measurements. Substantial error of PI, PT and SS measurements occurs with pelvic rotation in the coronal plane of more than 20°. The LLD up to 5 cm appeared to have a negligible influence on PI, PT and SS measurements. Pelvic rotation in the coronal plane while acquiring the radiograph may be calculated by use of the distance between the centers of the femoral heads on anteroposterior radiograph and the vertical distance between the centers of the femoral heads on the lateral radiograph. Further evaluation of influence of pelvic rotation in coronal plane on spinopelvic parameters with larger sample would be valuable.

## Compliance with ethical standards

**Conflict of interest** None.

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