



Mobility of the lumbo-pelvic-hip complex (spinopelvic mobility) and sagittal spinal alignment - implications for surgeons performing hip arthroplasty

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Abstract

Introduction The optimal positioning of the hip prosthesis components is influenced by the mobility and balance of the spine. The present study classifies patients with pathology of the spino-pelvic-hip complex, showing possible methods of preventing hip dislocations after arthroplasty.

Hypothesis Hip-Spine Classification helps arthroplasty surgeons to implant components in more patient-specific position.

Materials and methods The group of 100 patients treated with total hip arthroplasty. Antero-posterior (AP) X-rays of the pelvis in a standing position, lateral spine (standing and sitting) and AP of the pelvis (supine after the procedure) were analyzed. We analyzed a change in sacral tilt value when changing from standing to sitting (Δ SS), Pelvic Incidence (PI), Lumbar Lordosis (LL) Mismatch, sagittal lumbar pelvic balance (standing position). Patients were classified according to the Hip-Spine Classification. Postoperatively, the inclination and anteversion of the implanted acetabular component were measured.

Results In our study 1 A was diagnosed in 61% of all cases, 1B in 18%, 2 A in 16%, 2B in 5%. 50 out of 61 (82%) in group 1 A were placed within the Lewinnek “safe zone”. In 1B, 2 A, 2B, the position of the acetabular component was influenced by both the spinopelvic mobility and sagittal spinal balance. The mean inclination was 43.35° and the anteversion was 17.4° .

Conclusions Categorizing patients according to Hip-Spine Classification one can identify possible consequences the patients at risk. Pathology of the spino-pelvic-hip complex can lead to destabilization or dislocation of hip after surgery even though implanted according to Lewinnek’s indications. Our findings suggest that Lewinnek safe zone should be abandoned in favor of the concept of functional safe zones.

Keywords Spinopelvic mobility · Sagittal spinal alignment · Total hip arthroplasty · Hip spine classification · Lewinnek safe zones

Introduction

The gold standard treatment of care for advanced degenerative changes in the hip joint is total arthroplasty (THA) [1]. Despite the high satisfaction of patients after THA, endoprosthesis instability remains a costly and multifactorial problem that significantly reduces postoperative outcomes and quality of life [2]. Dislocations can occur after primary arthroplasty and these are the important cause of revision. It is estimated that with the use of modern implants and surgical techniques, the incidence of dislocations is about 2% [3].

Proper type of surgical technique and positioning of the implants can decrease the risk of instability. The “safe zone” (acetabular inclination $40^\circ \pm 10^\circ$ and anteversion $15^\circ \pm 10^\circ$)

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was proposed by Lewinnek et al. in 1978 as a guideline to help avoid mechanical complications [4]. However, studies have shown that Lewinnek safe zone (LSZ) does not fully predict hip stability after arthroplasty [5]. More recently, Abdel et al. showed that 58% of patients experienced an endoprosthesis dislocation even though the acetabulum was implanted in a “safe zone” whose orientation is derived from static X-rays [6]. Esposito et al. found no difference in the positioning of the prosthetic components between the dislocated and normal groups [7]. Recent studies suggest that acetabular inclination and anteversion measured on the basis of static pelvic X-rays taken before surgery or intra-operatively differs from acetabular positioning after repositioning the body. It is defined as the functional position of the acetabulum and is measured from the lateral x-ray images in standing and sitting positions [8, 9].

The spine, pelvis and hips form a dynamic complex, and their interactions are essential for movement and maintaining proper body posture [10]. The spino-pelvic mobility is associated with a change in body posture from standing to sitting. Normally, lumbar lordosis decreases (Δ LL), the hip joint is flexed (Δ PFA), the pelvis tilts (Δ APPt) and the angle of the sacral slope (Δ SS) decreases during sitting. During this movement, the acetabulum opens, increasing the functional anteversion to allow the femur to flex at the hip joint [11]. For each degree (1.0°) of pelvic tilt backwards, acetabular anteversion increases by about 0.7° – 0.8° [12]. Therefore, the anterior-inclination (AI) measured on

the lateral X-ray image when changing from standing to sitting position increases and the combined sagittal index (CSI) decreases. CSI is a newly presented parameter by Heckmann et al. as the amount of acetabular anterior inclination (AI) and hip flexion (PFA) [13] (Fig. 1).

Abnormal mobility of the complex is commonly classified as stiffness (Δ SS $< 10^\circ$) or hypermobility (Δ SS $> 30^\circ$) when changing from standing to sitting. Patients with insufficient spinal mobility are at increased risk of endoprosthesis dislocation and poorer surgical outcome [14]. The stiff spine prevents the pelvis from tilting backwards correctly, thus increasing the functional anteversion of the acetabulum. This can lead to anterior impingement and a posterior dislocation in a sitting position [15].

Sagittal spinal balance is assessed according to the difference between pelvic incidence (PI) and lumbar lordosis (LL) in a standing position. A PI – LL (pelvic incidence – lumbar lordosis) mismatch $> 10^\circ$ on a lateral X-ray image indicates a flatback deformity. This abnormality should also be considered by surgeons performing hip arthroplasty because of the increased likelihood of complications [16]. Patients with flat deformity of the spine show increased posterior tilt of the pelvis (APPt) in the standing position. They are therefore associated with an increased risk of posterior impingement and anterior dislocation when standing upright [17].

Correct implantation of the acetabular component of an endoprosthesis in patients with abnormal mobility and balance in the sagittal plane is a major challenge for surgeons.

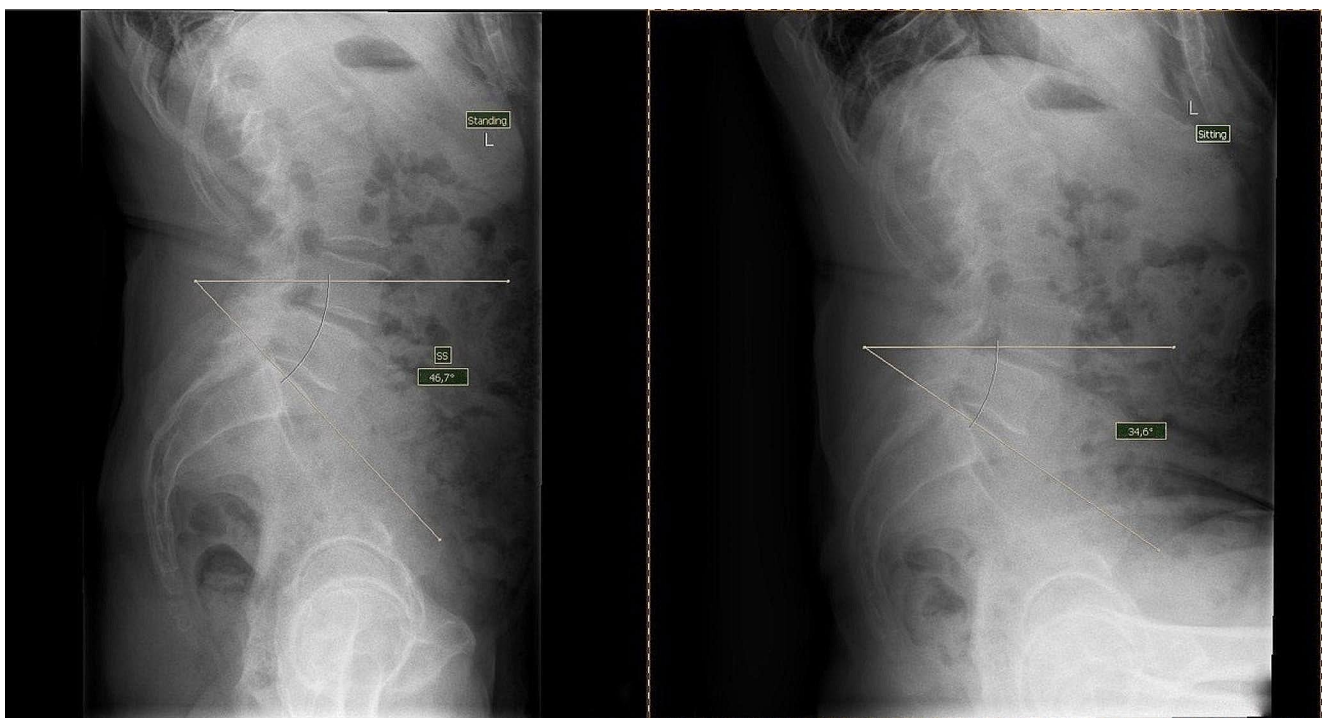


Fig. 1 The anterior - inclination (AI) measured on the lateral X-ray image when changing from standing to sitting position increases and the combined sagittal index (CSI) decreases

Due to limited mobility of the spino-pelvic-hip complex during changing posture, some authors suggest increasing the anteversion of the implanted acetabulum in order to avoid anterior impingement and posterior dislocation when sitting down, while in the case of sagittal imbalance, the angle of the acetabulum should be adjusted to the functional position of the pelvis (FPP). For patients with pathology related to both spinopelvic mobility and sagittal spinal alignment in the standing position, there is a very narrow “safe zone” of acetabular positioning; this results in the highest risk of instability in this group of patients. Therefore, especially in these patients, dual-mobility articulation should be considered [18].

Assumptions and purpose of the work

The aim of the study was to present the relationship between the spine, pelvis and hip in patients with advanced osteoarthritis of the hip before arthroplasty. It also presents the factors influencing the non-optimal (according to Lewinnek) positioning of the endoprosthesis components, which have a significant impact on the reduction of postoperative results. The study evaluates patients with pathology of the spino-pelvic-hip complex; it also presents possible methods of preventing the instability of the endoprosthesis in abnormal groups by supporting the correct orientation of the acetabulum. Hip-Spine Classification helps arthroplasty surgeons to implant components in more patient-specific position.

Materials and methods

The study included consecutive 100 patients cohort (men $n=56$; 56%, women $n=44$; 44%) diagnosed with osteoarthritis of the hip, treated at the Department of Trauma and Orthopedic Surgery prior to hip arthroplasty in the secondary care hospital Table 1.

Each patient received extensive information about the clinical trial and signed a written informed consent. All patients who underwent a hemiarthroplasty or revision arthroplasty with a diagnosis of a hip fracture or having improper X-ray images were excluded from the study protocol. Hip arthroplasty was performed by two surgeons with at least 15 years of experience. All procedures were performed via a posterior approach with repair of the articular capsule.

The severity of osteoarthritis in the examined hip joint was classified according to Tonnis classification. Preoperative X-rays of the pelvis were taken in the standing AP position of both hips [19].

The following radiological analysis of the spinopelvic mobility and sagittal alignment was performed: lateral images were taken of the spine and pelvis from L1 to the proximal end of the femur, standing and sitting (relaxed position on a chair adjusted to patient height, knee and hip joints flexed to 90°, thighs parallel to the floor) [20]. X-ray procedures were target to film distance standardized with centering of the X-ray beam.

Measured parameters:

1. Δ Sacral Slope (tilt) (Δ SS) - change in the angle of the sacrum while changing from standing to sitting position (the angle between the horizontal line and the tangent to the sacral endplate) (Fig. 2). This measurement helps identify patients with spinal stiffness or hypermobility [21].
2. Pelvic Incidence (PI) - Lumbar Lordosis (LL) Mismatch (PI-LL) - sagittal lumbar pelvic balance measured in a standing position using PI (the angle between the straight line connecting the center of the femoral heads with the center of the S1 endplate and the line perpendicular to the base of the sacrum) and LL (lumbar lordosis curve angle) (Fig. 2) [22]. Pelvic Incidence is a morphological parameter that remains constant despite the movement of the spine and pelvis throughout adulthood, and does not change as a result of degenerative

Table 1 Basic descriptive statistics of the study group

	N	n (%)				
Gender	100					
F		44	(44%)			
M		56	(56%)			
Laterality	100					
Right		52	(52%)			
Left		48	(48%)			
ASA	100					
I		18	(18%)			
II		71	(71%)			
III		11	(11%)			
	<i>N</i>	<i>M</i>	<i>SD</i>	<i>Me</i>	<i>Min.</i>	<i>Max.</i>
Age	100	66.41	9.12	67.32	30.00	84.00
BMI	100	27.63	3.93	29.12	17.87	38.09

N- number of valid observations, M - mean, SD - standard deviation, Me - median, Min - minimum value, Max - maximum value

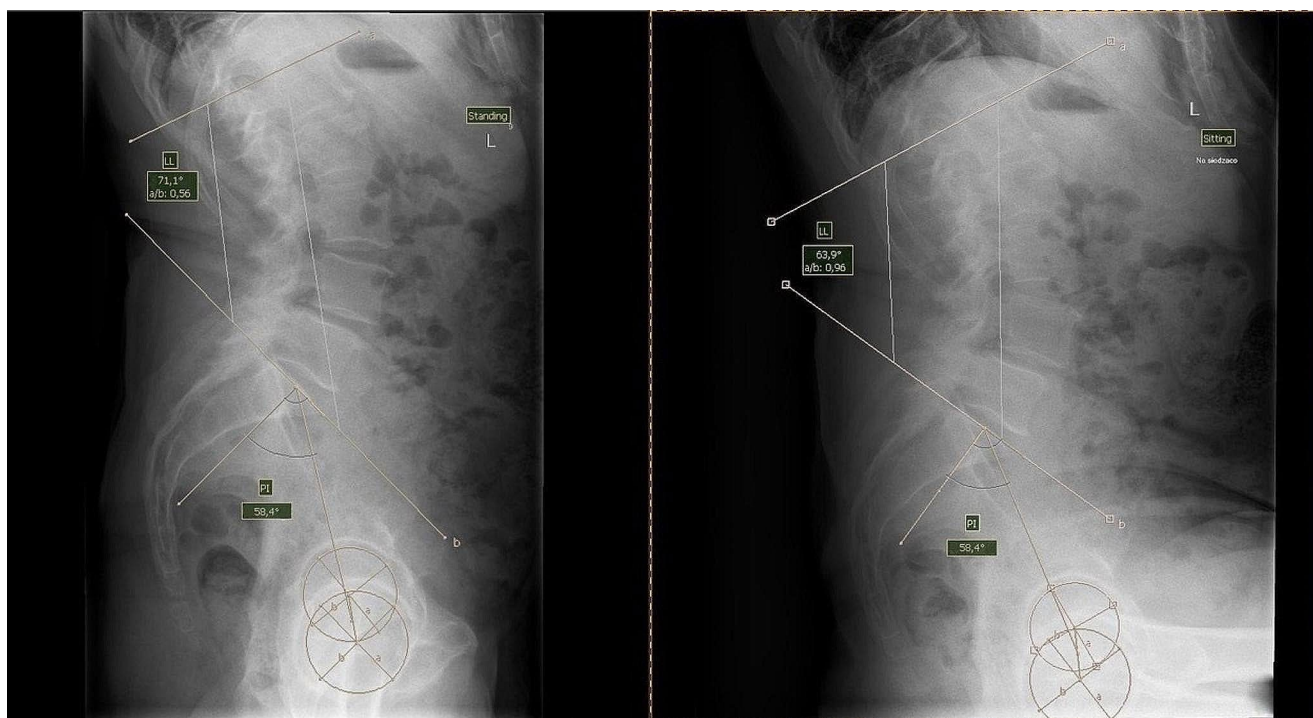


Fig. 2 Δ Sacral Slope (tilt) (Δ SS) - change in the angle of the sacrum while changing from standing to sitting position (the angle between the horizontal line and the tangent to the sacral endplate)

diseases of the spine. Pelvic Incidence-Lumbar Lordosis Mismatch (PI-LL Mismatch) is often used by spine surgeons to define sagittal deformities. For arthroplasty surgeons, it is an important measure to help identify patients with flatback deformity resulting from abolition of lordosis and a posterior tilt of the pelvis in a standing position [18].

Postoperatively, the position of the acetabular component of the prosthesis was measured by taking a standard AP X-ray of the pelvis supine with the limbs in a neutral position [23]. Anteversion and inclination angles can be determined anatomically, radiologically and intraoperatively [24]. Acetabular position was measured according to Lewinnek et al. [25]. The angle of acetabular inclination was determined based on one line through the upper and lower edges of the acetabulum along the long axis of the ellipse, and horizontal line through the lower ends of Köhler's tears or the tuberosity of the ischial bones [26]. The angle of opening (anteversion) of the acetabulum was calculated from the measurement of the length and width of the acetabular opening thus: $\arcsin = \text{short axis} / \text{long axis}$. The edge of the acetabulum was outlined, and the short and long axis of the ellipse were drawn using computer software. Anteversion was then calculated using the formula (Fig. 3) [27]. Reflecting the exact center or inclination of the three-dimensional anatomical structures on the two-dimensional (2D) sagittal radiographs

is limited, resulting in measurement errors. We measured every case 3 times, and calculated mean solution. Vrtovec et al. reported that, for PI measurements, 2D radiographic images showed approximately 5° overestimation compared with 3D CT images. In addition, Yamada et al. also reported that PI also tends to be larger by approximately 5° . In conclusion we accepted error range $\pm 2.5^\circ$.

Analysis

The spinopelvic mobility when changing from standing to sitting was assessed as follows: Δ SS $< 10^\circ$ - stiffness, Δ SS $> 10^\circ$ - preserved mobility. When determining the balance of the lumbo-pelvic-hip complex in the sagittal plane in the standing position, PI-LL $> 10^\circ$ indicated mismatch, imbalance and flatback deformity of the spine, while PI-LL $< 10^\circ$ indicated that the balance was preserved.

Patients were assigned to four groups according to the Hip-Spine Classification [28]:

- 1 A. Normal balance (PI-LL) $< 10^\circ$ and normal mobility (Δ SS $> 10^\circ$).
- 1B. Normal balance (PI-LL) $< 10^\circ$ and abnormal mobility (Δ SS $< 10^\circ$).
- 2 A. Abnormal balance (PI-LL) $> 10^\circ$ and normal mobility (Δ SS $> 10^\circ$).
- 2B. Abnormal balance (PI-LL) $> 10^\circ$ and abnormal mobility (Δ SS $< 10^\circ$).

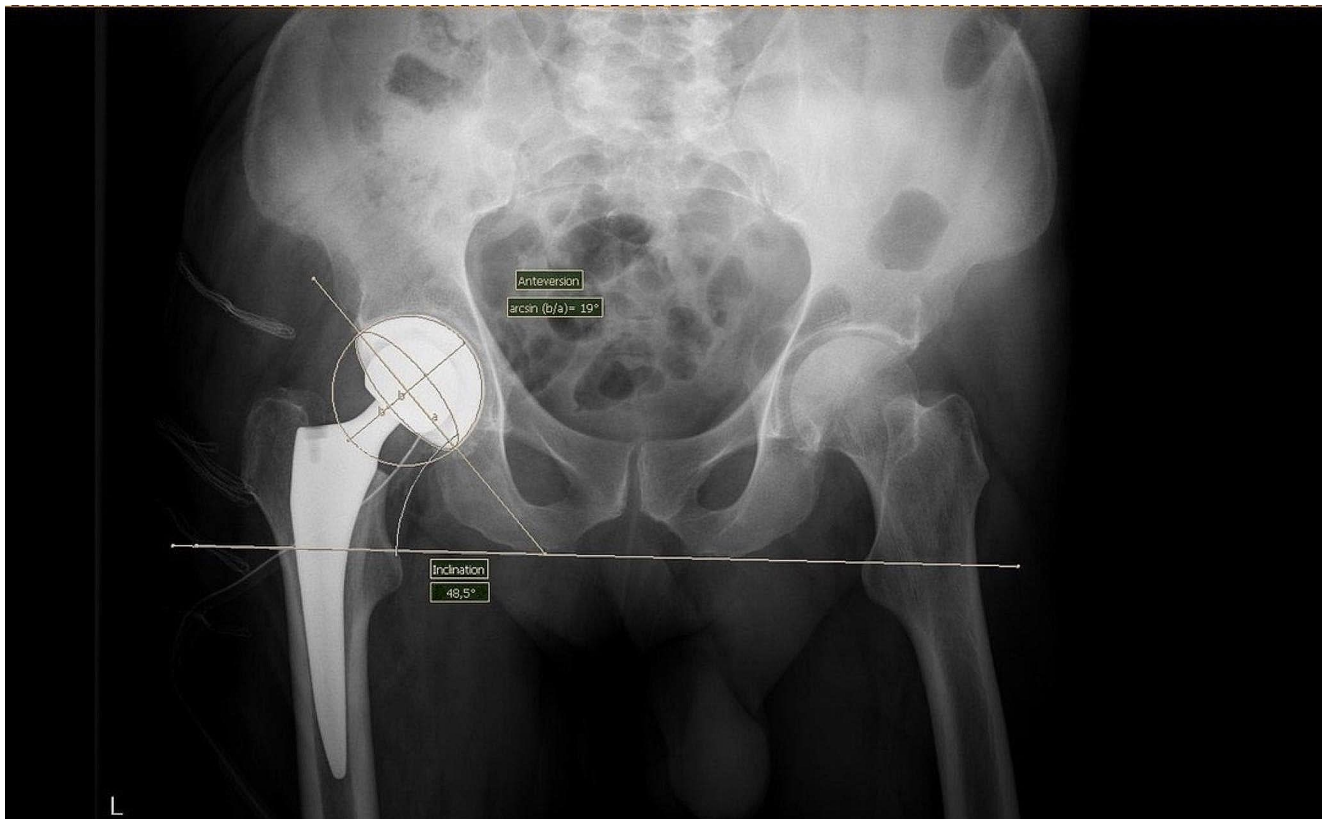


Fig. 3 The angle of opening (anteversion) of the acetabulum was calculated from the measurement of the length and width of the acetabular opening thus: $\arcsin = \text{short axis} / \text{long axis}$

After the THA was performed, the angles of inclination and anteversion of the acetabular component were analyzed and it was checked whether they were in the “safe zone” according to Lewinnek [29]. In groups with abnormalities in the spine, preoperative planning was modified to increase anteversion in groups 1B and 2B, while acetabular implantation was adjusted to the functional position of the pelvis in groups 2 A and 2B. The outcome was assessed postoperatively by X-rays- inclination and anteversion angles of implanted cup component were measured and precisely compared with modified preoperative planning.

A 100 patients treated in the years 2021–2022 by means of THR meet the criteria of the study. The mean age of the patients was 66.41 (30 to 84), of which 56% were men and 44% women. The vast majority of indications for surgery were primary osteoarthritis of the hip (90%); the remaining 10% were AVN, advanced acetabular femoral conflict CAM, hip dysplasia and secondary post-traumatic changes.

According to Tonnis classification, 7% of patients were classify as class I, 34% as class II and 59% as class III.

The change in the angle of the sacrum when moving from standing to sitting and the difference in PI-LL parameters in the standing position were used to assess the mobility and sagittal balance of the spino-pelvic-hip complex. Patients

were assigned to the appropriate groups according to the Hip-Spine Classification given above: 1 A (n=61; 61%), 1B (n=18; 18%), 2 A (n=16; 16%), 2B (n=5; 5%).

Minimum follow up of included patients was 14 months, range 14–23 months (03.10.21–05.07.22).

Results

In patients from group 1 A, the arthroplasty was performed in accordance with the Lewinnek “safe zone” guidelines (anteversion 15 ± 10 and inclination 40 ± 10). The postoperative X-rays indicated that of the 61 patients assigned to group 1 A, six (9.8%) did not meet the criteria for inclination (increased angle implantation) and five (8.2%) for anteversion (four reduced angle, one increased). The mean inclination in this group was 44.73° , while the anteversion was 15.6° . In total, 50 out of 61 (82%) acetabular cups in group 1 A were placed within the “safe zone” according to Lewinnek.

In the case of abnormal groups (1B, 2 A, 2B), the position of the acetabular component was adjusted in relation to the spinopelvic mobility and the balance in the sagittal plane: the aim of the procedure was not LSZ implantation.

In group 1B, the mean inclination was decreased by 4° to the mean of 40.41°, the anteversion was increase by 5° to the mean of 20.5°.

In group 2 A, that for each 10° of pelvic tilt, the acetabular anteversion changes by 7° and the inclination by 3°, we additionally measured pelvic tilt in these patients and adjusted anteversion and inclination of the implemented cup to deviation functional pelvic plane from the sagittal axis. In result, the mean inclination was 43.84°, the anteversion was 15.7°.

Preoperative mean sagittal measurements and postoperative mean cup positioning angles for each group shows Table 2.

However, in group 2B, with a complex pathology within the spine and pelvis, the acetabulum was implanted with an average inclination of 45.8° and anteversion of 16.1°. Overall, in the groups with an increased risk of instability (1B, 2 A, 2B), the mean inclination was 43.35°, and the anteversion was 17.4°. Range of PI was 36.5°–78.8°. The mean PI value is 54.3°. The mean PI – LL (lumbar lordosis mismatch) is 0.08°

In addition to increasing anteversion in relation to FPP, other measures were also taken to prevent dislocation of the endoprosthesis. In preoperative planning, the offset was carefully calculated and appropriate mandrels were used to ensure that it was not reduced after surgery. Stems with increased offset, lipped liners and heads with a size of 36 mm were used in every case and acetabular osteophytes were removed, which could cause impingement. In addition, in four patients, dual mobility bearings were used to further improve stability.

One case of posterior prosthesis dislocation was observed. Dislocation rate: Group 1 A: 0%, 1B 5.56%, 2 A 0%, 2B 0% Though, dislocations occur early if acetabular cup is placed incorrectly we are still following these patients carefully.

Discussion

In recent years, much attention has been paid to the interaction between the hip, pelvis and spine [17, 30]. Malfunction of the spino-pelvic complex is a significant etiological factor of THA instability [31]. DelSole et al. recently found the

Table 2 Preoperative mean sagittal measurements and postoperative mean cup positioning angles for each group according to Hip spine classification

Group	1 A (n=61; 61%)	1B (n=18; 18%)	2 A (n=16; 16%)	2B (n=5; 5%)
ΔSS	22.48°	5.26°	23.36°	3.56°
PI-LL	-4.67°	-3.96°	17°	20.1°
Inclination	44.73°	40.41°	43.84°	45.8°
Anteversion	15.6°	20.5°	15.7°	16.1°

incidence of dislocations in patients with spinal pathology to be 8%, compared to 1.5% in a control group [16]. Similarly, Bedard et al. found that the dislocation frequency in these patients to be 16.7% [32].

Patients with reduced spinal mobility due to osteoarthritis, deformities and post-spondylodesis are at increased risk of acetabular component functional misalignment, instability and endoprosthesis revision surgery [33]. The most significant independent factor of early dislocation after THA is previous spondylodesis, doubling the risk of dislocation and tripling the need for revision surgery [14, 34]. A meta-analysis of 363 studies involving 2912 patients with a history of lumbar spondylodesis and THA shows that the risk of dislocation increases with the number of vertebrae stabilized. With 1–2 horizontal spondylodesis, the risk of dislocation was 2.73%, increasing to 4.62% for 3–7 levels; in comparison, the risk was 1.55% in the control group [39].

There are two separate matters for pelvic position that should be considered in pre-operative planning of THA to avoid post-operative instability. The first issue is the deformation of the spine in the sagittal plane. In these patients, the positioning of the acetabular component should be based on the non-standard functional position of the pelvis and not the native anatomy. The second is the stiffness of the spino-pelvic-hip complex. The surgeon, diagnosis this pathology, should compensate intraoperatively for the lack of mobility of the spine by correctly setting the acetabulum. When performing hip arthroplasty in patients with pathology of the spine, special attention should be paid to the functional positioning of the acetabular component [35, 36].

The performed study holistically presents the radiological relationships between the spine and the pelvis in patients diagnosed with osteoarthritis of the hip joint. Unlike other publications, the present study includes patients with newly-diagnosed spinal pathology or a history of disease, making the cohort more representative of patients reporting for surgery [37]. The scale of the problem is emphasized by the fact that abnormalities were detected in as many as 39% of patients. According to some authors, additional lateral X-rays should be taken especially in patients with lumbosacral spondylodesis, kyphotic standing, degenerative diseases in the spine and contracture in the hip joint [38]. We agree with the suggestion to take lateral x-rays in a standing and seated position in all patients waiting for THA; this will optimize implantation of the prosthesis components to avoid impingement, reduce the risk of dislocation and wear, and improve postoperative outcomes [39].

The patients were divided according to the Hip Spine Classification based on the ΔSS and PI-LL measurements showed that in the abnormal groups (1B, 2 A, 2B), the pre-operative planning was extended and modified. In order to avoid impingement and dislocation, stems with increased

offset, lipped liners and heads with a size of 36 mm were used, and the position of the acetabular component of the prosthesis was modified. Inclination and anteversion were adjusted for the presence of spinal stiffness and pelvic tilt in the sagittal imbalance groups. Our goal was to achieve combined anteversion with cup positioning than to compensate with stem anteversion to avoid creating a new anteverted position of the leg, thus we attempted to implant the stem at 10° to 15° anteversion in every case. In the group with limited mobility (1B), an attempt was made to increase anteversion in accordance with Luthringer et al. [1]. These patients demonstrate a lack of adequate pelvic tilt when changing from standing to sitting position ($\Delta SS < 10^\circ$), and this increases the risk of anterior impingement and posterior dislocation. Postoperative measurements confirmed successful enhancement of anteversion of the acetabular component: mean anteversion 20.5° (1B) vs. 15.6° (1A).

In the sagittal malalignment group (2A), it was attempted to adjust the anteversion and inclination to the pelvic tilt angle (APPt) to account for the functional position of the acetabulum. It has been shown that for each 10° of pelvic tilt, the acetabular anteversion changes by 7° and the inclination by 3° [40]. An imbalance in the sagittal plane in these patients while standing ($PI-LL > 10^\circ$) increases the risk of posterior impingement and anterior dislocation. To adjust to the functional position of the pelvis (FPP), the acetabulum was implanted with an average inclination of 43.84° and an anteversion of 15.7°.

In Group 2B, with complex pathology (both spinal stiffness and imbalance in the sagittal plane), the safe zone is very narrow. An acetabulum with an average inclination of 45.8° and a 16.1° anteversion was implanted to prevent anterior impingement when seated without causing excessive anteversion to FPP when standing, which would increase the risk of posterior impingement. Like Stefl et al., we propose the use of dual-mobility articulation in this group of patients [15, 41].

However, the study has some limitations. Radiological diagnostics was performed during hospitalization, and patients were classified to risk groups on the basis of preoperative x-rays. After the procedure, only X-rays of both AP hips were taken; although these suggested that the parameters may change, studies show that the mobility of the spine and the sagittal balance in standing and sitting positions change only little or not at all after surgery [20]. Hence, preoperative measurements may to some extent predict the relationship between the spine and the pelvis after arthroplasty. In addition, the above two functional items were selected for evaluation as they have been the most extensively studied and discussed elsewhere. As a consequence, no other photos were taken, e.g. in deepened flexion while sitting or in hyperextension [42]. However, further testing in

various static and dynamic positions is advisable [37, 43]. Another limitation was that due to the lack of access to postural images, X-ray images were only taken from the lumbar spine to the proximal parts of the femurs, without the cervical and thoracic spine. Thus, the potential dependencies of other parts of the spine in relation to mobility and sagittal alignment could not be investigated [44]. Nevertheless, the projections made allowed the patients to be assigned to the appropriate groups according to the Hip-Spine Classification. Moreover, the issue of stem anteversion was omitted in the study, so further investigation is needed to demonstrate the relationship between spinal abnormalities and the summary position of the stem and acetabulum. Furthermore, endoprostheses were implanted without the use of computer navigation (precision of acetabular positioning 4.4°); this probably reduced the accuracy of acetabular component positioning in relation to preoperative planning, and of the intended modification of inclination and anteversion depending on the presence of pelvic spine pathology [12, 45]. It should be remembered that instability after THA is also influenced by other factors, such as the choice of surgical approach, soft tissue damage, previous operations, or incorrect positioning of implants, and that acute postoperative dislocations are typically not associated with pelvic spine pathology [46]. The postoperative observation period for instability, dislocation of the endoprosthesis or loosening of the acetabular component was quite short. However, most dislocations occur in the first 90 days after arthroplasty. In the study group, with a minimum follow-up of one year, one case of posterior prosthesis dislocation was observed (patient was classified to group 1B, regardless the acetabulum was implanted in insufficient anteversion). We plan a long-term follow-up to verify the relationship between patients in the abnormal groups according to Hip Spine Classification and the instability of the prosthetic components.

Conclusions

The problem of abnormal relationships between the spine and the pelvis in patients waiting for THA was analyzed and determined, and the factors significantly influencing the reduction of postoperative outcomes were presented. Taking standing and sitting lateral X-rays of all patients prior to arthroplasty and dividing into normal and abnormal groups according to the Hip-Spine Classification helps to identify possible consequences in patients at risk. This can improve preoperative planning and possible strategy modification among hip and spine surgeons. The pathology of the spino-pelvic-hip complex provides an insight into why the hip prosthesis components become unstable and dislocated,

even though implanted according to Lewinnek guidelines. Our findings call into question the validity of the Lewinnek safe zone in favor of the concept of functional safe zones.

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Author contributions Conceptualization, M.L., methodology, M.L., validation, A.B., M.L. and M.S., formal analysis, M.L., M.N., investigation, M.L., W.N., data curation, M.L., M.N., writing—original draft preparation, M.L., writing—review and editing, M.L., A.B., M.D., visualization, Ł.O., supervision, A.B.

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Data availability All data supporting reported results are available on request.

Declarations

Ethical approved All authors have read and agreed to the published version of the manuscript.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent to publish The authors affirm, that human research participants provided informed consent for publication of images in Figs. 1, 2 and 3.

Institutional Review Board Statement The study was approved by the Bioethics Commission, Medical University of Lodz (RNN/178/14/KE). All procedures involved in the study were performed in accordance with the standards given in the 2013 declaration of Helsinki.

Conflict of interest The authors declare no conflict of interest.

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