

Research Article

Impact of spinopelvic mobility and functional safe zone conformity on functional outcomes after total hip arthroplasty

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ABSTRACT

Objective: This study aimed to evaluate the association between spinopelvic mobility, functional safe zone (FSZ) conformity, and patient-reported outcomes following total hip arthroplasty (THA).**Methods:** This retrospective observational study included 60 patients (22 males, 38 females; mean age 62.5 ± 9.7 years) who underwent primary THA between October 2021 and October 2023 and completed at least 1 year of follow-up. Mean time since surgery was 22.18 ± 6.31 months. Spinopelvic mobility was assessed using standing and relaxed-seated lateral radiographs and categorized as stiff (sacral slope) $\Delta SS \leq 10^\circ$, normal ($\Delta SS 11^\circ-29^\circ$), or hypermobile ($\Delta SS \geq 30^\circ$). Acetabular component orientation was evaluated according to FSZ conformity using the combined sagittal index. Clinical outcomes were assessed using the Harris Hip Score (HHS), Oxford Hip Score (OHS), Short Form-12 (SF-12), and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Group comparisons were performed using one-way analysis of variance (ANOVA) or Welch's ANOVA with Bonferroni or Games-Howell post-hoc analyses, as appropriate.**Results:** Spinopelvic mobility was classified as stiff in 18 patients (30%), normal in 34 patients (56.6%), and hypermobile in 8 patients (13.3%). Patients with normal spinopelvic mobility demonstrated significantly better postoperative HHS, OHS, WOMAC, and SF-12 scores compared with the stiff and hypermobile groups (all $P < .001$). Acetabular components were classified as FSZ-conforming in 38 hips and FSZ-non-conforming in 22 hips. The FSZ-conforming group demonstrated significantly superior HHS ($P = .003$), OHS ($P = .025$), WOMAC ($P = .001$), and SF-12 scores ($P = .028$) compared with the non-conforming group.**Conclusion:** Normal spinopelvic mobility and FSZ-conforming acetabular component alignment were associated with superior postoperative functional outcomes and quality of life after THA. These findings highlight the clinical relevance of dynamic spinopelvic assessment and patient-specific cup positioning during preoperative planning for THA.**Level of Evidence:** Level III, Prognostic Study.

Introduction

Total hip arthroplasty (THA) is a highly safe and effective surgical intervention to alleviate pain, enhance mobility, and improve physical function in patients diagnosed with hip osteoarthritis.¹ However, inaccurate positioning of the acetabular component during the surgical procedure can result in severe complications, including premature polyethylene wear caused by abnormal edge loading, ceramic insert fractures, and even hip dislocation.^{2,4}

Traditionally recommended and defined as the "Lewinnek Safe Zone", the $30^\circ-50^\circ$ inclination and $5^\circ-25^\circ$ anteversion range has long been considered the standard for acetabular cup positioning. However, this approach is based solely on static measurements and overlooks dynamic spinopelvic movements.⁵ During functional activities such as standing and sitting, although the cup remains fixed within the pelvis, its functional orientation changes. This is because the spatial position of the acetabulum is synchronized

with pelvic motion, which rotates in the sagittal plane during postural adjustments. This alteration in cup orientation is known as the functional cup position and is closely linked to spinopelvic motion.^{6,7} The close relationship among spine-pelvis-hip biomechanics has gained significant attention from this perspective. These 3 segments are interconnected through a kinetic chain and work synergistically. Pathologies of the spine affect the mobility of the pelvis, acetabulum, and range of motion of the hip. In individuals with normal spinopelvic mobility, the transition from standing to sitting decreases both sacral slope (SS) and lumbar lordosis. As the pelvis tilts posteriorly, acetabular anteversion increases, effectively preventing anterior impingement of the hip joint. Conversely, the reverse motion occurs when transitioning from sitting to standing, guarding against posterior impingement. However, in patients with limited lumbosacral mobility, the failure to adapt to these movements leads to abnormal functional cup orientation, increasing the likelihood of joint pain and functional impairment.^{8,9} Most atraumatic dislocations occurring with

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modern implants likely result from atypical pelvic kinematics that lead to abnormal functional acetabular orientation. This finding underscores the need for dynamic assessment of spinopelvic alignment and has introduced the concept of the “Functional Safe Zone” (FSZ), which aligns with patient-specific surgical goals.¹⁰ Functional safe zone, developed based on parameters such as the pelvic-femoral angle (PFA) and anteinclination (AI) during functional positions such as standing and sitting, is gradually replacing the traditional concept of the safe zone.¹¹

While the current literature includes studies investigating the relationship between dynamic measurements of functional acetabular cup orientation and lumbo-pelvic kinematics in relation to hip dislocation risk, studies evaluating the effect of functional cup orientation on postoperative functional outcomes in THA patients remain very limited.¹²⁻¹⁴ This study aimed to determine the effect of spinopelvic kinematics and functional cup orientation on pain, function, and quality of life in patients undergoing THA.

Material and methods

This study was conducted as a retrospective observational study based on institutional clinical and radiographic records. Between October 2021 and October 2023, 124 patients who underwent THA at Ordu University Training and Research Hospital were identified from the institutional database. These surgeries were performed as part of routine clinical care and not within the scope of any research protocol. A total of 60 patients with at least 1 year of available clinical and radiographic follow-up were included in the study.

This study included only patients with uncemented cups and stems containing highly cross-linked polyethylene liners. Dual mobility cups or constrained liners were not used in any case. Component positioning was performed using landmarks of the standard posterior approach; no intraoperative adjustments were made based on spinopelvic mobility classification. Patients with developmental dysplasia of the hip were included only if classified as Crowe type 1 or 2. Patients with Crowe type 3-4 were excluded to avoid the influence of severe pelvic deformities on spinopelvic measurements. Patients were excluded if they had a body mass index (BMI) > 40 kg/m², contralateral THA, advanced contralateral hip OA, underwent revision procedures, had modular neck implants, a history of lower extremity surgery, inflammatory arthritis, neurological diseases affecting lower extremity motor function, hip contracture, or a leg length discrepancy greater than 2 cm that could affect pelvic alignment.

All surgeries were performed by an experienced arthroplasty surgeon. The study was approved by the Ordu University Clinical Research Ethics Committee (2024/19) and was conducted in accordance with

the Declaration of Helsinki. Informed consent was obtained from all the patients.

Radiographic assessment

Radiographic assessment was performed for each patient by using anteroposterior and lateral radiographs of the lower lumbar spine, pelvis, and femur. Evaluations were conducted in both standing and relaxed-seated positions with the femurs parallel to the floor on a height-adjustable chair.^{15,16}

Measurements of AI, SS, and PFA were performed on lateral radiographs taken in both standing and relaxed-seated positions by an experienced orthopedic surgeon using the General Electric Centricity Picture Archiving and Communication System (PACS).¹⁷ All radiographic measurements were independently repeated by a second experienced orthopedic surgeon to assess inter- and intra-observer reliability. Intraclass correlation coefficients (ICC) were calculated for key parameters, demonstrating excellent agreement (ICC = 0.87-0.94).

The evaluation of spinopelvic mobility through radiographic means relies on the measurement of the SS, defined as the angle between a horizontal line and the S1 endplate, and its variations (Δ SS) in standing and sitting positions. Spinopelvic mobility was categorized as stiff (Δ SS $\leq 10^\circ$), normal (Δ SS 11° - 29°), or hypermobile (Δ SS $\geq 30^\circ$). The PFA was measured as the angle formed by 2 lines: one connecting the sacrum's superior border midpoint to the femoral head's center, and the other along the femoral shaft. Anteinclination was measured as the angle between the long axis of the acetabular component and a horizontal reference line, representing both anteversion and inclination of the component. The combined sagittal index (CSI) was determined by adding AI and PFA. Acetabular component alignment was retrospectively assessed for conformity to the FSZ and was classified as FSZ-conforming and FSZ-non-conforming. Conformity was determined using CSI: hips were classified as FSZ-conforming if the CSI was greater than 151° in the sitting position and less than 242° in the standing position; hips were considered non-conforming if the CSI was less than 151° in the sitting position or greater than 242° in the standing position.¹⁷ Radiographic measurements are shown in Figure 1.

Patient-reported outcome measures

The Harris Hip Score (HHS) is a clinician and patient-reported measure that evaluates hip function through domains such as pain, mobility, and range of motion, with a total score ranging from 0 to 100.^{18,19} The Oxford Hip Score (OHS) is a 12-item, patient-reported questionnaire used to assess pain and functional status in individuals undergoing hip interventions, scored from 0 (worst) to 48 (best).^{20,21} The SF-12 is a general health survey evaluating physical and mental health-related quality of life across 8 domains, with scores converted to a 0-100 scale.²² The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) is a validated instrument assessing pain, stiffness, and physical function in patients with hip or knee osteoarthritis, frequently used in surgical outcome studies.²³⁻²⁵

Statistical analysis

Descriptive statistics were used to summarize the study population. Continuous variables are presented as mean $\pm$ SD, whereas categorical variables are expressed as number (percentage). Normality was assessed using histograms, Q-Q plots, and the Shapiro-Wilk test, and homogeneity of variances was evaluated with Levene's test. Comparisons among the 3 groups were performed using one-way

HIGHLIGHTS

- This retrospective observational study examined the relationship between spinopelvic mobility, functional safe zone (FSZ) conformity, and patient-reported outcomes after primary total hip arthroplasty (THA).
- Normal spinopelvic mobility was associated with superior postoperative Harris Hip Score, Oxford Hip Score, Short Form-12, and Western Ontario and McMaster Universities Osteoarthritis Index scores compared with stiff and hypermobile patterns.
- Acetabular cups positioned within the FSZ were associated with better postoperative function and quality of life.
- Dynamic spinopelvic evaluation may support more patient-specific cup planning in THA.

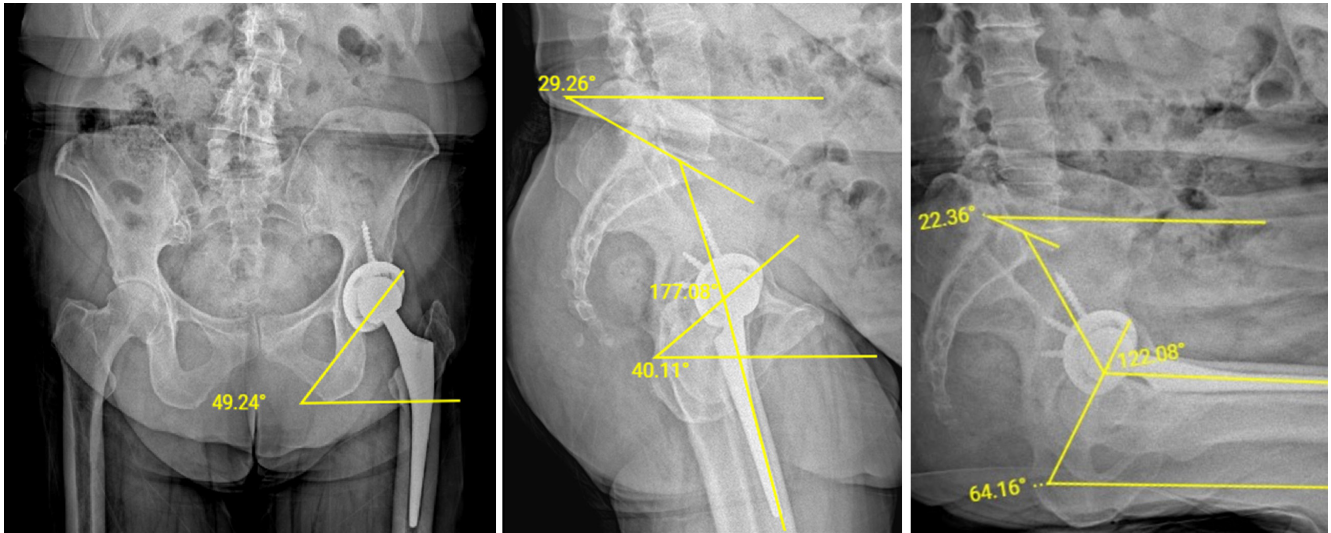


Figure 1. Illustration of radiographic measurements for cup inclination (IN), anteinclination (AI), sacral slope (SS), pelvic femoral angle (PFA), and combined sagittal index (CSI) in standing and sitting positions. The measurements are as follows: IN: 49, SS standing: 29, SS sitting: 22, AI standing: 40, PFA standing: 183, CSI standing: 223, AI sitting: 64, PFA sitting: 122, CSI sitting: 186.

analysis of variance (ANOVA) when the assumptions of normality and homogeneity of variances were satisfied. When the assumption of homogeneity of variances was violated, Welch's ANOVA was applied. Following a significant overall group effect, post-hoc pairwise comparisons were conducted using the Bonferroni correction when equal variances were assumed and the Games-Howell test when they were not. All statistical analyses were performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). A two-sided P value of $< .05$ was considered statistically significant.

Results

Participant characteristics

A total of 60 patients were included in the final analysis. The detailed patient screening process is presented in Figure 2. Of these patients,

33 underwent surgery for primary osteoarthritis, 11 for femoral head avascular necrosis, 11 for dysplasia, 3 for sequelae of Perthes disease, and 2 for femoral neck fractures. The clinical and demographic characteristics of the study participants are presented in Table 1.

Spinopelvic mobility

Sixty participants were included in the study and categorized into 3 groups based on spinopelvic mobility: stiff ($n=18$), normal ($n=34$), and hypermobile ($n=8$). There were no significant differences in age or BMI between the groups (Table 2).

Functional outcome measures revealed significant differences among the 3 groups (stiff, normal, and hypermobile). Regarding HHS, the stiff group scored significantly lower (71.61 ± 14.23) than the normal group (87.00 ± 12.05), with the hypermobile group showing

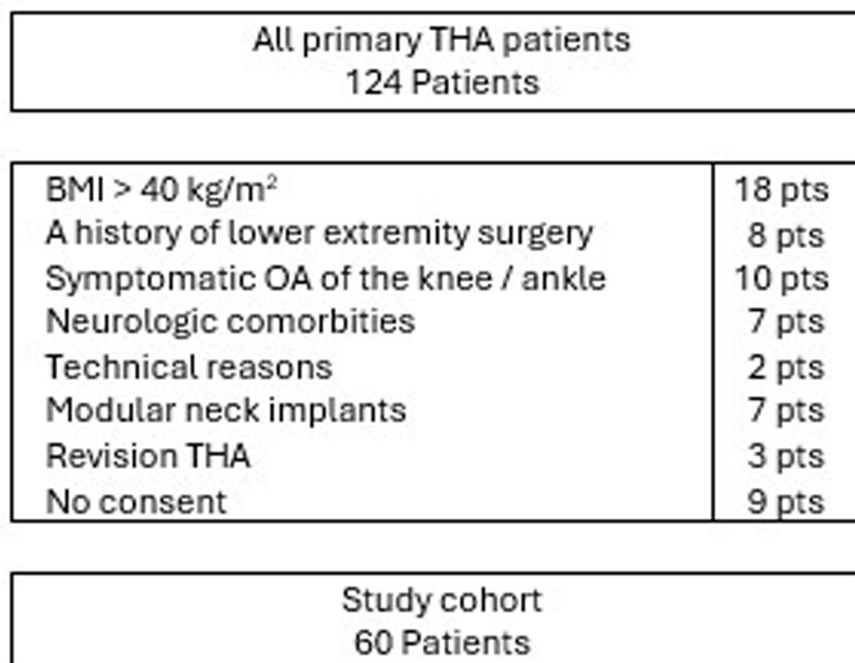


Figure 2. Flow chart illustrating the identification of the study cohort.

Table 1. The clinical and demographic characteristics of the participants

Variables	Mean $\pm$ SD	Range
Age, years	62.5 $\pm$ 9.7	38-83
BMI, kg/m ²	29.9 $\pm$ 4.2	22.0-39.7
TSS, months	22.18 $\pm$ 6.31	12-36
PROMs		
HHS	79.65 $\pm$ 15.51	
OHS	36.27 $\pm$ 8.52	
WOMAC	20.87 $\pm$ 13.85	
SF-12	73.95 $\pm$ 13.98	
Gender	n (%)	
Male	22 (36.7)	
Female	38 (63.3)	
Diagnosis	n (%)	
Primary osteoarthritis	33 (55.0)	
Secondary osteoarthritis	25 (41.7)	
Femoral neck fracture	2 (3.3)	

BMI, body mass index; HHS, Harris Hip Score; OHS, Oxford Hip Score; PROMs, patient-reported outcomes; SF-12, Short Form-12; TSS, Time Since Surgery; WOMAC, Western Ontario and McMaster Universities Arthritis Index.

a similar low score (66.50 ± 15.00) ($P < .001$). For OHS, the normal group scored significantly higher (41.06 ± 5.31) compared to both the stiff (30.22 ± 8.25) and hypermobile groups (29.50 ± 7.52), driving the overall difference ($P < .001$). WOMAC scores showed a similar trend, with the normal group having significantly lower scores (13.35 ± 9.59) compared to both the stiff (29.94 ± 12.32) and hypermobile groups (32.38 ± 13.36), which accounted for the overall difference ($P < .001$). Short Form-12 scores revealed significant differences, driven by higher scores in the normal group (79.62 ± 11.85) compared to the stiff (68.61 ± 12.84) and hypermobile groups (74.17 ± 13.89) ($P = .001$).

The spinopelvic parameters showed significant variation among the groups. While SS standing showed a trend toward significance ($P = .050$), SS sitting was significantly different, with the stiff group having the highest value ($24.33^\circ \pm 10.84^\circ$) compared to the normal ($18.82^\circ \pm 11.37^\circ$) and hypermobile ($1.63^\circ \pm 19.38^\circ$) groups ($P < .001$). Similarly, Δ SS was significantly lower in the stiff group ($4.89^\circ \pm 3.08^\circ$)

and higher in the hypermobile group ($34.25^\circ \pm 4.20^\circ$) ($P < .001$). While no significant differences were observed in AI standing ($P = .249$) or AI sitting ($P = .173$), Δ AI was significantly lower in the stiff group ($11.83^\circ \pm 7.98^\circ$) than in the normal ($21.53^\circ \pm 14.09^\circ$) and hypermobile ($28.13^\circ \pm 10.09^\circ$) groups ($P = .004$).

PFA standing showed no significant differences ($P = .354$). However, PFA sitting was significantly higher in the hypermobile group ($157.25^\circ \pm 25.94^\circ$) than in the other groups ($P = .011$). Δ PFA was significantly lower in the hypermobile group ($36.00^\circ \pm 16.75^\circ$) compared to the normal ($60.59^\circ \pm 16.85^\circ$) and stiff ($66.50^\circ \pm 17.49^\circ$) groups ($P < .001$).

Combined sagittal index also varied across groups. Although no significant differences were observed in CSI standing ($P = .143$), CSI sitting was significantly higher in the hypermobile group ($205.75^\circ \pm 36.62^\circ$) than in the other groups ($P = .045$). Δ CSI was significantly greater in the stiff group ($56.72^\circ \pm 23.65^\circ$) compared to the normal ($40.32^\circ \pm 24.91^\circ$) and hypermobile ($19.50^\circ \pm 15.75^\circ$) groups ($P = .002$). A comparison of the groups according to spinopelvic mobility is presented in Table 2.

Acetabular component alignment

Patients were divided into 2 groups based on functional cup orientation: FSZ-conforming and FSZ-non-conforming. Of these, 38 were conforming and 22 were non-conforming. There were no significant differences in demographic variables, including BMI and age, between the groups (Table 3).

Functional outcomes also showed significant differences. Patients in the FSZ-non-conforming group exhibited poorer HHS ($P = .003$), OHS ($P = .025$), and WOMAC scores ($P = .001$), along with lower quality-of-life scores reflected in SF-12 ($P = .028$).

AI standing was higher in the FSZ-non-conforming group (31.73 ± 15.07) than in the FSZ-conforming group (24.74 ± 10.69 , $P = .041$), while Δ AI was significantly lower in the FSZ-non-conforming

Table 2. The comparison of groups according to spinopelvic mobility type

Variables	Spinopelvic mobility type (mean $\pm$ SD)			P^1	P^2	P^3	P
	Stiff	Normal	Hypermobile				
n	18	34	8				
Age (years)	65.39 $\pm$ 9.30	62.38 $\pm$ 9.68	57.13 $\pm$ 9.61	.531	.348	.114	.134
BMI (kg/m ²)	30.50 $\pm$ 4.04	29.48 $\pm$ 3.95	29.78 $\pm$ 4.69	.670	.981	.909	.695
SS standing	28.33 $\pm$ 9.04	35.65 $\pm$ 9.46	30.00 $\pm$ 16.29	.050	.996	.203	.050
SS sitting	24.33 $\pm$ 10.84	18.82 $\pm$ 11.37	1.63 $\pm$ 19.38	.293	.003*	<.001*	<.001*
-SS	4.89 $\pm$ 3.08	18.76 $\pm$ 5.62	34.25 $\pm$ 4.20	<.001*	<.001*	<.001*	<.001*
AI standing	28.72 $\pm$ 12.45	28.21 $\pm$ 13.10	20.25 $\pm$ 11.51	.989	.258	.268	.249
AI sitting	40.56 $\pm$ 14.88	48.35 $\pm$ 14.35	47.88 $\pm$ 13.40	.161	.996	.460	.173
-AI	11.83 $\pm$ 7.98	21.53 $\pm$ 14.09	28.13 $\pm$ 10.09	.021*	.354	.007*	.004*
PFA standing	198.83 $\pm$ 13.36	195.41 $\pm$ 10.46	191.75 $\pm$ 14.36	.589	.716	.348	.354
PFA sitting	131.83 $\pm$ 20.68	134.82 $\pm$ 18.29	157.25 $\pm$ 25.94	.867	.017*	.012*	.011*
-PFA	66.50 $\pm$ 17.49	60.59 $\pm$ 16.85	36.00 $\pm$ 16.75	.464	.002*	<.001*	<.001*
CSI standing	227.9 $\pm$ 21.19	223.53 $\pm$ 16.81	211.88 $\pm$ 21.75	.703	.266	.120	.143
CSI sitting	172.61 $\pm$ 31.98	183.21 $\pm$ 28.18	205.75 $\pm$ 36.62	.463	.153	.035*	.045
-CSI	56.72 $\pm$ 23.65	40.32 $\pm$ 24.91	19.50 $\pm$ 15.75	.053	.072	.001*	.002*
HHS	71.61 $\pm$ 14.23	87.00 $\pm$ 12.05	66.50 $\pm$ 15.00	<.001*	.001*	.632	<.001*
OHS	30.22 $\pm$ 8.25	41.06 $\pm$ 5.31	29.50 $\pm$ 7.52	<.001*	<.001*	.964	<.001*
WOMAC	29.94 $\pm$ 12.32	13.35 $\pm$ 9.59	32.38 $\pm$ 13.36	<.001*	<.001*	.861	<.001*
SF-12	68.61 $\pm$ 12.84	79.62 $\pm$ 11.85	74.17 $\pm$ 13.89	.017*	.002*	.339	.001*

AI, anteinclination; BMI, body mass index; CSI, combined sagittal index; HHS, Harris Hip Score; OHS, Oxford Hip Score; PFA, pelvic-femoral angle; SF-12, Short Form-12; SS, sacral slope; WOMAC, Western Ontario and McMaster Universities Arthritis Index. **Bold:** statistically significant results.

* P values less than .05 were considered significant. P^1 value indicates differences between the stiff and normal groups, P^2 value between the normal and hypermobile groups, and P^3 value between the stiff and hypermobile groups.

Table 3. The comparison of groups according to acetabular component alignment

Variables	Functional safe zone, mean $\pm$ SD		P
	Conforming	Non-conforming	
Number of hips	38	22	
Age (years)	62.13 $\pm$ 9.96	64.82 $\pm$ 7.86	.179
BMI (kg/m ²)	29.84 $\pm$ 4.42	29.79 $\pm$ 3.36	.959
AI standing	24.74 $\pm$ 10.69	31.73 $\pm$ 15.07	.041*
AI sitting	47.58 $\pm$ 12.14	43.14 $\pm$ 18.04	.259
-AI	24.00 $\pm$ 13.44	11.73 $\pm$ 8.04	<.001*
PFA standing	194.66 $\pm$ 10.67	198.18 $\pm$ 13.81	.274
PFA sitting	140.84 $\pm$ 13.59	128.18 $\pm$ 27.82	.040*
-PFA	53.82 $\pm$ 14.45	69.59 $\pm$ 21.34	.003*
CSI standing	219.37 $\pm$ 14.86	230.09 $\pm$ 23.84	.066
CSI sitting	188.68 $\pm$ 20.47	171.32 $\pm$ 41.82	.064
-CSI	32.79 $\pm$ 19.15	59.18 $\pm$ 28.01	<.001*
HHS	84.08 $\pm$ 12.08	72.00 $\pm$ 17.95	.003*
OHS	38.13 $\pm$ 7.73	33.05 $\pm$ 9.04	.025*
WOMAC	16.58 $\pm$ 11.64	28.27 $\pm$ 14.49	.001*
SF-12	77.24 $\pm$ 13.00	66.86 $\pm$ 14.05	.028*

BMI, body mass index; SS, sacral slope; HHS, Harris Hip Score; OHS, Oxford Hip Score; WOMAC, The Western Ontario and McMaster Universities Arthritis Index; SF-12, Short Form-12. *statistically significant results.

P values less than .05 were considered significant.

AI, anteinclination; BMI, body mass index; CSI, combined sagittal index; HHS, Harris Hip Score; OHS, Oxford Hip Score; PFA, pelvic-femoral angle; SF-12, Short Form-12; WOMAC, Western Ontario and McMaster Universities Arthritis Index.

group ($P < .001$). Similarly, PFA sitting was reduced in the FSZ-non-conforming group ($P = .040$), and Δ PFA was markedly greater ($P = .003$). A comparison of the groups based on the acetabular component alignment is presented in Table 3.

Discussion

This study demonstrates that postoperative spinopelvic motion dysfunction was associated with worse patient-reported outcomes (PROMs). In both the stiff group (Δ SS $\leq 10^\circ$) and hypermobile group (Δ SS $\geq 30^\circ$), HHS, OHS, WOMAC, and SF-12 scores were significantly worse than those in the normal group. However, no statistically significant difference was observed between the stiff and hypermobile groups.

In the stiff group, the increase in AI from standing to sitting was smaller than in the normal and hypermobile groups (Δ AI: 11° vs. 21° and 28°). Such restricted motion may decrease patient satisfaction because the acetabular component cannot adequately adjust its functional orientation in the sagittal plane during sitting, which may increase the risk of anterior impingement.

The findings of the present study are consistent with previous studies on this topic. In a similar study examining changes in functional outcomes related to spinopelvic abnormalities after THA, Zandi et al reported lower pain and functional scores in the stiff and hypermobile patients among 160 primary THA cases.¹² Grammatopoulos et al found significantly more spinopelvic hypermobility in THA patients with spinal arthrodesis than in those without spinal arthrodesis and reported lower scores on WOMAC and OHS in these patients.²⁶

In the hypermobile group, the amount of hip flexion (PFA sitting: 157° vs. 131° and 134°) and the change in flexion (Δ PFA: 36° vs. 60° and 66°) was significantly lower than in the stiff and normal groups. Additionally, SS sitting was significantly lower than that in the other groups (SS sitting: 1° vs. 18° and 24°). A low SS sitting indicates posterior tilt. Heckman et al also demonstrated an inverse relationship between Δ SS and Δ PFA in a study of 20 patients who developed late

dislocations after THA.²⁷ Innmann et al, in a similar study conducted on 100 unilateral THA patients, observed significantly lower PFA sitting and Δ PFA in the hypermobile group than in the normal and stiff groups at the 1-year postoperative mark. They reported significantly lower standing AI values in patients with postoperative spinopelvic hypermobility than in those with normal or stiff spinopelvic mobility, suggesting that reduced AI may contribute to decreased hip flexion capacity. As a result, they hypothesized that the pelvis tilted excessively posteriorly, enabling sitting.¹³ In patients with persistent spinopelvic hypermobility despite restored hip motion following THA, decreased functional outcomes may be attributed to instability in sagittal balance, increased compensatory muscular effort, and altered neuromuscular control patterns.

There were no significant differences in age or BMI between the FSZ-conforming and non-conforming groups. The FSZ-non-conforming group included patients with high or low CSI values, which may be associated with a higher risk of posterior or anterior impingement, respectively. Therefore, it is believed that comparisons of other radiological parameters such as AI and PFA may vary depending on the numerical dominance of these 2 subgroups. However, the FSZ-non-conforming group showed significantly worse PROMs than the FSZ-conforming group. These results indicate that the mismatch between acetabular cup orientation and spinopelvic motion may be associated with poorer postoperative satisfaction and a higher risk of impingement.

Recent technological advances, such as robotic-assisted surgery, have contributed to the growing acceptance of patient-specific implant placement based on anatomical variation and functional acetabular orientation. This patient-specific approach may help reduce mechanical complications, such as impingement and edge loading.²⁸⁻³⁰ Çetin et al reported that preoperative spinopelvic assessment enabled the identification of mobility abnormalities and may help reduce postoperative instability risk following THA, further supporting the clinical relevance of dynamic spinopelvic evaluation during preoperative planning.³¹ In a phantom study, Tang et al used dynamic spinopelvic parameters and kinematic simulations to calculate the patient-specific safe zone and suggested that appropriate acetabular cup orientations could be achieved without impingement.¹⁰ Additionally, several studies have suggested that lower inclination and anteversion angles may be beneficial for hypermobile kyphotic hips, whereas higher inclination and anteversion angles may reduce complications related to cup placement.³²⁻³⁴ Accordingly, in patients considered at risk from a spinopelvic perspective, patient-specific AI targets and FSZ-based cup orientation may be useful considerations during surgical planning, although their effect on postoperative outcomes requires further prospective validation.

Several limitations should be acknowledged. First, cup inclination, combined anteversion and offset discrepancies may affect postoperative hip balance.^{35,36} However, the sample size was not sufficient to evaluate these parameters comprehensively. Second, the hypermobile subgroup included only a small number of patients; although significant between-group differences in functional scores were observed, this limits generalizability and warrants confirmation in larger cohorts. Third, to minimize dislocation risk, radiographs were obtained in the relaxed-seated position rather than deep flexion—an approach supported in the literature but one that may underestimate extreme anterior impingement, particularly in patients with spinopelvic stiffness.³⁷ Fourth, preoperative PROM data were unavailable,

limiting comparisons of functional improvement relative to baseline. Finally, the relatively short follow-up duration precludes assessment of longer-term outcomes and complications.

Overall, the findings highlight the importance of dynamic spinopelvic motion in the assessment of acetabular cup placement during THA. Normal spinopelvic mobility and FSZ-conforming alignment were associated with better functional outcomes and higher quality-of-life scores after THA. These findings suggest that spinopelvic imbalance may be relevant during preoperative planning and component positioning; however, there is still no consensus regarding the optimal management strategy for these patients. Further prospective studies are needed to determine whether patient-specific planning strategies based on spinopelvic parameters improve patient satisfaction and clinical outcomes.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethical committee approval was received from Ordu University Clinical Research Ethics Committee (Approval no: 04/19, Date: 26.04.2024).

Informed Consent: Verbal informed consent was obtained from the patients who agreed to take part in the study.

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