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Effect of Obesity on Radiographic Alignment and Short-Term Complications After Surgical Treatment of Adult Cervical Deformity

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■ OBJECTIVE: We investigated the 30-day complication incidence and 1-year radiographic correction in obese patients undergoing surgical treatment of cervical deformity.

■ METHODS: The patients were stratified according to World Health Organization's definition for obesity: obese, patients with a body mass index of ≥30 kg/m^2; and nonobese, patients with a body mass index of <30 kg/m^2. The patients had undergone surgery for the treatment of cervical deformity. The patient baseline demographic, comorbidity, and radiographic data were compared between the 2 groups at baseline and 1 year postoperatively. The 30-day complication incidence was stratified according to complication severity (any, major, or minor), and type (cardiopulmonary, dysphagia, infection, neurological, and operative). Binary logistic regression models were used to assess the effect of obesity on developing those complications, with adjustment for patient age and levels fused.

■ RESULTS: A total of 124 patients were included, 53 obese and 71 nonobese patients. The 2 groups had a similar T1 slope minus cervical lordosis (obese, 37.2° vs. nonobese, 36.9°; P = 0.932) and a similar C2–C7 (−5.9° vs. −7.3°; P = 0.718) and C2–C7 (50.1 mm vs. 44.1 mm; P = 0.184) sagittal vertical axis. At the 1-year follow-up examination, the T1 pelvic angle (1.0° vs. −3.1°; P = 0.021) and C2–S1 sagittal vertical axis (−5.9 mm vs. −35.0 mm; P = 0.036) were different, and the T1 spinopelvic inclination (−1.0° vs. −2.9°; P = 0.123) was similar. The obese patients had a greater risk of overall short-term complications (odds ratio, 2.5; 95% confidence interval, 1.1–6.1) and infectious complications (odds ratio, 5.0; 95% confidence interval, 1.0–25.6).

■ CONCLUSIONS: Obese patients had a 5 times greater odds of developing infections after surgery for adult cervical deformity. Obese patients also showed significantly greater pelvic anteversion after cervical correction.

Key words
- Alignment
- Cervical deformity
- Complications
- Obese
- Obesity
- Surgery

Abbreviations and Acronyms

BMI: Body mass index
BMP: Bone morphogenetic protein
CL: Cervical lordosis
cSVA: Cervical sagittal vertical axis
EQ5D: Euro-Qol 5 dimension
HRQL: Health-related quality of life
LL: Lumbar lordosis
mJOA: Modified Japanese Orthopaedic Association
NRS: Numerical rating scale
PI: Pelvic incidence
PT: Pelvic tilt
SS: Sacral slope
SVA: Sagittal vertical axis
TS: T1 slope
TPA: T1 pelvic angle

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Citation: World Neurosurg. (2019) 125:e1082-e1088.
https://doi.org/10.1016/j.wneu.2019.01.248

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

INTRODUCTION

Obesity has been increasing in prevalence worldwide.[1] Obesity is well-understood to be associated with the acceleration of musculoskeletal degenerative diseases and functional impairment secondary to spinal disorders.[2-4] Not only do obese patients present to spine surgeons more frequently, but also, in the lumbar spine, deformity procedures have been shown to have increased rates of complications, greater revision rates, and a lower magnitude of health-related quality of life (HRQL) improvements.[5-11] However, the effect of obesity in the less common arena of cervical deformity corrective procedures has not been studied.

Recent advances in the understanding of sagittal malalignment have described the importance of minimizing energetic expenditure to maintain an upright posture.[12,13] In 2016, Jalai et al.[9] showed that obese patients preferentially recruited pelvic compensation mechanisms to maintain horizontal gaze and an erect posture. In previous studies, obesity has been reported to increase the compressive loads on discs and shear stresses in the spine.[10,11] In postoperative analyses, Park et al.[14] showed different postoperative changes in the pelvic incidence (PI) minus lumbar lordosis (LL) mismatch and sagittal vertical axis (SVA) in obese patients.[14] These findings suggest that at both patients' presentation at baseline and when evaluating postoperative alignment improvements, deformities in obese patients might be considered differently than the same variable in nonobese patients. Such differences have not yet been quantified in cervical deformity studies.

Although the effect of obesity on postoperative complications in the lumbar spine has been well studied, the findings have been inconsistent with those from the cervical spine data. In lumbar spinal deformities, Soroceanu et al.[5] found increased major complications and wound infections. In the cervical spine, however, Buerba et al.[15] found no increased risk of complications in obese patients even with posterior fusion. However, this finding has been in direct conflict with other findings of an increased length of stay and risk of infections.[6,16,17] To the best of our knowledge, to date, no study has analyzed the effect of obesity on cervical deformity.

The effect of obesity on patient-reported and radiological outcomes has been the focus of much attention from surgeons but has remained poorly understood in the cervical spine. We examined the radiographic and complication differences in obese patients using a multiple-site cervical deformity database.

METHODS

Consecutive adult patients with cervical deformity were prospectively enrolled by the International Spine Study Group across 13 participating sites from January 2013 through September 2016. The institutional review board at each site approved the present study.

The inclusion criteria for the study database were age $\geq$18 years, radiographically defined cervical deformity, and surgical treatment to correct the deformity. Radiographic cervical deformity was defined as any of the following markers on the preoperative radiographs: cervical kyphosis (C2–C7 sagittal Cobb angle $\geq 10°$), cervical scoliosis (C2–C7 coronal Cobb angle $\geq 10°$), C2–C7 SVA $\geq$4 cm, and/or chin-brow vertical angle $\geq 25°$. Patients with an active neoplasm in the spine, a spinal infection, pregnancy, or a post-traumatic deformity were excluded.

The patient demographic data, radiographic assessments, surgical and clinical details, complications, and patient-reported outcome scores were collected by the enrolling surgeon at baseline and 6 weeks, 3 months, and 1 year postoperatively.

The primary analysis queried for differences in the incidence and severity of complications and amount of realignment (change from baseline to 1-year postoperatively) achieved in obese (body mass index [BMI] >30 kg/m^2) and nonobese (BMI $\leq$30 kg/m^2) patients. The secondary analyses compared the differences in demographic data, surgical and clinical details, and patient-reported outcome measures between the obese and nonobese groups.

Primary Analysis

The incidence of short-term (within 30 days) and long-term (30 days to 1 year) complications were compared between the obese and nonobese patients using a binary logistic regression model, controlled for age, levels fused, and baseline cervical deformity (cervical SVA [cSVA]). Complications were defined according to severity, as previously reported: any (any deviation from protocol), major (any complication that involved invasive intervention or had resulted in prolonged or permanent morbidity or death), and minor.[18] The complications were also stratified by type (e.g., cardiopulmonary, dysphagia, infection, neurological, operative).

Realignment success between the obese and nonobese patients was analyzed by comparing the change from baseline to 1 year postoperatively using t tests. The alignment measurements considered were as follows: cervical (i.e., T1 slope [TS] minus cervical lordosis [CL], C2–C7 CL, C2–T3 CL, C2–C7 SVA, C2–T3 SVA, C2 slope), spinopelvic (i.e., sacral slope [SS], pelvic tilt [PT], pelvic incidence [PI], PI-LL, L1–S1 LL, and T12-S1 LL), and global (i.e., C2–S1 global alignment, C2–S1 SVA, C7–S1 SVA, and T1 pelvic angle [TPA]). To control for demographic and clinical differences between the 2 groups, propensity score matching was used to match the obese and nonobese patients according to age, levels fused, and severity of the baseline deformity.

Secondary Analysis

A secondary, descriptive analysis compared the obese and nonobese patients' demographic data, surgical and clinical details, and patient-reported outcome measures. For continuous variables, normality was tested using a Kolmogorov-Smirnov test and compared using Student t tests for normally distributed variables and the Wilcoxon test for non-normal data. Categorical variables were assessed using the χ^2 or Fisher exact test. Demographic variables included age, BMI, height, weight, Charlson comorbidity index, sex, race, history of cervical surgery, and comorbidities. The surgical and clinical details assessed were approach, staged surgery (i.e., surgery in which the anterior and posterior portions were performed on different days in the same hospitalization, within 2 weeks of the index procedure), bone morphogenetic protein (BMP) use, anterior levels fused, and posterior levels fused. Finally, the patient-reported outcome measures included the baseline and 1-year postoperative numeric rating scale (NRS) score for the back and neck, Neck Disability Index, Euro-Qol 5-dimension (EQ5D) questionnaire results, EQ5D visual analog

Table 1. Independent Samples *t* Tests and χ^2 Tests for Baseline Demographic Data

Variable	Nonobese (*n* = 62)	Obese (*n* = 46)	*P* Value
Age (years)	61.7	60.9	0.689
BMI (kg/m^2)	24.4	37.6	<0.001
Height (cm)	165.6	165.8	0.933
Weight (kg)	67.7	104.2	<0.001
Charlson comorbidity index	0.58	0.77	0.329
Female sex (%)	40.9	59.1	0.407
Race (%)			0.312
White	93.4	90.7	
Black	4.9	2.3	
Other	1.6	7.0	
History of cervical surgery (%)	46.7	39.5	0.303
Comorbidities (%)			
Clinical depression	30.6	31.8	0.532
Diabetes	4.8	13.6	0.107
Osteopenia	4.8	2.3	0.447
Osteoporosis	12.9	11.4	0.530
No comorbidities	26.5	19.5	1.298

BMI, body mass index.

Table 2. Independent Samples *t* Tests for Patient-Reported Quality of Life Scores

Variable	Nonobese (*n* = 62)	Obese (*n* = 46)	*P* Value
Baseline			
NRS back	5.3	5.2	0.885
NRS neck	7.0	6.5	0.293
NDI	47.9	49.5	0.644
mJOA	13.7	13.3	0.496
EQ5D	0.74	0.73	0.449
EQ5D VAS	78.5	74.0	0.866
At 1 year			
NRS back	4.3	4.9	0.401
NRS neck	4.3	3.9	0.621
NDI	34.4	41.0	0.171
mJOA	14.4	13.3	0.146
EQ5D	0.78	0.79	0.476
EQ5D VAS	87.0	59.0	0.293

NRS, numerical rating scale; NDI, Neck Disability Index; mJOA, modified Japanese Orthopaedic Association; EQ5D, Euro-Qol 5 dimension; VAS, visual analog scale.

scale score, and modified Japanese Orthopedic Association (mJOA) score for myelopathy. Myelopathy severity was defined using previously reported mJOA score cutoffs: asymptomatic, score 18; mild, score 15–17; moderate, score 12–14; and severe, score 0–11.[19] All statistical tests were 2-tailed. $P < 0.05$ was considered to indicate statistical significance. All statistical analyses were performed using SPSS Statistics, version 23.0 (IBM Corp., Armonk, New York, USA).

RESULTS

Descriptive Analyses

A total of 124 patients were eligible for inclusion in the present study. In the overall cohort and before matching, the obese patients did not differ significantly from the nonobese patients for any non–weight-related demographic category (Table 1). The patients' age, height, sex, Charlson comorbidity score, race, history of cervical surgery, and individual comorbidities did not differ between the 2 groups ($P > 0.005$ for all).

All 124 patients had presented with deformities meeting the thresholds established in the Ames cervical deformity classification system. For the cSVA, 63% of patients met the deformity cutoff at >4 cm, with 8% meeting the severe deformity cutoff at >8 cm. For TS-CL, 92.7% of the patients were symptomatic at >15°, and 87% had met the severe deformity cutoff at >20°. For myelopathy, 7.8% of the patients did not have myelopathy symptoms and 32.8%, 39.7%, and 19.8% had had mild, moderate, and severe symptoms, respectively. The obese patients had a similar cSVA ($P = 0.357$) and TS-CL ($P = 0.740$) deformity distribution.

The obese and nonobese patients had a similar myelopathy severity using the mJOA scale (obese, 13.3 vs. nonobese, 13.7; $P = 0.496$). No differences were found in ambulatory status (obese, 2% nonambulatory vs. nonobese, 4% nonambulatory; $P = 0.537$), osteopenia (obese, 2% vs. nonobese, 5.4%; $P = 0.652$), or osteoporosis (obese, 12% vs. nonobese, 14.9%; $P = 0.348$).

The preoperative and 1-year HRQL measurements for the obese and nonobese patients are listed in Table 2. No difference was found in the preoperative or 1-year HRQL results in any tested metric: NRS back, NRS neck, Neck Disability Index, mJOA scale score, EQ5D, or EQ5D visual analog scale ($P > 0.05$ for all).

Differences in the surgical details are presented in Table 3. Staged surgery (2 different anesthesia events) were more frequently used for obese patients (obese, 46.2% vs. nonobese, 13.8%; $P = 0.032$). BMP was also used more frequently in the obese patients (obese, 65.8% vs. nonobese, 43.4%; $P = 0.028$). The overall complication rates did not differ between the patients who had undergone staged surgery and those who had not ($P = 0.369$) nor between the patients who had received BMP and those who had not ($P = 0.343$). Similarly, the rates of infection did not differ when stratified by the use of surgical staging ($P = 0.183$) or BMP ($P = 0.951$).

Primary Analysis: Complication Discrepancy

According to the univariate analysis, no differences were present in the complication rates between the 2 groups in the short or long

Table 3. Independent Samples *t* Tests and χ^2 Tests Showing Clinical Details, Stratified by Obesity Status

Variable	Nonobese (*n* = 62)	Obese (*n* = 46)	*P* Value
Approach			
Anterior	14.5	15.2	0.564
Posterior	48.4	50.0	0.511
Combined	37.1	34.8	0.483
Staged surgery	13.8	46.2	0.032
BMP use	43.4	65.8	0.028
Levels fused			
Anterior	1.9	1.6	0.501
Posterior	8.1	7.2	0.372

BMP, bone morphogenetic protein.

term (Table 4). Multivariate regression analysis, which was controlled for age, levels fused, and baseline cervical deformity, revealed a significant difference in the incidence of short-term complications. Obese patients had a greater risk of overall short-term complications (odds ratio, 2.5; 95% confidence interval, 1.1–6.1) and posterior infection complications (odds ratio, 5.0; 95% confidence interval, 1.0–25.6). No significant differences were found in the long-term complications between the 2 groups after multivariate adjustment.

Primary Analysis: Realignment

Before matching, the obese and nonobese patients showed different cervical radiographic parameters that were not statistically significant (Table 5). However, significant differences were present in the global SVA parameters: C2–S1 SVA (obese, 73.6 mm vs. nonobese, 36.7 mm; $P = 0.023$), C7–S1 SVA (obese, 32.7 mm vs. nonobese, −3.2 mm; $P = 0.012$). The spinopelvic parameters were not significantly different statistically ($P > 0.05$). However, the PI-LL (obese, 5.2 vs. nonobese, −0.9; $P = 0.086$) showed a trend toward a difference, and the TPA was greater in the obese patients (obese, 17.7° vs. nonobese, 12.1°; $P = 0.023$).

After matching the patients according to the baseline C2–C7 SVA, none of the baseline cervical parameters differed between the obese and nonobese groups ($P > 0.05$; Table 6). The cervical correction achieved was similar in the 2 cohorts. Improvements in alignment were seen in both cohorts: TS-CL decreased (obese, −8.9° vs. nonobese, −11.5°; $P = 0.674$), C2–C7 SVA decreased (obese, −5.5 mm vs. nonobese, −7.4 mm; $P = 0.728$), and C2–C7 cervical lordosis increased (obese, +13.9° vs. nonobese, +15.4°; $P = 0.801$).

Despite matching for baseline cervical SVA and the subsequent similarity in the baseline radiographic parameters, the obese and

Table 4. Independent Samples *t* Tests and Logistic Regression Analysis Results

Variable	Nonobese (*n* = 62)	Obese (*n* = 46)	*P* Value	OR (95% CI)
Intraoperative and <30 days				
Any complication	45.2	63.0	0.098	2.5 (1.1–6.1)
Major	16.1	15.2	0.910	4.5 (0.8–25.6)
Minor	27.4	34.8	0.416	1.6 (0.6–3.9)
Cardiopulmonary	9.7	13.0	0.617	1.5 (0.3–7.4)
Dysphagia	14.5	8.7	0.363	0.4 (0.1–1.9)
Infection	4.8	15.2	0.089	5 (1.0–25.6)
Instrumentation	1.6	0	0.395	NA
Neurological	14.5	17.4	0.707	2 (0.6–6.9)
After 30 days				
Any complication	53.2	63.0	0.581	1.8 (0.7–4.6)
Major	24.2	13.0	0.344	0.9 (0.3–3.2)
Minor	9.7	10.9	0.841	1.1 (0.3–4.2)
Cardiopulmonary	6.5	2.2	0.445	0 (0–0)
Dysphagia	3.2	4.3	0.763	1.2 (0.1–13.8)
Infection	4.8	2.2	0.473	NA
Instrumentation	3.2	4.3	0.763	1.9 (0.2–15.4)
Neurological	11.3	15.2	0.582	0.8 (0.2–3.1)

OR, odds ratio; CI, confidence interval; NA, not applicable.

Table 5. Independent Samples *t* Tests Showing Differences in Preoperative Sagittal Alignment

Variable	Nonobese (*n* = 62)	Obese (*n* = 46)	*P* Value
Cervical			
TS-CL	37.5	37.5	0.998
C2–C7 CL	−6.6	−5.1	0.732
C2–T3 CL	−16.6	−15.5	0.791
C2–C7 SVA	45.4	50.4	0.306
C2–T3 SVA	77.6	86.2	0.304
C2 slope	38.1	38.3	0.966
Spinopelvic			
SS	35.4	34.1	0.446
PT	18.3	21.5	0.159
PI	54.2	55.6	0.567
PI-LL	−0.9	5.2	0.086
L1–S1 LL	54.6	50.4	0.198
T12–S1 LL	52.4	47.2	0.198
C2–S1 GA	−2.4	−3.9	0.750
C2–S1 SVA	36.7	73.6	0.023
C7–S1 SVA	−3.2	32.7	0.012
TPA	12.1	17.7	0.023

TS, T1 slope; CL, cervical lordosis; SVA, sagittal vertical axis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; LL, lumbar lordosis; GA, global alignment; TPA, T1 pelvic angle.

Table 6. Independent Samples *t* Tests Showing Differences in 1-Year Postoperative Radiographic Alignment in Groups Propensity Score Matched for C2–C7 Sagittal Vertical Axis

Variable	Nonobese (*n* = 39)	Obese (*n* = 39)	*P* Value
Cervical			
TS-CL	28	28.3	0.628
C2–C7 CL	10.3	8.3	0.076
C2–T3 CL	−0.7	−3	0.190
C2–C7 SVA	42.9	44.6	0.713
C2–T3 SVA	78.2	84.5	0.571
C2 slope	26.6	27.4	0.549
Spinopelvic			
SS	33.2	35.8	0.583
PT	19.7	18.6	0.989
PI	53.6	54.5	0.587
PI-LL	2.8	−0.4	0.809
L1–S1 LL	49.8	54.9	0.960
T12–S1 LL	47.8	51.9	0.985
C2–S1 GA	6.5	7.9	0.815
C2–S1 SVA	59.9	61	0.782
C7–S1 SVA	20.4	20.5	0.719
TPA	15.3	14.2	0.866

TS, T1 slope; CL, cervical lordosis; SVA, sagittal vertical axis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; LL, lumbar lordosis; GA, global alignment; TPA, T1 pelvic angle.

nonobese patients had significantly different postoperative alignment. LL had decreased in obese patients but had increased in nonobese patients (obese, −3.8 vs. nonobese, +3.6; $P = 0.016$). Furthermore, the TPA had decreased in the obese patients but had increased in the nonobese patients (obese, −2.1 vs. nonobese, +2.8; $P = 0.022$). The C2–S1 global angle was similar in obese and nonobese patient groups (obese, 7.9 vs. nonobese, 6.5; $P = 0.815$), as was the C2–S1 SVA (obese, 61 mm vs. nonobese, 59.9 mm; $P = 0.782$).

The pelvic alignment was similar preoperatively in the cSVA-matched cohorts (Table 6). At 1 year postoperatively, however, differences were found in the SS and PT. The SS had increased slightly in the obese patients but had decreased in the nonobese patients (obese, +2.5 vs. nonobese, −1.5; $P = 0.022$). Also, the PT had decreased in the obese patients but had increased in the nonobese patients (obese, −2.8 vs. nonobese, +1.0; $P = 0.033$).

DISCUSSION

Patient characteristics influence deformity progression, compensatory mechanisms in malalignment, and postoperative changes after surgical realignments.[20,21] Obesity has been shown to be an important clinical factor, because obese patients will preferentially recruit lower extremity compensation rather than pelvic mechanisms.[9] However, understanding how the obese patients' different anatomy effects the changes after cervical deformity realignment surgery has not yet been studied. Obesity has also been under scrutiny as a factor affecting patient outcomes but has not yet been investigated rigorously for its effect on complications and outcomes in the setting of cervical deformity.[5]

Short-term infectious complications occurred at greater rates in obese patients after controlling for age, levels fused, and baseline cervical deformity. Obese patients had a 5 times greater risk of sustaining surgical site infections with a rate of >15%. These results are similar to those reported by Pull ter Gunne et al.,[6] who studied adult spinal deformity infection risks and found an infection rate of 5% in the overall population and 13% in obese patients. In contrast, the present study found corresponding rates of 5% and 15%. Obese patients also had a 2.2 times greater risk of any overall short-term complications; however, the difference was disproportionately composed of infectious complications. In terms of noninfectious complications, no statistically significant differences were reported. Several recent studies have found no increased incidence of short-term complications in obese patients after cervical spine surgery.[15,17] Although access and visualization of the surgical site will be compromised in obese patients, the statistically significant differences in the incidence of complications might be confined to the lumbar spine.[5]

In an analysis of the mid-term incidence of complications, no difference was found in the complication rates in the previous 30 days. In an analysis of the revision rates in obese and nonobese patients 2 years after lumbar spinal deformity surgery, Soroceanu et al.[5] found no difference (20% in nonobese patients, 22.7% in obese patients). Although obesity is theoretically a risk factor for the loss of correction and radiographic complications, resulting from increased stress on the surgical construct, the present analysis did not show any loss of correction in the obese cohort.

Pathologic progression of sagittal malalignment usually stems from disc degeneration, which results in loss of lumbar lordosis.[22,23] The primary aim of compensatory mechanisms is to maintain Dubousset's "cone of economy," where the center of gravity is positioned over the feet.[24] Recent radiographic studies of obese and nonobese patients have shown that obese patients recruit lower extremity compensation in response to spinopelvic mismatch.[9] Additionally, obese patients have shown a lesser degree of pelvic retroversion, postulated to result from hip hyperextension owing to obese patients' excessive weightbearing in proximity to the hip and pelvis.

In the present study, the postoperative realignment was compared between the obese and nonobese patients with a matched baseline cSVA. TPA and LL, both measures of forward sagittal malalignment, showed a more significant decrease in obese patients.[23] Correspondingly, obese patients showed greater pelvic anteversion. This was most likely reflective of, despite the matched baseline radiographic findings, the different baseline compensation mechanisms that were in place. Specifically, although nonobese patients might recruit pelvic motion to compensate for anterior sagittal malalignment, obese patients have been revealed to, instead, incorporate greater lower limb compensation (e.g., knee flexion).[9] For obese patients, pelvic motion might be physiologically restricted owing to excessive weightbearing in proximity to the hips and pelvis, leading to an increased reliance on lower limb compensation. This might explain why, in our study, nonobese patients showed a statistically significant postoperative increase in the PT, but nonobese patients did not (and vice versa for SS, which is mathematically related to PT and the constant physiological parameter of PI using the following formula: $PI = SS + PT$). In the present study, because the SVA was operatively moved posteriorly and the compensation measures were placated, the pelvis of the obese patients showed greater reciprocal retroversion compared with the pelvis of the nonobese patients.

Study Limitations

The present study had several limitations. The study design did not account for patient frailty, muscular and soft tissue pathologic features, or the distribution of central obesity, all of which might play a role in deformity compensation. Furthermore, large sample sizes are very difficult to obtain in studies of cervical deformity. Thus, the present study might have suffered from a lack of power. Another limitation of the present study was the greater rate of staged surgery and the use of BMP among the obese patient population. Although neither staged surgery nor BMP use was associated with the overall complication or infection rates, these procedural differences could still have affected the patient outcomes. Furthermore, information regarding the interval between surgical stages was unavailable, which also could have affected the patient outcomes.

CONCLUSIONS

Our results have shown that obese patients have a 5 times elevated risk of developing infections after surgery for adult cervical deformity. In a purely cervical alignment analysis, the preoperative, except for the cervical SVA, and postoperative alignment did not differ between the obese and nonobese patients. However, obese patients presented for cervical deformity correction with worse SVA, TPA, and LL. After propensity score matching, which was controlled for these differences, the postoperative thoracolumbar and global alignment compensation differed by obesity status. TPA and LL, both measures of forward sagittal malalignment, showed more significant decreases in the obese patients. Also, the obese patients showed significantly greater pelvic anteversion after cervical correction.

REFERENCES

1. Flegal KM, Carroll MD, Kit BK, Ogden CL. Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999-2010. *JAMA*. 2012;307:491-497.
2. Runhaar J, Koes BW, Clockaerts S, Bierma-Zeinstra SMA. A systematic review on changed biomechanics of lower extremities in obese individuals: a possible role in development of osteoarthritis. *Obes Rev*. 2011;12:1071-1082.
3. Browning RC, Kram R. Effects of obesity on the biomechanics of walking at different speeds. *Med Sci Sports Exerc*. 2007;39:1632-1641.
4. Rodriguez-Martinez NG, Perez-Orribo L, Kalb S, et al. The role of obesity in the biomechanics and radiological changes of the spine: an in vitro study. *J Neurosurg Spine*. 2016;24:615-623.
5. Soroceanu A, Burton DC, Diebo BG, et al. Impact of obesity on complications, infection, and patient-reported outcomes in adult spinal deformity surgery. *J Neurosurg Spine*. 2015;23:656-664.
6. Pull ter Gunne AF, van Laarhoven CJHM, Cohen DB. Incidence of surgical site infection following adult spinal deformity surgery: an analysis of patient risk. *Eur Spine J*. 2010;19:982-988.
7. Puvanesarajah V, Shen FH, Cancienne JM, et al. Risk factors for revision surgery following primary adult spinal deformity surgery in patients 65 years and older. *J Neurosurg Spine*. 2016;25:486-493.
8. Djurasovic M, Bratcher KR, Glassman SD, Dimar JR, Carreon LY. The effect of obesity on clinical outcomes after lumbar fusion. *Spine (Phila Pa 1976)*. 2008;33:1789-1792.
9. Jalai CM, Diebo BG, Cruz DL, et al. The impact of obesity on compensatory mechanisms in response to progressive sagittal malalignment. *Spine J*. 2017;17:681-688.
10. Fanuele JC, Abdu WA, Hanscom B, Weinstein JN. Association between obesity and functional status in patients with spine disease. *Spine (Phila Pa 1976)*. 2002;27:306-312.
11. Vismara L, Menegoni F, Zaina F, Galli M, Negrini S, Capodaglio P. Effect of obesity and low back pain on spinal mobility: a cross sectional study in women. *J Neuroeng Rehab*. 2010;7:3.
12. Lafage V, Schwab F, Patel A, Hawkinson N, Farcy J-P. Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. *Spine (Phila Pa 1976)*. 2009;34:E599-E606.

13. Schwab FJ, Lafage V, Boyce R, Skalli W, Farcy J-PP. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. *Spine (Phila Pa 1976)*. 2006;31:E959-E967.

14. Park P, Wang MY, Nguyen S, et al. Comparison of complications and clinical and radiographic outcomes between nonobese and obese patients with adult spinal deformity undergoing minimally invasive surgery. *World Neurosurg*. 2016;87:55-60.

15. Buerba RA, Fu MC, Grauer JN. Anterior and posterior cervical fusion in patients with high body mass index are not associated with greater complications. *Spine J*. 2014;14:1643-1653.

16. Sebastian A, Huddleston P III, Kakar S, Habermann E, Wagie A, Nassr A. Risk factors for surgical site infection after posterior cervical spine surgery: an analysis of 5,441 patients from the ACS NSQIP 2005-2012. *Spine J*. 2016;16:504-509.

17. Srinivasan D, La Marca F, Than KD, Patel RD, Park P. Perioperative characteristics and complications in obese patients undergoing anterior cervical fusion surgery. *J Clin Neurosci*. 2014;21:1159-1162.

18. Smith JS, Ramchandran S, Lafage V, et al. Prospective multicenter assessment of early complication rates associated with adult cervical deformity surgery in 78 patients. *Neurosurgery*. 2016;79:378-388.

19. Tetreault L, Kopjar B, Nouri A, et al. The modified Japanese Orthopaedic Association scale: establishing criteria for mild, moderate and severe impairment in patients with degenerative cervical myelopathy. *Eur Spine J*. 2017;26:78-84.

20. Legaye J, Duval-Beaupere G. Sagittal plane alignment of the spine and gravity: a radiological and clinical evaluation. *Acta Orthop Belg*. 2005;71:213-220.

21. Diebo BG, Ferrero E, Lafage R, et al. Recruitment of compensatory mechanisms in sagittal spinal malalignment is age and regional deformity dependent: a full-standing axis analysis of key radiographical parameters. *Spine (Phila Pa 1976)*. 2015;40:642-649.

22. Farcy JP, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. *Spine (Phila Pa 1976)*. 1997;22:2452-2457.

23. Gelb DE, Lenke LG, Bridwell KH, Blanke K, McEnery KW. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. *Spine (Phila Pa 1976)*. 1995;20:1351-1358.

24. Tang JA, Scheer JK, Smith JS, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. *Neurosurgery*. 2012;71:662-669 [discussion: 669].

Conflict of interest statement: The International Spine Study Group is funded through research grants from DePuy Synthes and individual donations. Dr. Passias reports a consultancy with Medicrea and Spinewave, speaking or teaching arrangements with Zimmer Biomet, a grant from CSRS, and scientific advisory board membership at Allosource. Dr. Daniels reports a consultancy with Stryker, DePuy Synthes, Globus, and Stryker and research/fellowship support from Orthofix. Dr. Sciubba reports consultancy with DePuy Synthes, Medtronic, Stryker, NuVasive, and K2M. Dr. Smith reports grants from DePuy Synthes, consultancy with Zimmer-Biomet, NuVasive, and Cerapedics, royalties from Zimmer-Biomet, speaking or teaching arrangements from Zimmer-Biomet and Nuvasive. Dr. Shaffrey reports grants from DePuy Synthes, National Institutes of Health, Department of Defense, and AOSpine; a consultancy with Medtronic, Nuvasive, Zimmer Biomet, K2M, Stryker, and In Vivo; royalties/patents from Medtronic, Nuvasive, and Zimmer Biomet; and stockholder earnings from Nuvasive. Dr. Lafage reports grants from SRS, DePuy, K2M, Stryker, and NuVasive; speaking or teaching arrangements from DePuy, MSD, and AOSpine; consultancy from NuVasive; and shareholder/board of directors for Nemaris Inc. Dr. Schwab reports royalties from Zimmer Biomet, MSD, and K2M; stock ownership in Nemaris Inc.; consulting for NuVasive, Zimmer Biomet, and Medtronic; speaking and teaching for MSD, NuVasive, and Zimmer Biomet; membership on the board of directors for Nemaris Inc.; and grants from DePuy Spine, NuVasive, Stryker, and K2M. Dr. Bess reports consultancy for K2M and Allosource and support of non—study-related clinical or research efforts from DePuy Synthes, Medtronic, NuVasive, K2M, and Orthofix. Dr. Ames reports grants from DePuy; consultancy from DePuy, Medtronic, Stryker; and royalties from Stryker and Zimmer Biomet. Dr. Hart reports grant from Medtronic; speaking fees from Globus, Seaspine, and DePuy; and other disclosures from CSRS, ISSG, and ISSLS. Dr. Mundis reports a consultancy from K2M and DePuy Synthes; royalties from K2M; and nonfinancial support from Nuvasive.

Received 9 May 2018; accepted 24 January 2019

Citation: World Neurosurg. (2019) 125:e1082-e1088.
https://doi.org/10.1016/j.wneu.2019.01.248

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