Original article
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An alternative method for measuring patient's sagittal balance parameters in sitting and standing positions

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Abstract

Introduction The understanding of the biomechanics of movements in the spinopelvic segment plays an important role in the successful treatment of patients with hip-spine syndrome. Analysis of the biomechanical processes occurring in the biokinematic chain of the spine-pelvis-hip during the transition from standing position to sitting position allows us to conclude that the acetabular axis of rotation of the pelvis in space is not the only one. Classical methods for measuring PI, PT, overhang S1 are applicable for patients in a standing position and use the hip joint as a starting point, since it is the point of rotation of the pelvis in space in a standing position. Previously, using mathematical modeling, we described spatial changes in the pelvis during a given change in the body position and showed the presence of a second point of pelvis rotation in space, which appears in a sitting position. We assumed that in a sitting position, it is necessary to use other methods for calculating indicators of spinopelvic relationships for their determination.

Purpose of the study was to evaluate the parameters of patients' sagittal balance using the proposed alternative method in standing and sitting positions.

Materials and methods Medical documentation and the results of X-ray examination of 20 patients with unilateral idiopathic coxarthrosis who underwent total hip replacement surgery were analyzed. The radiographic parameters were calculated: PI, PT, overhang S1 in standing and sitting positions, anterior inclination of the acetabular component; parameters PI ischial, PT ischial, deviation of the ischial tuberosities in standing and sitting positions were proposed and calculated.

Results The study shows that there is no statistical difference in the values of the angles PI standard for a standing position and PI ischial for a sitting position. It corresponds to objective data and is generally accepted. Examples of changes in radiographic parameters of the sacral slope and the deviation of the ischial tuberosities were shown reflecting the rotation of the pelvis in space through the second, ischial axis, that confirm the biaxial concept of pelvic rotation.

Discussion The calculations demonstrated the possibility of using alternative indicators of spinopelvic relationships (PT, distance of overhang of the sacrum (overhang S1), deviation of the ischial tuberosities). They enabled assessment of the spatial transformation of the pelvis and the ability to predict the spatial position of the acetabulum, which is an important factor for successful treatment of patients with combined pathology of the hip joint and spine.

Conclusion Our findings complement the biaxial concept of pelvic rotation. An alternative method for measuring sagittal balance parameters in a sitting position has been proposed. Further research is required to assess the practical significance of this method.

Keywords: spine, hip joint, lower extremity, spinopelvic relationship, orientation, parameters

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INTRODUCTION

Dislocation of the head of the hip joint implant or instability of the hip implant occurs in approximately 3 % of patients after surgery. This complication is the most common early complication of total hip replacement and the most common reason for revision interventions in total hip replacement. The identified risk factors are repeated interventions, low level of surgeon's skills, female gender, age over 70 years, history of previous fractures or arthritis, obesity, the nature of the joint damage and the complexity of the replacement performed, the size of the acetabular component relative to the implant head, and the method of suturing the surgical wound [1].

The spinopelvic relationships recently described in numerous publications show a great interest of orthopaedic surgeons in understanding the kinematics of the pelvis to prevent complications after hip replacement, since the instability of the implant is frequently associated with various deviations in the spinopelvic balance [2–16]. The study of Legaye et al. describes the main parameters of the spinopelvic balance and methods for their measurement [17]. Classical measurements of spinopelvic parameters such as SS, PT, PI and overhang S1 are performed on a lateral radiograph of the pelvis relative to the upper endplate of the sacrum and the femoral heads.

Thus, Legaye et al. formed the idea of pelvic rotation only relative to the heads of the femurs with static centers of rotation, which is a paradigm for orthopaedists. Subsequent investigations considered spinopelvic relationships solely based on the standing position, and for planning operations on the spine, the surgeons proceeded only from spinal curves in the standing body position, without considering their inevitable changes in the sitting position. It obviously does not correspond to real postures in everyday life.

In a previously published article, we used mathematical modeling to describe spatial changes in the pelvis by changing body positions from a standing position to a sitting position, with the formation of a second point of rotation of the pelvis in space, being the ischial tuberosities [18]. Based on that, we made the assumption that in a sitting position, calculations of spinopelvic balance parameters should be made with a different method.

The purpose of the work was to evaluate the parameters of the patient's sagittal balance in standing and sitting positions using the proposed alternative method.

MATERIAL AND METHODS

The study included 20 patients: 8 men (mean age 57 years) and 12 women (mean age 62 years) with ASA II physical status (classification of the American Association of Anesthesiologists) who underwent total hip replacement surgery for unilateral idiopathic coxarthrosis and a healthy contralateral joint, who had a fully restored hip joint function 4–6 months after surgery (Harris hip score 70–75 points), without clinical manifestations of hip-spine syndrome. Non-inclusion criteria were bilateral coxarthrosis, limited range of motion in the contralateral joint, significant difference in the length of the lower extremities (more than 2 cm), dislocations and subluxations in the hip joint, installation of the acetabular component outside the Lewinnek "safe zone", malposition of the femoral component, dislocation, traumatic dislocation of the femoral component which occurred under significant force (trauma, fall from height, etc.), history of periprosthetic infection, obesity of the third grade or more, concomitant pathology of the lumbar spine with clinical manifestations.

The patients took radiographs of the pelvis in standing and sitting positions, in frontal and lateral projections.

Parameters studied:

1. PI ischial (Fig. 1): the angle between a line drawn perpendicular to the middle of the upper endplate of the S1 vertebra and a line connecting the middle of the upper endplate of the S1 vertebra with the lowest point of tuberosity of the ischium (or the middle of the ischium) bone;

2. PT ischial (Fig. 2): the angle between the line connecting the middle of the upper endplate of the S1 ver-tebra with the lowest point of the tuberosity of the ischium, and a vertical line drawn through the lowest point of the tuberosity of the ischium;
3. Deviation of S1 relative to the ischial tuberosities (Fig. 3): the distance between the middle of the upper endplate of the S1 vertebra and a vertical line drawn through the lowest point of the ischial tuberosity. The classic parameter "overhang of S1" reflects the overhang of the S1 vertebra, and ultimately of the pelvis over the support. In the standing position, the support is on the heads of the femurs, in the sitting position on the ischial tuberosities;
4. classical PI (Fig. 4): the angle between a line drawn perpendicular to the middle of the S1 endplate and a line connecting the middle of the S1 endplate to the center of the femoral head;
5. PT is the angle between the vertical and the line connecting the middle of the upper endplate of S1 to the center of the femoral heads.

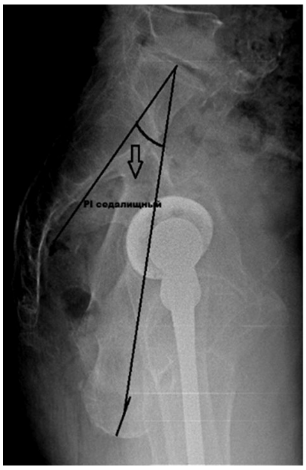

Fig. 1 PI ischial

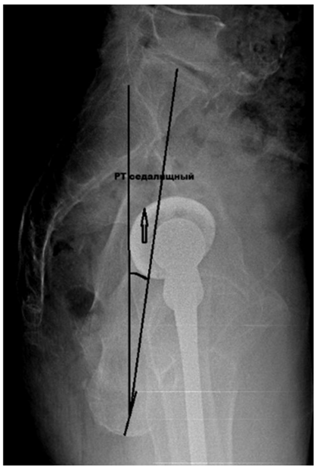

Fig. 2 PT ischial

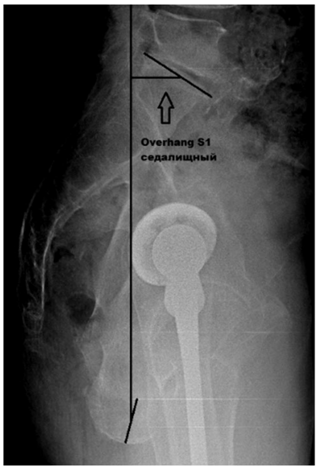

Fig. 3 Deviation of ischial tuberosities

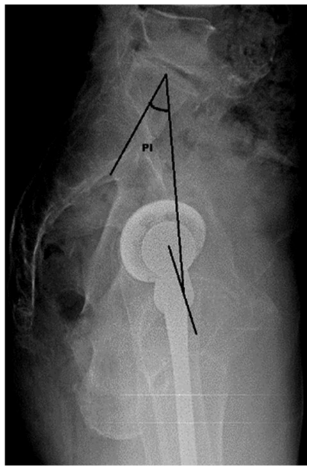

Fig. 4 PI angle

Empirical data distributions were tested for agreement with the law of normal distribution using the Shapiro – Wilk test. Due to non-normality of the data, non-parametric tests were used to compare the parameters. We compared the data obtained with alternative measurements of the parameters PI, PT and overhang S1 and the lateral slope of the acetabulum with the results obtained with the standard measurement using the paired Wilcoxon test. Descriptive characteristics are presented as median [first quartile; third quartile] (MED [Q1; Q3]), mean ± standard deviation (MEAN ± SD), minimum and maximum values (MIN–MAX). To assess the differences between the compared indicators, the pseudomedian of paired differences (PMED) with a 95% confidence interval (95 % CI) and the standardized mean difference (SMD) with a 95% CI were calculated. The difference was considered statistically significant if $p < 0.05$. All statistical calculations were carried out in the IDE RStudio (version 2023.09.0 Build 463 — © 2009–2023 Posit Software, PBC) in the R language (version 4.1.3 (2022-03-10)).

RESULTS

Comparing the results of the standard and ischial PI angles, no significant differences were noted depending on changes in body positions, which corresponds to the concept of incidence (Table 1, Fig. 5 and Fig. 6).

Table 1

Table of values of pelvic incidence (PI, PT) standard and ischil, sacral overhang (overhang S1) and lateral inclination of the acetabular component in standing and sitting positions

Parameter, n = 20		MED [Q1; Q3], Mean ± sd; MIN-MAX		Comparison of standing vs sitting	
		Standing	Sitting	Evaluation of difference PMED [95 % CI] SMD [95 % CI]	Wilcoxon test, p
PI standard		52.5 [49.75; 56.25], 54.4 ± 10.41; 40–78	52.5 [50; 56.25], 54.5 ± 10.4; 39–78	0 [0; 0.5], 0.01 [−0.61; 0.63]	0.813
PI ischial		35 [31; 40.25], 36.75 ± 8.25; 25–55	34 [31.5; 39.25], 36.15 ± 8.37; 22–53	0.5 [0.5; 2], 0.07 [−0.55; 0.69]	0.173
Comparison standard vs ischial	PMED [95 % CI] SMD [95 % CI]	17.5 [17; 17.5], 1.88 [1.13; 2.63]	18 [17.5; 18.5], 1.94 [1.18; 2.7]	–	
	Wilcoxon test, p	< 0.001*	< 0.001*		
PI standard		11.5 [6; 18.25], 12.6 ± 8.18; 1–27	40.5 [35; 44.5], 38.6 ± 10.51; 12–56	26 [25.5; 27.5], 2.76 [1.88; 3.64]	< 0.001*
PI ischial		−5.5 [−12; 3.25], −3.95 ± 8.4; −16–9	20.5 [15.75; 23.5], 19.55 ± 8.03; 1–32	23.5 [22,5; 24], 2.86 [1.97; 3.75]	< 0.001*
Comparison standard vs ischial	PMED [95 % CI] SMD [95 % CI]	17 [16.5; 17], 2.13 [1.58; 2.67]	20 [19.5; 20], 2.16 [1.61; 2.71]	–	
	Wilcoxon test, p	< 0.001*	< 0.001*		
Overhang S1, mm		24.5 [9.75; 36.75], 26.25 ± 17.33; 3–57	75.5 [70.25; 81.25], 73.85 ± 14.68; 32–100	46.5 [36.5; 57.5], 2.96 [2.05; 3.87]	< 0.001*
Lateral inclination of the acetabulum, °		39.5 [30; 48.5], 39.5 ± 11.36; 18–59	61 [51.75; 68], 60.2 ± 12.15; 38–83	20.5 [16; 25], 1.76 [1.02; 2.5]	< 0.001*

Note: * significantly different values, $p < 0.05$

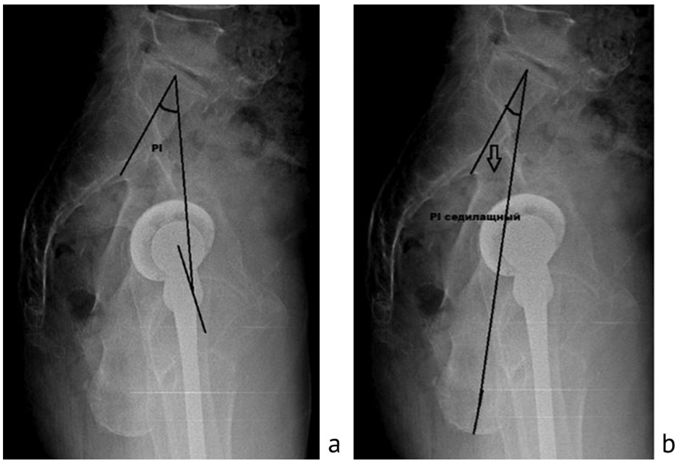

Fig. 5 Lateral radiograph of the pelvis in standing position: *a* finding the PI angle in standing position; *b* finding the PI ischial angle in standing position

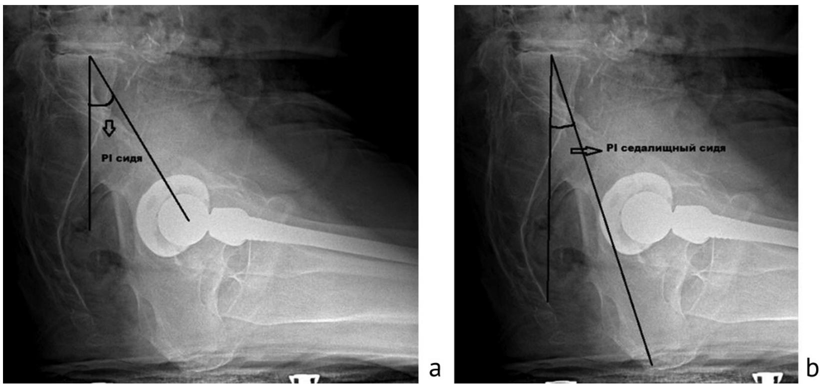

Fig. 6 Lateral radiograph of the pelvis in sitting position: *a* finding the PI angle in sitting position; *b* finding the PI ischial angle in sitting position

When comparing the values of pelvic inclination angles with their standard measurement (PT standard), these changes are consistent with the generally accepted concept. By changing body positions, the angle of inclination of the pelvis in standing position averages 11.5°, and in sitting position reaches 20.5° with an angle difference of 9° ($p < 0.001$), which, in fact, does not contradict the concept of rotation of the pelvis around an axis, drawn through the centers of rotation of the femoral heads. However, if we consider the differences in the angles of inclination of the pelvis (PT ischial) relative to the ischial tuberosities, as a support and the corresponding axis of rotation, then in the standing position the pelvic tilt will be –5.5°, and in the sitting position, respectively, +20.5° with the difference in angles is up to 25°, the values of the standing and sitting angles differ by 2.5 times (Table 1, Fig. 7). This is explained by the true deviation of the pelvis when resting on the ischial tuberosities, since in the final phase of taking the sitting position there is no support on the heads of the femurs bones, and, accordingly, the pelvis cannot rotate relative to them according to the laws of physics. Thereby, the heads of the femurs and acetabulum are displaced posteriorly with simultaneous separation, which is demonstrated in a mathematical model [18].

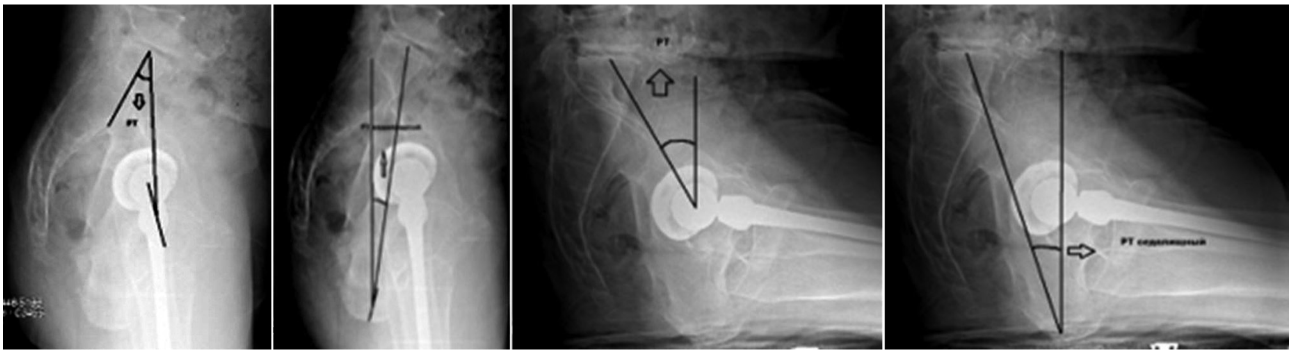

Fig. 7 Lateral radiograph of the pelvis with calculation of standard PT and PT ischial in standing and sitting positions

The last statement is confirmed by the obtained results of measuring overhang S1 (overhang of the sacrum) (Table 1, Fig. 8). Please note that, according to the incidence matrix, the distance (graph) between the vertices (the middle of S and the center of rotation G) relative to the pelvis is constant, and changes that occur when changing the position of the body relative to the vertical drawn from point S are possible only when the pelvis rotates. Thus, in standing position, the average values of overhang are 26.25 ± 17.33 mm with a median of 24.5 mm; the range of values in the group from 9.75 to 36.75 mm reflects the rigidity or excessive mobility of the spinopelvic relations, while by sitting, due to retroversion, the overhang of the sacrum over the center of rotation (acetabulum) decreases, the sacrum shifts backwards increasing the distance from the center of rotation by an average of 75.5 mm ($p < 0.001$).

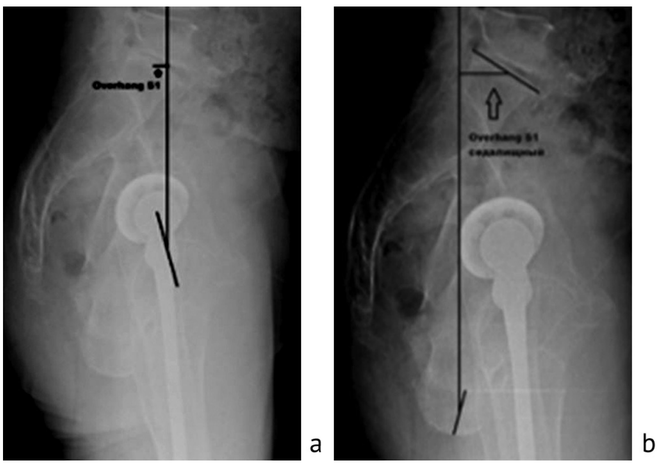

Fig. 8 Lateral radiograph of the pelvis in standing position: *a* finding the value "overhang of S1" in standing position; *b* finding the values of "deviation of the ischial tuberosities" in standing position

Our judgments of sacral deviation are based on determining the distance between two landmarks that are a vertical line drawn from the middle of the endplate and the center of rotation, which is static, as generally accepted. However, if we add a third landmark, taking it as zero, we can evaluate the spatial transformation of the previous landmarks relative to the last one. For this purpose, we introduced a third landmark, proposing the concept of "deviation of the ischial tuberosities" by analogy with the overhang of the sacrum (overhang S1). When measuring the "deviation of the ischial tuberosities," the distances O and V in the standing position were 49.5 mm and 23.5 mm, respectively. But in sitting position, the distances O_1 (15 mm) and V_1 (61) change in inverse proportion, with distance O decreasing and distance V increasing (Table 2, Fig. 9). Changes in the values of $V–V_1$ distance correlate with changes in the values of overhang S1, which reflects the backward inclination of the pelvis (retroversion of the pelvis) and corresponds to the generally accepted deviation; however, a decrease in the $O–O_1$ distance reflects the linear displacement of the acetabulum backward relative to the ischial tuberosities during support on them with a displacement of on average up to 50 mm, while the linear displacement S_1 is 84 mm. This difference is explained by the difference in radii, if the point of rotation of the pelvis upon completion of acquiring the sitting position is the ischial tuberosities.

Table 2

Values of "Deviation of the ischial tuberosities relative to the middle of the endplate S_1 (V) and the centers of rotation of the femoral heads (O) in standing and sitting positions"

Deviation of the ischial tuberosities, *n* = 20		MED [Q1; Q3], MEAN ± SD; MIN-MAX		Comparison standing vs sitting	
		Standing	Sitting	Evaluation of difference PMED [95 % CI] SMD [95 % CI]	Wilcoxon test, *p*
Relative to the rotation centers of femoral heads (O)		49.5 [44.75; 54.25], 48.4 ± 8.88; 27–61	15 [7.75; 21], 14.55 ± 8.13; 1–29	35.5 [28.5;40.5] 3.98 [2.89;5.07]	< 0.001*
Relative the middle of the endplate S_1 (V)		23.5 [15; 36], 25.25 ± 18.64; −23–55	−61 [−70.75; −49.25], −56.7 ± 25.87; −92–24	86.5 [72;99] 3.63 [2.61; 4.66]	< 0.001*
Comparison O vs V	PMED [95 % CI] SMD [95 % CI]	23.5 [15.5;29.5] 1.59 [0.87; 2.3]	74.89 [68.5; 80.5] 3.72 [2.68; 4.76]	–	
	Wilcoxon test, *p*	< 0.001*	< 0.001*		

Note: * significantly different values, $p < 0.05$

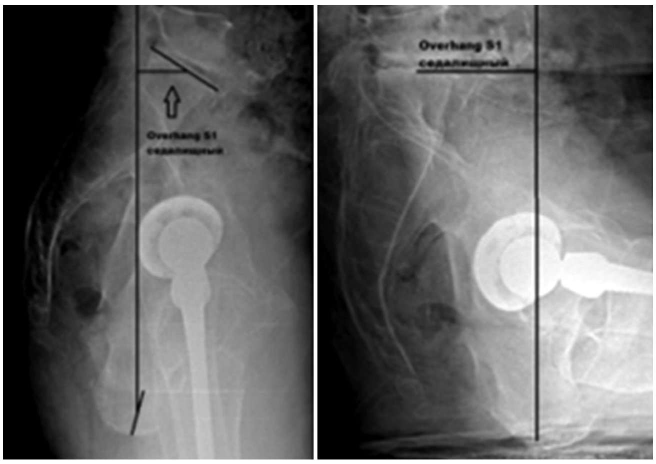

Fig. 9 Lateral radiographs of the pelvis with calculation of the deviation of the ischial tuberosities in standing and sitting positions

Having shown radiographic signs of pelvic kinematics relative to two axes of rotation, in confirmation of the correctness of the mathematical model of pelvic rotation described by us earlier, we assumed that if a second body is installed into the incidence matrix (pelvis), then the spatial transformation of the second body will correspond to the kinematics of the pelvis.

We have come to understand the following situation: if a second body (acetabular component) is installed in a stable rigid incidence matrix (pelvis) with its rigid fixation, then the spatial transformation of the acetabular component will correspond to the kinematics of the pelvis, making turns similar to the rotation of the pelvis. In this case, the spatial transformation of the acetabular component can be assessed by determining the anterior inclination angle of the acetabulum (lateral angle of acetabulum inclination) on lateral radiographs in standing and sitting positions.

A comparative analysis of the lateral inclination of the acetabular component in standing and sitting positions showed significant differences in the angle of lateral inclination (Table 1).

DISCUSSION

The support of the structures of the ilium on the head of the femur forms the points of rotation of the pelvis, centers of rotation, with the formation of the axis of rotation of the latter, characteristic of standing position. For judging pelvic rotation Legaye et al. introduced the parameters of "the sacral slope (SS)" and "the pelvic tilt (PT)". The peculiarity of these parameters is that they are measured in relation to the horizontal SS and vertical PT lines, which are relative zeros [17]. Thereby, the lines that form the above parameters are interconnected. Their relationship is described by the theory of graphs and incidence as a fundamental feature of rigid systems, in particular the pelvis, which has constant rigidly interconnected landmarks with stable connections (distance, angles and direction), which in discrete mathematics is called the incidence matrix [19]. The incidence of the vertices corresponds to the middle of the endplate and the centers of the heads of the femurs, and the edges of the graph are the line connecting them, as well as the vertical and horizontal lines that create the adjacency of the graph vertices to form the parameters SS, PT, PI. Thus, the pelvic incidence (PI) allows us to establish other incident vertices (anatomical landmarks) and connection graphs (horizontal and vertical lines drawn from selected anatomical landmarks) in a connected rigid system, which we used in our work.

From the works of Kapandzhi, we know that there are two main trabecular systems that transfer loads from the spine via the sacroiliac joint to the acetabulum and ischium, bearing the body weight in sitting position [20]. We find confirmation of the existing loads on the femoral heads in the work of Philippot et al., in which the authors describe the positioning of the acetabulum above the femoral head, while the extended hip in standing position allows the load of the upper body to be shunted to the pelvis [21]. The ischial tuberosities in sitting position take on the weight of the body and become fulcrum points, similar to the support of the structures of the iliac bones on the heads of the femurs in standing position. Thus, a second axis of rotation of the pelvis is formed, characteristic of sitting position. In our previous study, we used mathematical modeling to describe spatial changes in the pelvis in changing body positions [18]. For practical purposes, we decided to evaluate changes in the position of the pelvis in lateral radiographs with the possibility of proving the rotation of the pelvis around two axes depending on its position, standing or sitting. To do this, we used new methods for determining spinopelvic parameters.

The method we used is similar to that described by Legaye et al., using the principles of the incidence matrix [17, 18]. But in our study, the radiographs of the pelvis in the lateral view taken in standing posture were supplemented by an additional lateral X-ray of the pelvis taken in sitting position, with the calculation of new parameters: PI ischial, PT ischial, deviation of the ischial tuberosities. Since we assumed that there is rotation of the pelvis if the support goes to the ischial tuberosities in sitting position, we designated the ischial tuberosities with the corresponding point, connected them to the middle of the endplate of the S1 segment of the sacrum and drew a vertical line, obtaining the angles PI ischial and PT ischial pelvic, inherent in the sitting position, similar to PI standard and PT standard pelvic, characteristic for standing position with the pelvis resting on the heads of the femurs. Further, using the parameter to "overhang of S1", in contrast to it, the concept and the parameter "deviation of the ischial tuberosities" was introduced, correlating the ischial tuberosities already designated by a point with the point indicating the centers of rotation of the heads of the femurs, using vertical lines drawn through the previously designated landmarks by dots. It is assumed that these angles and linear values relative to the vertical zero would characterize the rotation of the pelvis relative to the ischial tuberosities while taking a sitting position, by transition from one axis of rotation of the pelvis to another. We also assumed that the rotation of the pelvis relative to the ischial axis is based on the physical principle of rotation of the wheel with the formation at each point of contact with a hard surface of an instantaneous center of rotation with a linear displacement of the overlying axis of rotation. According to our hypothesis, the acetabular axis (intercapitular axis, a conventionally drawn line through the centers of rotation of the acetabulum) of pelvic rotation is not static, but shifts in space by a linear amount in the direction of pelvic rotation.

Currently, there are studies that question the integrity of the Lewinnek safe zone concept by installing the acetabular component [23]. Many researchers studying the causes of implant instability and searching for the optimal orientation of the endoprosthesis cup focused their attention on the spinopelvic relationship. Thus, McKnight et al. pointed to the importance of the association between the impingement syndrome, implant dislocations and the motion of the spinopelvic complex [7]. The influence of spinopelvic motion on the implantation of the acetabular component was described by Sharma et al. [24]. Phan et al. classified patients according to the flexibility of the spinopelvic segment and whether the spinal deformity was balanced in an attempt to determine the position of the acetabular component and the sequence of treatment in a patient with both spinal pathology and hip pathology [11]. Riviere et al. presented spinopelvic relationships based on patient PI and spinal and pelvic mobility and described “hip users” and “spine users” with their inherent PI, PT, and functional movement patterns [25]. In their other work, they also proposed a method for determining the optimal installation of the cup to create a functional safe zone depending on the type of spinopelvic relationship [26]. Vigdorchik et al. conducted a large study showing the importance of using a personalized approach to arthroplasty in spinal pathology, using the hip-spine classification in preoperative planning [27]. Batra et al. presented their treatment regimen for patients with hip-spine syndrome, based on the degree of mobility of the spine and the characteristics of its relationship with the pelvis [28].

Lazennec et al. described spinopelvic relationships in standing and sitting positions, which were interpreted quite simply, explaining that the spine-pelvis-hip motion is synchronized to ensure hip flexion without conflict between the greater trochanter and the innominate bone or the lesser trochanter with the ischium [22]. However, the evaluation of the pelvic movements was based only on one SS parameter, the slope of the sacrum with a value from 35° to 20°. The statement that sacral slope is the most accurate indicator of dynamic changes is not refuted by us [28, 30].

In our study, which is based on the principle of pelvic incidence, we demonstrated the possibility of using other indicators of spinopelvic relationships (PT, overhang distance S1, deviation of the ischial tuberosities), which allow us to assess the spatial transformation of the pelvis, which was the main goal of this study.

The data we obtained show that there is no statistical difference in the values of the angles PI standard in standing position and PI ischial in sitting position and correspond to objective data that are generally accepted. The term “Overhang S1” proposed by Legaye, overhang of the sacrum S1, reflecting the linear displacement of the sacrum during rotation of the pelvis, corresponds to the concept of uniaxial rotation of the pelvis exclusively around the axis drawn through the heads of the femoral bones, since they are supports, what we indicated above, referring to the works Kapandji and Stefl et al. [20, 30].

However, it is difficult to explain the large backward turn of the pelvis only by rotation relative to one axis. After all, when a person makes successive transitions from lying to standing position and from standing position to sitting position, the movements of the pelvis consist of an increasing version (tilt) of the pelvis back from 20° to 40°. At the same time, it was noted that the sagittal orientation of the acetabular component or the anterior tilt of the acetabulum (acetabular tilt) changes (increases) consistently with this movement of the pelvis [29]. Accordingly, the second mechanism that provides such variability in the posterior pelvic tilt is complemented by rotation of the pelvis when resting on the ischial tuberosities, which is proven by changes in the values of the overhang of the sacrum, pelvic tilt and deviation of the ischial tuberosities (O, V).

Based on this, it becomes clear that there is a linear posterior displacement during retroversion of not only the S1 endplate, but also of the acetabulum, since these anatomical formations are components of the whole (pelvis). The posterior inclination of the pelvis which we described in a previous article using a mathematical model with the separation of the acetabulum and the head of the femur and formation of a gap of up to 8 mm fully corresponds to the biaxial concept of pelvic rotation. Thus, the significance of the sagittal orientation of the acetabular component becomes clear. Analysis of the angles of the sagittal orientation of the acetabular component, which in our work we called the lateral inclination of the acetabular component, showed changes in the angle up to 30° in accordance with the increase in the version of the pelvis. Tight fixation of the acetabular component with the formation of the vertex of the graph, according to the incidence of the pelvis, results in accurate repetition of the movements of the pelvis and would predict the angle of inclination of the acetabular component in sitting and standing positions. Accordingly, in sitting position, an increase in the angle of lateral inclination of the acetabular component with a linear displacement of the component backwards and separation of the head of the implant and the acetabular component with a decrease in the jump distance will create a high risk for implant dislocation, what possibly lies in the pathogenesis of type VI instability according to the Classification System for the Unstable Total Hip Arthroplasty modified by Wera et al. [31].

CONCLUSION

The findings obtained with the radiographic study and the calculation of radiographic parameters complement the notion of biaxial concept of pelvic rotation, and the obtained data on the changes in the angle of inclination of the acetabular component by changing body position do not contradict the data obtained previously, what confirms the correctness of our results. Further research is required to assess the practical significance of the proposed method for determining the parameters of the spinopelvic balance.

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