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Obesity Alters Spinopelvic Alignment Changes From Standing to Relaxed Sitting: the Influence of the Soft-tissue Envelope

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ABSTRACT

Background: Changes in spinopelvic and lower extremity alignment between standing and relaxed sitting have important clinical implications with regard to stability of total hip arthroplasty. This study aimed to analyze the effect of body mass index (BMI) on lumbopelvic alignment and motion at the hip joint.
Methods: A retrospective review of patients who underwent full-body stereoradiographs in standing and relaxed sitting for total hip arthroplasty planning was conducted. Spinopelvic parameters measured included spinopelvic tilt (SPT), pelvic incidence (PI), lumbar lordosis (LL), PI minus LL (PI-LL), proximal femoral shaft angle (PFSA), and standing-to-sitting hip range of motion. Propensity score matching controlled for age, gender, PI, and hip ostoarthritis grade. Patients were stratified into normal (NORMAL; BMI, 18.5-24.9), overweight (OW; 25.0-29.9), and obese (OB; 30.0-34.9) groups. Alignment parameters were compared using one-way analysis of variance.
Results: There were 84 patients in each group after propensity score matching. Standing alignment between BMI groups was similar for all parameters ($P > .05$) except for PFSA ($P < .001$). Significant differences were noted for sitting alignment between patients who are NORMAL, OW, and OB in: SPT ($P = .007$), PI-LL ($P = .018$), and LL ($P = .029$). PFSA between groups was not significantly different ($P > .05$). Significant differences were found for sitting-to-standing alignment across groups in PFSA change ($P < .001$), SPT change ($P = .006$), PI-LL change ($P = .005$), LL change ($P = .037$), and hip flexion ($P < .001$).
Conclusions: Significant differences in sitting and standing-to-sitting change in lumbopelvic alignment based on BMI suggest obese patients recruit more posterior spinopelvic tilt when sitting to compensate for soft-tissue impingement that occurs anterior to the hip joint and limiting hip flexion.

Introduction

Hip instability after total hip arthroplasty (THA) is a leading cause of revision [1]. Dislocation after THA is correlated with reduced quality of life and added health-care costs [2]. In maintaining hip stability, lumbopelvic alignment plays a crucial role. The pelvis acts as a regulator of sagittal plane alignment, and its positioning varies according to spinal alignment [3]. Patients with abnormal spinopelvic alignment or mobility, especially in combination with poor acetabular cup positioning or soft-tissue abnormalities, are at an increased risk of dislocation [4]. For these patients, the traditional safe zone for acetabular cup implantation positioning may not be appropriate [5,6]. Instead, adjusting cup

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positioning based on spinopelvic alignment may provide optimum stability after THA [5,7,8].

Implant dislocation tends to occur during changes in posture, most commonly when rising from a chair [1]. Thus, a comprehensive understanding of THA stability includes examining alignment not only during standing positions but also during postural changes. A combination of acetabular and femoral orientation impacts the distance between the rim of the acetabulum and the proximal femur and thus affects the chance of anterior femoroacetabular impingement and risk of posterior dislocation in sitting [9]. Acetabular orientation is altered by changes in spinopelvic tilt (SPT) [5]. Patients with dislocations tend to have different standing-to-sitting spinopelvic alignment changes, including changes in pelvic tilt and spine flexion, compared with normal patients, along with altered acetabular component orientation [10].

Changes in spinopelvic alignment may be attributed to multiple causes. Owing to the coordinated nature of spinopelvic motions, a limit in motion on one spine segment tends to increase mobility in other spine segments and in pelvic tilt to maintain spinopelvic "balance" [1]. Spine diseases, including degenerative disc disease (DDD), degenerative spondylolisthesis, and lumbar fusion, have been associated with abnormal spinopelvic alignment and mobility [9,11,12].

While the propensity for concomitant hip and spine disease has been well established, there is an even stronger association between obesity and osteoarthritis of the lower extremity [13,14]. Morbidly obese patients require THA a decade faster than patients of normal weight [15]. Prior studies have demonstrated an obesity-associated relative risk for dislocation after THA [16-18], yet the exact causality of the relationship between obesity and THA instability remains unclear. Information regarding BMI and spinopelvic alignment measurements is scarce and inconsistent [15,19-21].

In this study, we analyze spinopelvic alignment parameters among patients with different BMI in relaxed standing and sitting positions, as well as the change between positions. The purpose of this study was to investigate the effect of obesity on lumbopelvic alignment and motion at the hip joint. Pelvic tilt will be referenced in this article by the term "spinopelvic tilt" rather than anterior pelvic plane tilt because of the improved accuracy in measurement [22].

Material and methods

Inclusion and exclusion criteria

An institutional review board–approved retrospective review of patients visiting a single academic institution undergoing unilateral THA, who had full-body stereoradiographs in both the standing and relaxed seated positions for preoperative planning, was conducted.

Only patients with BMI between 18.5 and 35 were included to encompass 3 categories of BMI as per World Health Organization standards [23]. Underweight and morbidly obese patients were excluded because of lack of patients (n < 20 for each category). Patients with poor visualization of lumbar spine or femoral heads, lumbosacral transitional anatomy, or history of either hip arthroplasty or lumbar fusion were excluded because of the previously published literature demonstrating changes in sit-stand alignment.

Patient demographics

A total of 466 patients met the inclusion and exclusion criteria, of which 37.55%, 38.20%, and 24.25% were categorized into NORMAL, overweight, and obese groups, respectively. No differences were found in age (P = .430), standing PI (P = .185), and proportion of lumbar flatback deformity and DDD (P = .559). The proportion of DDD (42.86%, 45.51%, and 45.13%) and lumbar flatback (14.29%, 18.54%, and 19.47%) for NORMAL, overweight, and obese groups, respectively, were not statistically significant (P = .559). Proportion of severe hip osteoarthritis (37.71%, 44.38%, and 53.98%, P = .005) and female gender (75.88%, 53.76%, and 52.29%, P < .000) were statistically significant between groups.

Owing to the demographic differences between groups, propensity score matching (PSM) was performed. After PSM, there were 84 patients in each group. The average age was 60.07 ± 13.98, 60.55 ± 15.11, and 60.36 ± 12.25 years and average standing PI was 54.26 ± 13.11, 55.82 ± 11.86, and 54.60 ± 11.85 for NORMAL, overweight, and obese patients, respectively. There were 61.90%, 57.14%, and 60.71% female patients in NORMAL, overweight, and obese groups, respectively. Proportion of severe hip osteoarthritis was 49.41%, 54.88%, and 49.41%. No differences were found in the proportion of DDD (39.29%, 50.00%, and 46.43%) and lumbar flatback deformity (19.05%, 19.05%, and 17.86%) across groups after PSM (P = .647).

Image acquisition

All patients underwent low-dose radiation, head-to-foot, biplanar stereoradiographic images (EOS imaging, Paris, France). This is a slot-scanning radiographic device consisting of 2 radiograph source-detector pairs, allowing simultaneous orthogonal image acquisition. The standardized protocol included a weight-bearing free-standing position of comfort in standing and unsupported sitting position on a radiolucent chair, both with arms flexed at 45 degrees and fingers on clavicles to prevent superimposition of the upper extremities on the spine [24]. Owing to the field of view of the EOS, the lower extremity distal to the proximal femur was unable to be captured in the sitting position.

Radiographic measurements

Spinopelvic parameters measured included SPT (angle between a line from the bicoxofemoral axis to the midpoint of the sacral endplate and a vertical line), pelvic incidence (PI: angle between a line from the bicoxofemoral axis to the midpoint of the sacral endplate and the line perpendicular to the sacral endplate), pelvic incidence minus lumbar lordosis (PI-LL), and L1 to S1 lumbar lordosis (LL: angle between the superior endplate of L1 and the superior endplate of S1) (Fig. 1). Segmental lumbar lordosis (between the superior endplate of the upper vertebra and superior endplate of the lower vertebra) at levels L1-L4 and L4-S1 were also measured. An increase in SPT denotes an increase in posterior pelvic tilt. PI-LL was included because it is an important measurement of spinopelvic alignment that has been shown to predict worse clinical outcomes and quality of life when greater than 10° (flatback) [3]. Furthermore, increasing SPT (pelvic retroversion) has a strong relationship with PI-LL mismatch in adult spinal deformity literature, functioning as a "compensatory mechanism" for lumbar flatback deformity. In addition, proximal femoral shaft angle (PFSA: the angle between the axis of the femoral shaft and the vertical) and hip flexion (PFSA change between sitting and standing radiographs minus SPT change) were measured for each patient. Severity of hip osteoarthritis was graded using the Kellgren-Lawrence system [25]. Lumbar spines were considered degenerative if disc height loss is >50% and facet arthropathy or spondylolisthesis was present at either radiograph and flatback if patient presented degenerative criteria and PI-LL >10°.

Statistical analysis

PSM was performed to control for PI, age, gender, and hip ostoarthritis grade. Patients were stratified into 3 groups: normal

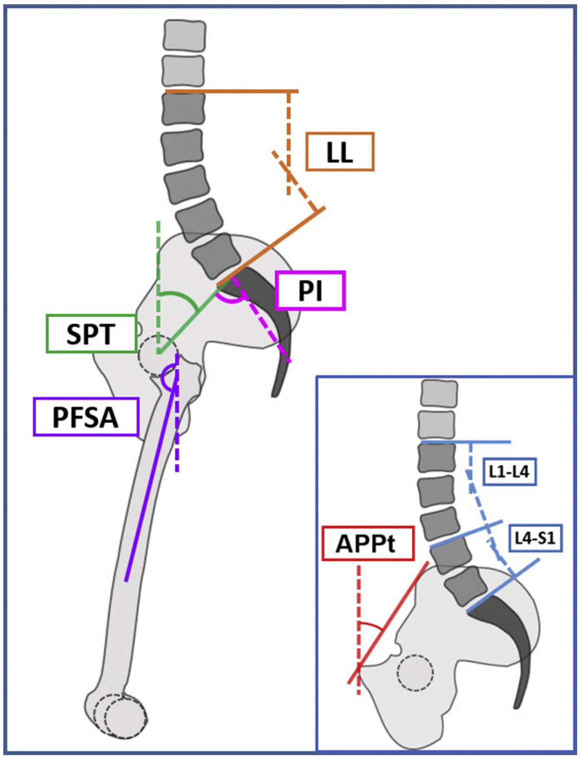


Figure 1. Sagittal spinopelvic alignment parameters measured in each patient are illustrated. Measured parameters include SPT, PI, L1 to S1 LL, and PFSA. Segmental lumbar lordosis was evaluated at levels L1-L4 (L4-L4) and L4-S1 (L4-S1). Pelvic tilt was referenced as SPT rather than anterior pelvic plane tilt (APPt) because of the improved accuracy in measurement [22].

(NORMAL; BMI, 18.5-24.9), overweight (25.0-29.9), and obese (30.0-34.9). Alignment parameters were compared using one-way analysis of variance, followed by the Turkey HSD test.

Results

Radiographic measurements

Standing alignment parameters (SPT, PI, PI-LL, LL) were similar between BMI groups ($P > .05$) except for standing PFSA, which was statistically significant among groups (NORMAL, 6.56 ± 4.11; overweight, 7.04 ± 4.70; obese, 9.74 ± 5.17, $P < .001$) (Table 1). Post-hoc Tukey test indicated the significant difference occurred in all groups except between NORMAL and overweight groups. A trend toward increased standing PFSA was observed among groups with increasing BMI.

Significant differences were found for sitting alignment for NORMAL, overweight, and obese patients in SPT (NORMAL, 25.57 ± 11.65; overweight, 26.95 ± 10.71; obese, 30.88 ± 11.14, $P = .007$), PI-LL (NORMAL, 16.95 ± 15.45; overweight, 17.86 ± 14.03; obese, 23.04 ± 15.20, $P = .018$), and LL (NORMAL, 38.40 ± 16.25; overweight, 38.53 ± 13.65; obese, 33.02 ± 15.68, $P = .029$) (Table 1). No significant differences were noted for sitting PFSA between groups (P >.05). Post-hoc Tukey test demonstrated statistically significant differences between all groups except between NORMAL and overweight groups for both SPT and PI-LL. Significant differences were only found between NORMAL and obese patients for SPT and PI-LL. The difference in LL between NORMAL and obese was close to significance ($P = .059$) but was not significant because of the methodologies of the Tukey test.

From standing to sitting, groups of increasing BMI were associated with significantly greater changes in SPT (NORMAL, 9.60 ± 11.69; overweight, 10.75 ± 12.07; obese, 15.14 ± 11.16, $P = .006$), PI-LL (NORMAL, 15.86 ± 12.78; overweight, 17.90 ± 14.32; obese, 22.54 ± 13.42, $P = .005$), and LL (NORMAL, -15.71 ± 12.82; overweight, −17.34 ± 14.68; obese, −21.09 ± 14.06, $P = .037$). Significantly smaller changes in PFSA (NORMAL, 90.02 ± 5.03; overweight, 88.47 ± 5.80; obese, 85.94 ± 6.26, $P < .001$) and hip flexion (NORMAL, 80.42 ± 12.52; overweight, 77.72 ± 15.29; obese, 70.87 ± 14.25, $P < .001$) occurred across groups of increasing BMI (Table 1). Results of standing to sitting alignment are highlighted in Figures 2 and 3. Post-hoc Tukey demonstrated statistically significant differences between all BMI groups for PFSA and SPT changes except between NORMAL and overweight groups. Significant differences in PI-LL and LL changes were only found between NORMAL and obese groups. Analysis of standing-to-sitting change in segmental lumbar lordosis revealed that only lordosis at L1-L4 (NORMAL, −4.82 ± 7.02; overweight, −6.16 ± 8.22; obese, −9.69 ± 8.61, $P < .001$) was significantly different across groups (Fig. 4).

Discussion

A body of evidence has demonstrated the increased risk of dislocation and revision in patients undergoing THA with adult spinal deformity [6,26], fixed spinopelvic alignment, [10] history of lumbar fusion [27-29], and noninstrumented spinal disease [6]. Several studies have also demonstrated an increased risk of dislocation after primary [16,18] and revision THA [17] in obese compared with normal-weight patients. Existing literature on the relationship between obesity and spinopelvic kinematics, and its potential contribution to THA instability, is inconsistent [15,19-21]. This study analyzed the effect of obesity on lumbopelvic alignment between standing and relaxed sitting postures.

Spinopelvic alignment plays a crucial role in maintaining THA stability. Because of the coordinated motion of the spine-pelvis-hip, patients with stiff spines require increased mobility of the hip joint from standing to sitting, with less change in SPT. These patients are thus at increased risk of anterior impingement and posterior dislocation while sitting [4]. On the contrary, patients with stiff hip joints require increased mobility of the spine from standing to sitting, which may account for the relatively high rates of back pain in osteoarthritic patients [4,30].

To our knowledge, our study is the first to examine sitting-standing changes in spinopelvic parameters between groups of different BMIs. Changes in spinopelvic alignment parameters of obese patients follow similar trends to patients with severe hip osteoarthritis. Buckland et al. [31] found greater magnitude of standing-to-sitting changes in SPT, PI-LL, and LL in patients with severe osteoarthritis than in patients with low-grade osteoarthritis. It was postulated that osteoarthritic patients have reduced hip range of motion and compensate by increasing SPT recruitment and increasing changes in LL and TL kyphosis. The mechanism underlying changes in spinopelvic parameters of patients with osteoarthritis may be similar to that in obese patients, with the exception that the restricted hip range of motion stems from extraarticular soft-tissue impingement in obese patients, rather than periarticular bony impingement in severe osteoarthritic patients. This is supported by the reduced hip flexion exhibited by obese patients compared to other groups. Soft-tissue impingement in obese patients may also lead to reduced femoral extension, indicated by the relatively greater standing PFSA. In contrast to patients with restricted hip motion, patients with stiff spines have standing femoral hyperextension and increased femoral motion [4,9].

Loss of hip motion may lead to increased requirement for spine mobility in obese patients. This is supported by the relatively large increase in standing-to-sitting LL magnitude. Increased LL change drives the greater SPT change observed in obese patients. SPT is

Table 1
Mean spinopelvic alignment parameters with standard deviations for normal, overweight, and obese patients in standing, sitting, and sitting-to-standing positions.

Spinopelvic measures	BMI category			*P* value
	Normal (n = 84)	Overweight (n = 84)	Obese (n = 84)	
Standing				
PFSA	6.56 ± 4.11	7.04 ± 4.70	9.74 ± 5.17	**.000**
SPT	14.97 ± 8.28	16.19 ± 7.62	15.74 ± 8.56	.615
PI	54.26 ± 13.11	55.82 ± 11.86	54.60 ± 11.85	.687
PI-LL	0.15 ± 12.67	−0.04 ± 10.57	0.50 ± 11.44	.954
L1-L4	19.00 ± 10.55	21.87 ± 8.44	21.78 ± 8.58	.075
L4-S1	35.10 ± 8.44	33.99 ± 8.65	32.33 ± 8.16	.101
LL	54.11 ± 12.98	55.86 ± 11.80	54.11 ± 11.98	.564
Sitting				
PFSA	96.59 ± 3.89	95.52 ± 4.01	95.67 ± 4.20	.181
SPT	25.57 ± 11.65	26.95 ± 10.71	30.88 ± 11.14	**.007**
PI	55.37 ± 12.06	56.39 ± 12.03	56.05 ± 12.22	.857
PI-LL	16.95 ± 15.45	17.86 ± 14.03	23.04 ± 15.20	**.018**
L1-L4	14.18 ± 11.98	15.72 ± 10.94	12.09 ± 11.14	.118
L4-S1	24.22 ± 9.52	22.81 ± 9.66	20.93 ± 8.62	.072
LL	38.40 ± 16.25	38.53 ± 13.65	33.02 ± 15.68	**.029**
Sitting-standing change				
PFSA	90.02 ± 5.03	88.47 ± 5.80	85.94 ± 6.26	**.000**
SPT	9.60 ± 11.69	10.75 ± 12.07	15.14 ± 11.16	**.006**
PI	0.15 ± 9.98	0.56 ± 9.32	1.45 ± 7.24	.631
PI-LL	15.86 ± 12.78	17.90 ± 14.32	22.54 ± 13.42	**.005**
L1-L4	−4.82 ± 7.02	−6.16 ± 8.22	−9.69 ± 8.61	**.000**
L4-S1	−10.89 ± 8.39	−11.18 ± 10.77	−11.40 ± 9.33	.941
LL	−15.71 ± 12.82	−17.34 ± 14.68	−21.09 ± 14.06	**.037**
Hip Flexion	80.42 ± 12.52	77.72 ± 15.29	70.87 ± 14.25	**.000**

Bold indicates statistically significant *P*-values (<.05).

influenced by both spinal and femoral alignment because of the position of the pelvis between the spine and hip [9]. Demonstrating this relationship, patients with limited spine mobility are not able to adequately increase SPT when transitioning from standing to sitting and thus need to recruit more hip flexion to move the femur from a vertical to horizontal position than healthy patients [10]. In

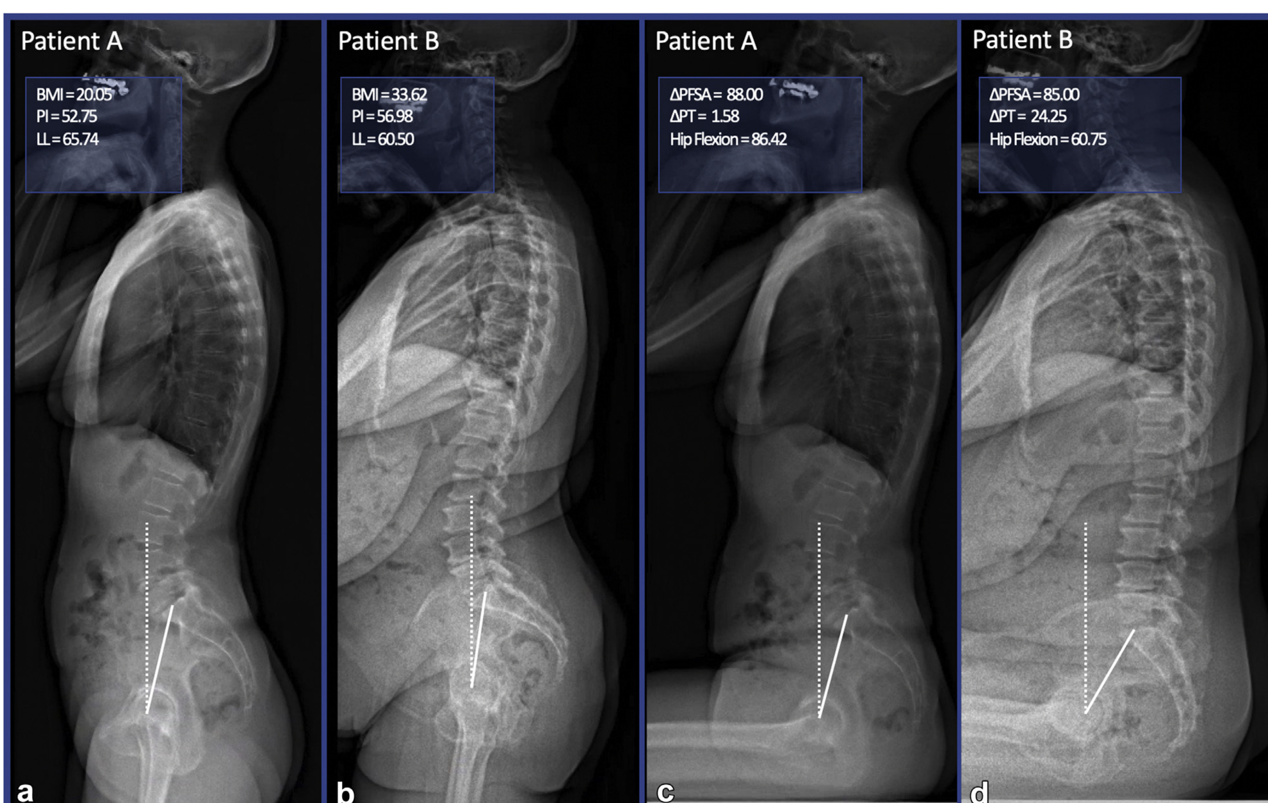
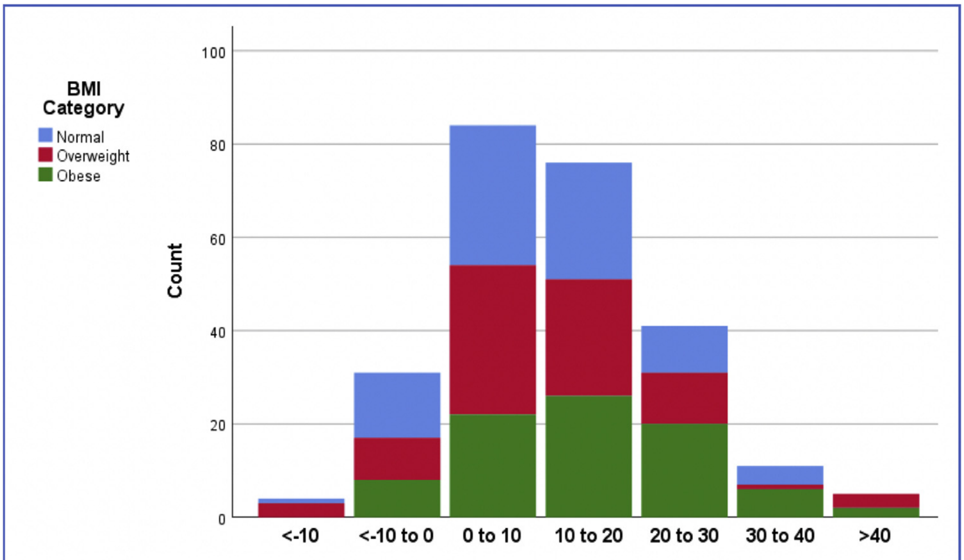


Figure 2. Standing and sitting lateral radiographs comparing obese and normal patients are shown. (a) Standing alignment of a patient with normal BMI. (b) Standing alignment of a patient with obese BMI. (c) Sitting alignment of a patient with normal BMI. (d) Sitting alignment of a patient with obese BMI. In the present study, standing alignment was found to be similar for patients with obese BMI and normal BMI. However, sitting alignment and change in alignment from sitting to standing was found to be significantly different. Obese patients recruit more pelvic tilt while sitting than normal BMI patients to compensate for greater soft-tissue impingement anterior to the hip, which limits hip flexion.



SPT Sitting-Standing		<-10 (n=4)	-10 to 0 (n=31)	0 to 10 (n=84)	10 to 20 (n=76)	20 to 30 (n=41)	30 to 40 (n=11)	>40 (n=5)
BMI Category	Normal	25%	45%	36%	33%	24%	36%	0%
	Overweight	75%	29%	38%	33%	27%	9%	60%
	Obese	0%	26%	26%	34%	49%	55%	40%

Figure 3. The relationship between BMI categories and change in sitting-standing SPT is demonstrated. A histogram was chosen over a scatter plot because of the large amount of noise in the data set that made it difficult to discern any patterns among individual data points. Compared with other BMI groups, obese patients tend to comprise larger proportions of patients with greater sitting-standing SPT changes. The proportions of overweight and normal-weight patients in each sitting-standing SPT category do not show well-defined trends.

addition, the relatively increased motion of the upper lumbar segments in obese patients from standing to sitting, indicated by the greater change in L1-L4 than that of L4-S1, is likely due to soft-tissue impingement around the groin crease in the sitting position.

Applying our results clinically, obesity may provide a protective mechanism against risk of prosthetic impingement. Each increase in degree of SPT is concomitantly associated with 0.7° of acetabular component anteversion [5]. Increased acetabular anteversion has been shown to decrease the risk for anterior impingement and, ultimately, posterior dislocation [32]. Thus, in planning THA, BMI may be an important factor in evaluating spinopelvic alignment and, ultimately, risk of impingement. Although obesity may protect against prosthetic impingement, obesity may be associated with overall increased THA instability risk, [16-18] which may be attributed to multiple alternate factors. For example, Callanan et al. [33] found that BMI increases risk of cup malpositioning for abduction only or for abduction and version combined. It was postulated that the inaccuracy was due to increased adipose tissue, leading to reduced incision size field and difficulty locating anatomic landmarks. However, when controlling for other factors that influenced instability risk (high-volume surgeon and standard posterolateral approach), McArthur et al. [34] found no correlation between obesity and risk of malpositioning. Weight loss preoperatively may also help reduce the risk of prosthetic dislocation.

Owing to the novelty of our field of study, we were unable to compare many of our findings to existing literature. In agreement with previous works, all groups adjusted to a change in alignment from standing to sitting using similar mechanisms, exhibiting increased SPT [3,35,36] and decreased LL [3]. However, previous reports on standing spinopelvic alignment in obese patients are conflicting. Corresponding to our results, Jalai et al. [37] found no differences in standing SPT, PI-LL, and LL between obese and nonobese patients. Horn et al. [38] also found no differences in standing SPT but significantly higher standing PI-LL in obese patients than in normal-weight patients. In contrast to our results, there are reports of both higher [39-41] and lower [21] standing SPT in obese patients than in normal-weight patients. Several studies have also demonstrated increased standing LL in obese patients compared with that in normal-weight patients [21,42].

Comparing existing reports on sitting-to-standing spinopelvic alignment, the correlation between reduced hip flexion and obesity has been validated by Yeung et al. [43]. Furthermore, Sparrey et al.

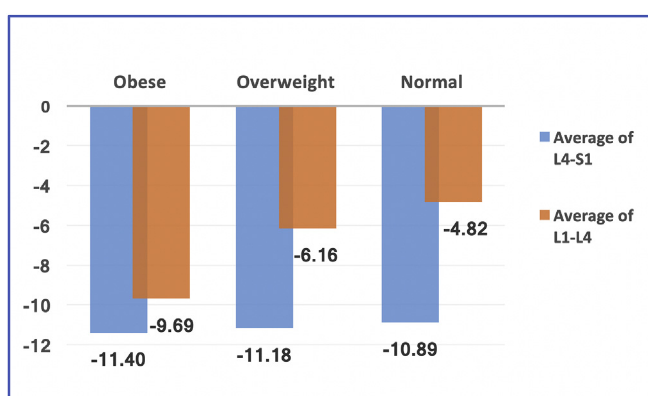


Figure 4. Change in segmental lumbar lordosis from standing to sitting was analyzed across BMI groups. While all groups had similar motion at the lower segments (L4-S1) of the lumbar spine, motion at the upper segments (L1-L4) was significantly increased across groups of increasing BMI. The increased motion is likely due to soft-tissue impingement around the hip in the sitting position.

claimed that BMI does not appear to correlate with LL but limits lumbar range of motion, especially in sitting positions [5,44,45].

Limitations

Although we minimized confounding variables by matching lumbar flatback and DDD rates across groups, as well as hip ostoarthritis grade, other characteristics associated with spine diseases may exist between groups. In addition, other unaccounted spine conditions may correlate with spinopelvic alignment changes such as disc herniation [12] or laminectomy [5] which cannot be accounted for in this analysis.

BMI does not distinguish between soft-tissue type and distribution. Given that soft-tissue impingement in obese patients could be a contributing factor to changes in spinopelvic parameters, future studies may be able to study more direct relationships by stratifying patients based on soft-tissue distribution instead of BMI.

Moreover, our study only analyzed alignment parameters at one cross-section of time. In the future, analysis of spinopelvic alignment parameters over time, including post-THA, would allow us to track progressive changes in alignment which may help us better understand hip instability.

Conclusions

Significant differences were noted in sitting alignment and the change in alignment from sitting to standing based on BMI. The results of this study suggest that obese patients recruit more posterior PT when transitioning from standing to sitting to compensate for soft-tissue impingement that occurs anterior to the hip joint during hip flexion.

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Appendix

Abbreviations

APPt: anterior pelvic plane tilt.

DDD: Degenerative disc disease.

LL: L1 to S1 lumbar lordosis – angle between the superior endplate of L1 and the superior endplate of S1.

PI: pelvic incidence – angle between a line from the bicoxofemoral axis to the midpoint of the sacral endplate and the line perpendicular to the sacral endplate.

PI-LL: PI minus LL.

PFSA: proximal femoral shaft angle – angle between the axis of the femoral shaft and the vertical.

PSM: propensity score matching.

SPT: spinopelvic tilt – angle between a line from the bicoxofemoral axis to the midpoint of the sacral endplate and a vertical line.

THA: total hip arthroplasty.