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ORIGINAL ARTICLE

Importance of the spinopelvic factors on the pelvic inclination from standing to sitting before total hip arthroplasty

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Abstract

Purpose Dislocation after total hip arthroplasty (THA) is a major postoperative complication. Even if the cup is in the safe zone, dislocation caused by implant impingement may occur during postural changes. The aim of the present study was to investigate the spinopelvic factors that influence pelvic inclination changes from standing to sitting in patients with hip diseases who were candidates for THA.

Methods 74 patients who underwent primary THA were included according to our criteria. The analysis of the sagittal balance of the spinopelvic complex was performed on standing and sitting lateral radiographs. Pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), lumbar lordosis angle (LLA), thoracic kyphosis angle (TK), and sagittal vertical axis (SVA) were measured. The differences between the standing and sitting positions regarding the spinal and pelvic parameters were analyzed. Correlations between the variables of the spinopelvic parameters were examined using Spearman's rank correlation coefficient.

Results The changes in SVA, TK, LLA, SS, PT, and PI from the standing to sitting positions, respectively, were -3.9 ± 48.2 mm, $-0.1° \pm 6.4°$, $21.4° \pm 17.7°$, $22.2° \pm 12.2°$, $-22.3° \pm 13.2°$, and $0.4° \pm 6.9°$. The lumbar lordosis was reduced and pelvic rotation was extended from the standing to the sitting position. The correlation coefficient between the change in the SS and that in the LLA was 0.72 ($p < 0.0001$). The correlation coefficient between the change in PT and that in the LLA was -0.68 ($p < 0.0001$).

Conclusions The change in pelvic inclination from standing to sitting is strongly related to the mobility of the lumbar spine in patients with hip diseases.

Keywords Total hip arthroplasty · Sagittal alignment · Pelvic inclination · Postural changes

Introduction

Dislocation after total hip arthroplasty (THA) is a major postoperative complication. With advances in surgical skills and the increased durability of implants, the long-term survival rate of THAs has improved [1]. As a consequence, the reoperation rate due to dislocation is increasing. Bozic et al. reported that dislocation was the leading cause of THA revision [2]. The data from several national registers also showed that dislocation was the major reason for revision surgery [3, 4]. Thus, an attempt to identify the means by which dislocation after THA can be prevented has gained importance in recent years. It is known that the causes of dislocation are multifactorial. The patient's co-morbidity, the surgical approach, and the implant type (e.g., diameter of the femoral head) have been proven to be factors that affect the dislocation rate [5, 6]. Implant positioning has also been proven to influence the occurrence of dislocation. Incorrect implant positioning, such as retroversion of an acetabular cup, could risk implant impingement, resulting in dislocation. Because appropriate acetabular cup positioning plays a key role in achieving both stability and mobility of an artificial hip joint, the so-called safe zone is often referred to for implant

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positioning [7–9]. In a daily practice, however, the greatest unsolved problem is that we often encounter a patient with dislocation in whom the implant was positioned accurately, within the safe zone, as shown by radiography with the patient supine. This oddity can be explained as being caused by the change in pelvic orientation in different postures. The safe zone was originally defined as an angle on radiographs with the individual in supine position although the orientation of the pelvis differs in each posture, such as supine, standing, or sitting. The degree of those changes is also different among individuals [10–20]. As a result, even if the cup is in the safe zone, dislocation caused by implant impingement may occur during postural changes. Thus, recent research has been trending toward studying dislocation by analyzing postures in sagittal alignment. Since the variations of pelvic inclination were less than 10° from standing to supine position in 90 %, the concept of safe zone was usually used supine and standing position [10, 20, 21]. Sagittal alignment during the sitting posture has become an area of interest only in recent years, although it has gained enormous attention in the field of hip arthroplasty because most dislocations occur while sitting [19, 20].

In normal physiological postural changes from standing to sitting, hip flexion during sitting is achieved in coordination with pelvic extension [22]. Thus, the degree of pelvic coordination for postural changes plays an important role in dislocation. It has been unclear, however, what influences the degree of pelvic coordination during postural changes. With this in mind, we explored the adjacent joint functions, including those of the thoracic and lumbar spine, and arrived at a hypothesis that spinal function could affect the coordination of pelvic orientation during postural changes. The aim of the present study was to investigate the spinopelvic factors that influence pelvic inclination during postural changes from standing to sitting in patients with hip diseases who were candidates for THA.

Materials and methods

Subjects

This endeavor was a radiographic study in which images were obtained before patients underwent primary THA to determine the effect of postural body changes on pelvic rotation. A total of 92 patients underwent THA performed during the period from April 2013 through February 2015. Exclusion criteria for this study were (1) a history of hip surgery including THA, osteotomy and osteosynthesis; (2) a history of spine surgery; (3) a history of spinal compression fracture; (4) a history of ankylosing spondylitis; (5) major contralateral hip contracture affecting pelvic alignment, and (6) a neurologic or musculoskeletal disorder or a disease that might adversely affect pelvic alignment. After those exclusion criteria, 18 of 92 patients were excluded in this study. 78 patients underwent primary THA, and 14 patients who had already undergone one-sided THA now underwent THA on the other side. One patient had hip osteotomy on ipsilateral side in childhood, one patient had hip osteosynthesis on contralateral side because of intertrochanteric femoral fracture and two patients had spinal compression fracture of lumbar spine. There were no patients who had prior spine surgery, ankylosing spondylitis, hip contracture affecting pelvic alignment and neurologic or musculoskeletal disorder. Finally, 74 patients were included for the analysis (Fig. 1).

The group included 14 men and 60 women with a mean age of 65.5 years (range 27–86 years), a mean height of 154.6 cm (range 139–180 cm), a mean weight 57.6 kg (range 41–93.3 kg) and a mean body mass index of 24.0 kg/m^2 (range 16.6–34.2 kg/m^2). Among them, 61 patients had osteoarthritis, and 13 had osteonecrosis. The main characteristics of the population are shown in Table 1.

The analysis

The analysis of the sagittal balance of the spinopelvic complex was performed on standing and sitting lateral radiographs of the full spine, including the pelvis and femoral head obtained within 3 days before THA [23]. Lateral radiographs of the spine were obtained on a vertical film maintaining a constant distance (200 cm) between the subject and the radiographic source.

Radiologic data were collected according to a strict protocol. In the standing position, each subject adopted a comfortable position, with the fingers resting on the clavicles. This position was described as reproducible and reliable [24, 25]. The sitting position comprised sitting in a comfortable position on an adjustable-height stool with hands on the clavicles. The knees were bent at a 90° angle, and both feet rested flat on the floor [15, 26].

Computerized picture archiving and communication system (PACS) technology (SYNAPSE; Fuji Film, Tokyo, Japan) was used. Morphologic and positional parameters on the pelvis and the spine were measured independently by two observers [16–18, 20, 22]. The ICC value of standing SS, and standing LLA were as follows: intra-observer reliability 0.92, 0.93, inter-observer reliability 0.91, 0.90, respectively. The intra-observer and inter-observer reliabilities of the measurements were known and had been validated in previous publications using this method [15, 27, 28].

The angular sagittal radiographic variables were as follows [22–24, 26, 28–34]:

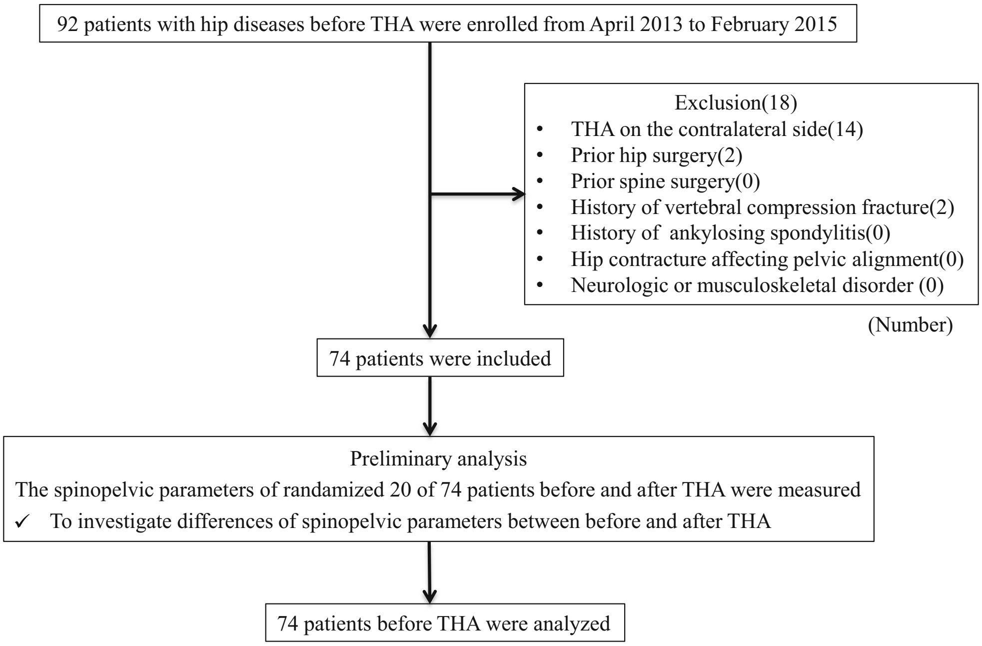

Fig. 1 Study flow chart

Table 1 Patients' characteristics

Number	74
Sex: men:women	14:60
OA:ON	61:13
Age (years)	65.5 ± 13.4 (27–86)
Height (cm)	154.6 ± 7.8 (139–180)
Weight (kg)	57.6 ± 11.7 (41–93.3)
Body mass index (kg/m^2)	24.0 ± 3.9 (16.6–34.2)

Results are given as the mean ± SD (range)

OA osteoarthritis, *ON* osteonecrosis

- Pelvic incidence (PI): the angle between the perpendicular plane to the upper plate of S1 in its middle and the line joining this point to the bicoxofemoral axis. The pelvic incidence is a morphologic parameter that is not affected by posture or the pelvic position.
- Sacral slope (SS): the angle between the horizontal plane and the upper plate of S1. The SS is a positional parameter, varying according to pelvis positioning.
- Pelvic tilt (PT): the angle between the vertical and the line joining the middle of the upper plate of S1 to the bicoxofemoral axis. The PT is a positional parameter.
- Lumbar lordosis angle (LLA): lumbar lordosis measured from the superior endplate of L1 to the superior endplate of S1. It is expressed as a positive value and kyphosis as a negative value.
- Thoracic kyphosis angle (TK): defined as the angle between lines drawn along the inferior endplate of the T12 vertebrae and the superior endplate of T4. Lordosis was expressed as a negative value and kyphosis as a positive value.
- Sagittal vertical axis (SVA): defined as the horizontal distance between the C7 plumb line and the posterior superior corner of the superior margin of S1.

We defined the pelvic inclination according to the SS and PT angles. Previous research showed that SS was usually used when the pelvic inclination was estimated by sagittal spinopelvic radiography [13–16]. The changes in each spinopelvic parameter between the standing and sitting radiographs were measured [23].

Preliminary analysis of the spinopelvic parameters before and after THA

In order to investigate the influence of the THA on sagittal balance after THA, 20 of 74 patients were examined the differences of spinopelvic parameters in standing and sitting positions before and after THA. The period we examined was average 9 months (range 6–15 months) after THA. All cases had no complications after THA. The mean values for SVA, TK, LLA and SS in the standing position before and after THA, respectively, were as follows: SVA 25.6 ± 53.2 and 19.2 ± 40.0 mm; TK 21.3 ± 11.3° and 22.0 ± 10.6°; LLA 46.8 ± 19.0° and 48.0 ± 20.4°; SS 39.5 ± 12.8° and 37.1 ± 13.7°. There were no significant differences between before and after THA in the standing position. The mean values for SVA, TK, LLA and SS in the sitting position before and after THA, respectively, were as follows: SVA 36.2 ± 43.3 and 65.2 ± 36.1 mm; TK

22.2 ± 10.5° and 22.7 ± 10.2°; LLA27.6 ± 15.8° and 27.6 ± 15.8°; SS 21.8 ± 12.6° and 25.2 ± 12.0°. There were no significant differences except SVA between before and after THA in the sitting position. PT and PI might be changed because of THA, so these were not measured. The parameter of SVA in sitting position did not affect the following study strongly, so we could use preoperative data equivalent to the postoperative data in this study.

Statistical analysis

A professional medical statistical consultant performed the statistical analyses using JMP software package version 11.2 (SAS Institute, Cary, NC, USA). A paired *t* test was used to analyze the differences between the before and after THA regarding the spinal and pelvic parameters at the preliminary analysis. A paired *t* test was used to analyze the differences between the standing and sitting positions regarding the spinal and pelvic parameters. Correlations between the variables of the spinopelvic parameters were examined using Spearman's rank correlation coefficient. In all validity analyses, the coefficient values were characterized as follows: 0–0.19 was poor, if any; 0.20–0.39 was fair; 0.40–0.59 was moderate; 0.60–0.79 was good; 0.80–1.00 was high/strong [35]. Values of $p < 0.05$ were considered to indicate a statistically significant difference.

Spinopelvic parameters were divided into three groups on the basis of the mean ± standard deviation in our series. We defined the normal group as being in the range from the mean value minus the standard deviation to the mean value plus the standard deviation [20].

Results

Parameters for standing to sitting positions

The mean values for SVA, TK, LLA, SS, PT, and PI in the standing and sitting positions, respectively, were as follows: SVA 48.0 ± 48.8 and 52.0 ± 41.1 mm; TK 28.2 ± 14.4° and 28.4 ± 14.2°; LLA 44.7 ± 17.3° and 23.3 ± 16.8°; SS 38.5 ± 13.0° and 16.2 ± 13.6°; PT 15.7 ± 12.0° and 38.0 ± 12.6°; and PI 54.7 ± 13.6° and 54.4 ± 12.5° [mean ± standard deviation (SD)]. The changes in SVA, TK, LLA, SS, PT, and PI from the standing to sitting positions, respectively, were -3.9 ± 48.2 mm, −0.1 ± 6.4°, 21.4 ± 17.7°, 22.2 ± 12.2°, −22.3 ± 13.2°, and 0.4 ± 6.9°. No statistically significant differences between the standing and sitting positions were observed for SVA, TK, or PI (Table 2).

The lumbar lordosis was reduced and pelvic rotation was extended from the standing to the sitting position. SVA and thoracic kyphosis were barely changed by that position change (Fig. 2).

Correlations among the pelvic inclination change, standing spinopelvic parameters, and changes in spinopelvic parameters from standing to sitting positions

The correlation coefficient between the change in the SS and that in the LLA was 0.72 ($p < 0.0001$). The correlation coefficient between the change in PT and that in the LLA was −0.68 ($p < 0.0001$). The pelvic inclination change was strongly influenced by the change in LLA. The correlation coefficient between the change in the SS and that of the standing SS was 0.42 ($p < 0.0001$). The coefficient between the change in PT and the standing PT was 0.49 ($p < 0.0001$). The pelvic inclination change was moderately influenced by the standing pelvic inclination. There were only poor or fair correlations between the pelvic inclination change and the standing spinal parameters (Table 3).

The correlation coefficient between the change in the SS and the standing LLA was 0.26 ($p < 0.05$). The pelvic inclination change (Change in SS) and standing LLA were divided into three groups on the basis of the mean ± SD in our series (normal group, Change in SS: 10–34.4°,

Table 2 Spinopelvic parameters in standing and sitting positions and changes from standing to sitting

	Standing	Sitting	Change from standing to sitting
SVA (mm)	48.0 ± 48.8 (−30.5 to 210.1)	52.0 ± 41.1 (−67 to 168)	−3.9 ± 48.2 (−153.4 to 137)
TK (°)	28.2 ± 14.4 (5 to 68)	28.4 ± 14.2 (5 to 66)	−0.1 ± 6.4 (−14 to 17)
LLA (°)	44.7 ± 17.3 (−3 to 72)	23.3 ± 16.8 (−29 to 62)*	21.4 ± 17.7 (−17 to 77)
SS (°)	38.5 ± 13.0 (−3 to 64)	16.2 ± 13.6 (−21 to 42)*	22.2 ± 12.2 (0 to 61)
PT (°)	15.7 ± 12.0 (−25 to 45)	38.0 ± 12.6 (7 to 68)*	−22.3 ± 13.2 (−57 to 5)
PI (°)	54.7 ± 13.6 (18 to 92)	54.4 ± 12.5 (21 to 86)	0.4 ± 6.9 (−19 to 23)

Results are given as the mean ± SD (range)

* $p < 0.0001$, paired *t* test

Change standing minus sitting for each parameter

Standing LLA: 27.4–62°). In some cases, the standing LLA in the normal and the above groups had less change in pelvic inclination (10 of 74 patients: 13.5 %) (Fig. 3).

Discussion

We investigated spinopelvic factors that influence pelvic inclination during postural changes from standing to sitting in patients with hip diseases who were candidates for primary THA. The data showed a strong relation between the amount of pelvic inclination change during postural changes from standing to sitting and the lumbar lordosis change. Thoracic spine parameters were not related to the pelvic inclination change. These results are of clinical importance in that they showed that suitable hip joint movement during sitting requires the coordination of lumbar spine movements—but not of the thoracic spine. As previously reported, positioning of the acetabular cup is a key factor in hip dislocation that is influenced by the pelvic inclination. Also, each patient has a different change in pelvic inclination from standing to sitting [10–20].

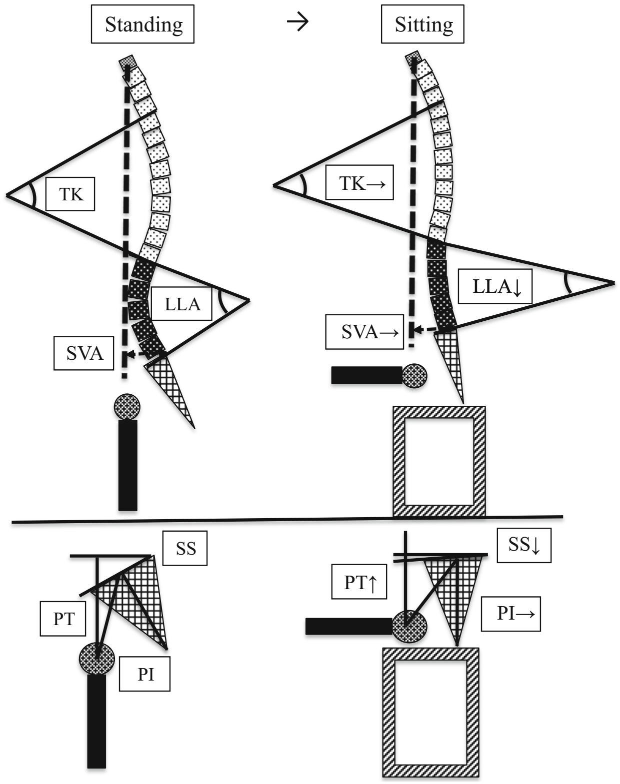

Fig. 2 Spinopelvic change from standing to sitting position

Considering all of our data, it appears that the acetabular orientation during postural changes is greatly influenced by the mobility of the lumbar spine. Thus, we believe that preoperative planning for THA using the greatest precautions against the possibility of dislocation should include consideration of lumbar spine mobility. This paradoxically explains the higher dislocation rate in patients with ankylosing spondylitis or after lumbar fusion, because those patients cannot coordinate their lumbar spine during postural changes [16, 36]. This inability is due to immobilization, resulting in minimum pelvic inclination change. It thus constitutes a risk of inadequate acetabular cup orientation for the sitting position. In such cases, if hip flexion exceeds the maximum range of the artificial joint, dislocation occurs because of impingement.

Our results highlight the fact that there is a population who has less mobility of the lumbar spine although not having any specific spinal pathology. The results also emphasize the importance of dynamic evaluation of sagittal postural changes. Although any two patients may have the same lumbar lordosis and pelvic inclination during static evaluations (e.g., during standing radiography), their pelvic inclination and acetabular orientation during sitting may be different depending on the mobility of their individual lumbar spine. For example, a patient in pelvic flexion and lumbar spine lordosis while standing but who has less mobility of the lumbar spine might have inadequate pelvic extension when sitting. If the cup in that patient was positioned with insufficient anteversion, the hip might be at increased risk of anterior impingement in the sitting position. In contrast, a patient with pelvic extension and a straight lumbar spine who has a less mobile lumbar spine and less pelvic inclination change might have adequate pelvic extension when sitting. If the cup was positioned

Table 3 Correlations among the pelvic inclination change, standing spinopelvic parameters, and changes in the spinopelvic parameters from standing to sitting position

Measurement	Standing SVA	Standing TK	Standing LLA	Standing SS	Standing PT	Standing PI	Change in SVA	Change in TK	Change in LLA
Change in SS	−0.23**	−0.15	0.26**	0.42**	−0.28**	0.19	−0.08	0.054	0.72*
Change in PT	0.29**	0.15	−0.21	−0.27**	0.49*	0.07	0.14	−0.003	−0.68*

Spearman's rank correlation: * $p < 0.0001$;** $p < 0.05$

Change standing minus sitting for each parameter

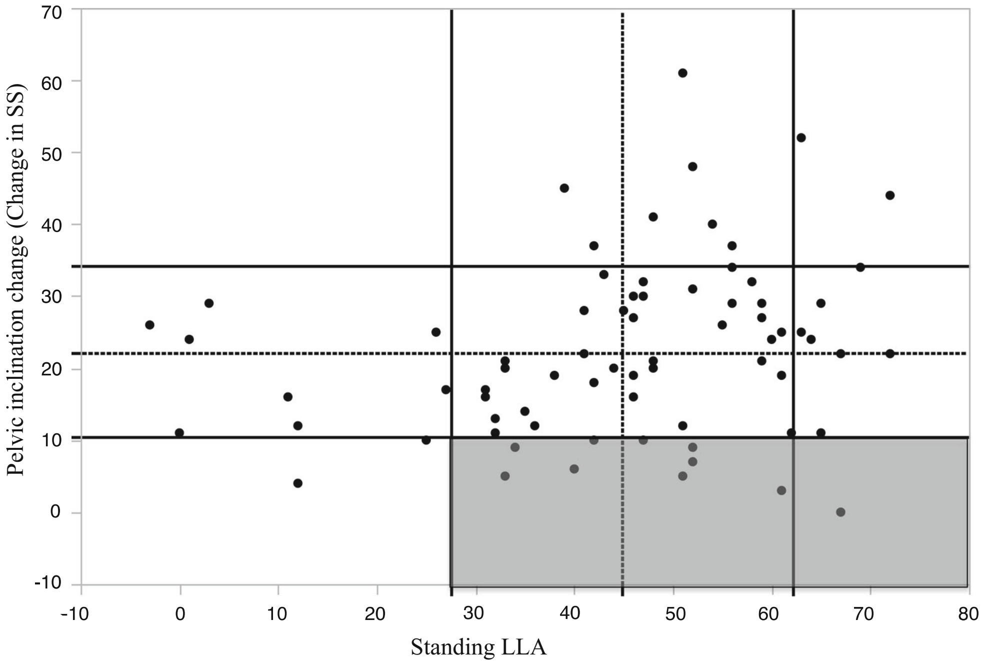

Fig. 3 Correlations between the pelvic inclination change (change in SS) and the standing lumbar lordosis angle (Standing LLA). *Dotted line* the mean of each parameter. *Solid line* the mean ± SD. In some cases, the standing LLA in the normal and the above groups had less change in pelvic inclination (13.5 %)

with excessive anteversion, however, the hip might be at increased risk of posterior impingement during standing.

The pelvis can rotate around the femoral head, following the bicoxofemoral axis. When the pelvis rotates in retroversion, the SS decreases. When the pelvis rotates in anteversion, the SS increases. SS is a positional parameter, as is the pelvic inclination [32]. In the standing position, the SS is high and acetabular inclination is low. Conversely, in the sitting position, the SS decreases, and acetabular inclination increases [16]. The PI angle is a key characteristic of the pelvis. It is an anatomical feature unique to each individual that becomes set at the end of growth, regardless of its position [23, 26, 29]. The PI is readily calculated and has become the most widely used reference angle [31]. Although the relation between the PI and sagittal balance has been studied, the subject is still controversial. Some articles have reported that, theoretically, subjects with a high PI angle have greater lumbar lordosis as the range of adaptation of the SS is increases. Conversely, in subjects with a low PI angle, theoretically there is less lumbar lordosis, and the adaptability of the SS may be more limited. Theoretically, these subjects have less available extension and a weaker capacity to adapt to sagittal imbalance due to aging [17]. The degree of the SS determines the position of the lumbar spine, because the sacral plateau forms the base of the spine. Pelvic parameters affect the entire underlying sagittal profile of the spine [33]. Several studies demonstrated the chain of correlations, with spinopelvic parameters playing the main role in the PI, determining the organization of the lumbothoracic spine [34].

Unlike those reports, however, our data showed that there is no correlation between the PI angle and the change in pelvic inclination. We believe that functional mobility of the lumbar spine has more influence on pelvic inclination than does individual static morphology such as the PI. The most important factor in pelvic inclination change is the mobility of the lumbar spine. Lazennec et al. noted that lumbosacral junction mobility was the main parameter influencing the variations in acetabular anteversion between the standing and sitting positions. Stiffness of the lumbar spine is a risk factor for THA subluxation and dislocation, resulting from the lack of variation in acetabular anteversion from a standing to a sitting position [18]. Further investigation on the relation between the PI and sagittal balance is necessary.

As a limitation of this study, firstly, we evaluated the parameters of preoperative THA and a few postoperative THA. Ideally, since the final aim of those studies on sagittal alignment in patients with THA is to provide any informative data for anti-dislocation, it might be better to consider postoperative status. However, we believe that preoperative assessment can be useful for cup orientation. Maratt et al. mentioned that there was no significant change in pelvic inclination following THA in 6 weeks [37]. They emphasized the importance of preoperative standing X-ray. Besides, as mid-term study, Blondel et al. reported that there was no significant variation in pelvic inclination between preoperative and 3-year follow-up values after THA [38]. Therefore, they insisted that the individual preoperative value should be integrated to achieve proper acetabular cup placement during THA. Although some papers mentioned increased pelvic posterior tilt after THA possibly due to pain relief and natural course of skeletal aging, those changes were not seen in all patients, and the extent of it has large variation between each individual [39]. Even if it occurs, it generally requires long-term period. Radcliff et al. mentioned that spinopelvic alignment in standing position was not changed before and after THA [40]. In our data, there were also less spinopelvic alignment changes in standing and sitting positions except SVA in sitting position between before and after THA. The parameter of SVA in sitting position was changed anteriorly after THA. The reason of this mechanism needs to be explored in the future with a large sample. Taking into consideration of those, we believe that our preoperative data of both standing and sitting is applicable for an assessment of postoperative sagittal alignment and has a great value for anti-dislocation. Secondly, we did not evaluate the causes of less mobility of the lumbar spine. The soft tissues such as muscles and ligaments around the hip and spine also affect the mobility of hip and spine. Further imaging, such as with computed tomography or magnetic resonance imaging, would be able to detect more detailed spinal pathophysiology related to the mobility of the lumbar spine and pelvic inclination change and is needed in the future. However, those applications contain the potential for radiation exposure and additional cost. We believe that our method could be easily performed in all hospitals, and it is not invasive or expensive. Lastly, we did not compare pelvic changes with those in a control group with normal hips. Total hip replacement is performed in patients with hip diseases and can be associated with arthritis of the spine, which limits pelvic mobility, as was shown in this study.

In conclusion, the change in pelvic inclination during the postural changes from standing to sitting is strongly related to the mobility of the lumbar spine in patients with hip diseases who are candidates for THA. The preoperative consideration of lumbar spine mobility using standard radiography with dynamic evaluations in the standing and sitting positions might contribute to better patient outcome.

Conflict of interest None.

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