The impact of age on surgical goals for spinopelvic alignment in minimally invasive surgery for adult spinal deformity

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OBJECTIVE Achieving appropriate spinopelvic alignment in deformity surgery has been correlated with improvement in pain and disability. Minimally invasive surgery (MIS) techniques have been used to treat adult spinal deformity (ASD); however, there is concern for inadequate sagittal plane correction. Because age can influence the degree of sagittal correction required, the purpose of this study was to analyze whether obtaining optimal spinopelvic alignment is required in the elderly to obtain clinical improvement.

METHODS A multicenter database of ASD patients was queried. Inclusion criteria were age ≥ 18 years; an MIS component as part of the index procedure; at least one of the following: pelvic tilt (PT) $> 20^\circ$, sagittal vertical axis (SVA) > 50 mm, pelvic incidence to lumbar lordosis (PI-LL) mismatch $> 10^\circ$, or coronal curve $> 20^\circ$; and minimum follow-up of 2 years. Patients were stratified into younger (< 65 years) and older (≥ 65 years) cohorts. Within each cohort, patients were categorized into aligned (AL) or mal-aligned (MAL) subgroups based on postoperative radiographic measurements. Mal-alignment was defined as a PI-LL $> 10^\circ$ or SVA > 50 mm. Pre- and postoperative radiographic and clinical outcomes were compared.

RESULTS Of the 185 patients, 107 were in the younger cohort and 78 in the older cohort. Based on postoperative radiographs, 36 (33.6%) of the younger patients were in the AL subgroup and 71 (66.4%) were in the MAL subgroup. The older patients were divided into 2 subgroups based on alignment; there were 26 (33.3%) patients in the AL and 52 (66.7%) in the MAL subgroups. Overall, patients within both younger and older cohorts significantly improved with regard to postoperative visual analog scale (VAS) scores for back and leg pain and Oswestry Disability Index (ODI) scores. In the younger cohort, there were no significant differences in postoperative VAS back and leg pain scores between the AL and MAL subgroups. However, the postoperative ODI score of 37.9 in the MAL subgroup was significantly worse than the ODI score of 28.5 in the AL subgroup ($p = 0.019$). In the older cohort, there were no significant differences in postoperative VAS back and leg pain score or ODI between the AL and MAL subgroups.

CONCLUSIONS MIS techniques did not achieve optimal spinopelvic alignment in most cases. However, age appears to impact the degree of sagittal correction required. In older patients, optimal spinopelvic alignment thresholds did not need

ABBREVIATIONS AL = aligned; ASD = adult spinal deformity; LLIF = lateral lumbar interbody fusion; MAL = mal-aligned; MIS = minimally invasive surgery; ODI = Oswestry Disability Index; PI-LL = pelvic incidence to lumbar lordosis mismatch; PT = pelvic tilt; SVA = sagittal vertical axis; TLIF = transforaminal lumbar interbody fusion; VAS = visual analog scale.

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to be achieved to obtain similar symptomatic improvement. Conversely, in younger patients stricter adherence to optimal spinopelvic alignment thresholds may be needed.

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KEYWORDS age; elderly; spinopelvic alignment; minimally invasive; spine; surgery; outcomes; sagittal balance; deformity

ADULT spinal deformity (ASD) can cause significant pain and disability. When the deformity is refractory to medical management, spinal deformity surgery can effectively improve pain and function.¹⁴ Presently, there are many options for the surgical treatment of ASD, including minimally invasive surgery (MIS).^{2,4,9,10,16,17} The potential advantages of MIS primarily reflect a significantly diminished exposure-related morbidity resulting in decreased bleeding, length of stay, and pain, and possibly faster recovery. Initial applications of MIS for ASD involved either a combination of approaches, such as multilevel lateral lumbar interbody fusion (LLIF), and/or MIS transforaminal lumbar interbody fusion (TLIF) followed by percutaneous fixation or hybrid surgeries typically involving LLIF combined with open posterior surgery. However, one of the potential disadvantages of MIS is that if more advanced techniques, such as anterior column realignment, are not performed, inadequate sagittal correction is a possibility.

In the treatment of spinal deformity, there is substantial evidence that sagittal alignment is correlated with clinical outcomes. Glassman et al. evaluated 302 patients treated for ASD and observed that a positive sagittal balance was associated with increased pain and decreased physical and social function.⁶ Subsequently, several key radiographic parameters, consisting of the sagittal vertical axis (SVA), pelvic tilt (PT), and pelvic incidence to lumbar lordosis mismatch (PI-LL), have been shown to correlate highly with patient-reported outcomes.^{11,13} Originally, it was proposed that an SVA < 50 mm, PT < 20°, and PI-LL within 9° were optimal postoperative radiographic goals.^{1,12} However, recent evidence has questioned whether less-stringent spinopelvic parameters are needed in the elderly to achieve symptomatic improvement.⁸ The aim of this study was to evaluate whether achieving optimal spinopelvic parameters in elderly patients who underwent MIS for ASD was necessary to obtain a meaningful clinical benefit.

Methods

After institutional review board approval was granted by each institution, a multicenter database of patients treated from 2009 to 2014 for ASD was queried. Inclusion criteria consisted of age ≥ 18 years; an MIS component as part of the index procedure; at least one of the following: PT > 20°, SVA > 50 mm, PI-LL > 10°, or coronal curve > 20°; and a minimum 2-year follow-up. Identified patients were stratified into a younger cohort (< 65 years) and an older cohort (≥ 65 years). Within each cohort, patients were categorized into aligned (AL) or mal-aligned (MAL) subgroups based on postoperative radiographic measurements. Mal-alignment was defined as a PI-LL > 10° or SVA > 50 mm. Radiographic and clinical outcomes were then compared within each cohort.

Surgical Technique

Patients underwent either circumferential MIS surgery or hybrid surgery. A combination of MIS approaches was used in patients undergoing circumferential MIS, including LLIF, MIS TLIF, axial lumbar interbody fusion, and percutaneous pedicle screw placement. In patients undergoing hybrid procedures, LLIFs were used in conjunction with an open posterior approach.

Radiological Assessment

Preoperative and postoperative 36-inch standing radiographs were obtained in all patients. The coronal Cobb angle as well as standard spinopelvic parameters consisting of SVA, PT, pelvic incidence (PI), lumbar lordosis (LL), and PI-LL were measured. All radiographs were sent to a central site where the measurements were obtained using Surgimap software (Nemaris, Inc.).

Clinical Outcome Assessment

Outcomes were measured preoperatively and at the 2-year follow-up using the visual analog scale (VAS) for back and leg pain and the Oswestry Disability Index (ODI) to assess functional disability.

Statistical Analysis

AL and MAL subgroup comparisons were done within each age group using the Mann-Whitney U-test. Categorical variables were compared using the chi-square test. ANOVA was used to control for the surgical approach when significant differences between groups were present. Significance was set at $\alpha < 0.05$. All statistical analyses were performed using IBM SPSS (version 23, IBM Corp.).

Results

A total of 185 patients were identified in the database, with 107 in the younger group and 78 in the older group. Based on postoperative spinopelvic parameters, the 107 younger patients were divided into AL and MAL subgroups of 36 (33.6%) and 71 (66.4%) patients, respectively. The remaining 78 older patients were separated into AL and MAL subgroups of 26 (33.3%) and 52 (66.7%), respectively.

In the younger cohort, patient and surgical characteristics were similar (Table 1). At baseline, the mean coronal Cobb angle in the AL subgroup was 40.4°, which was significantly higher than the mean 32.2° in the MAL subgroup ($p = 0.036$). The preoperative PI-LL and SVA also differed significantly, with means of 7° and 8.7 mm in the AL subgroup compared with 15.8° and 40.6 mm in the MAL subgroup, respectively ($p = 0.011$, $p = 0.001$). All other baseline radiographic parameters as well as VAS

TABLE 1. Patient characteristics, and radiographic and clinical outcomes in the younger (< 65 years) cohort

	AL	MAL	p Value
No. of patients	36	71	
Age (yrs)	50.1	52.7	0.178
BMI	26.4	26.8	0.582
Follow-up, mos	38.6	39.5	0.879
Approach, n (%)			0.73
Hybrid surgery	18 (50.0)	38 (53.5)	
MIS	18 (50.0)	33 (46.5)	
Staged, n (%)	19 (52.8)	35 (49.3)	0.734
Levels instrumented	7.4	6.5	0.565
IBF levels	3.4	3.1	0.703
Preop VAS back pain	6.7	7	0.282
Preop VAS leg pain	6.1	5.5	0.237
Preop ODI	51.4	54.5	0.349
Preop maximum Cobb (°)	40.4	32.2	0.036
Preop SS (°)	31.2	30.5	0.885
Preop PT (°)	19.7	23.3	0.133
Preop PI (°)	50.4	54.3	0.073
Preop PI-LL (°)	7	15.8	0.011
Preop LL (°)	44.2	38.2	0.233
Preop SVA (mm)	8.7	40.6	0.001
Postop VAS back pain	3.8	4.2	0.816
Postop VAS leg pain	2.3	2.6	0.985
Postop ODI	28.5	37.9	0.019
Postop maximum Cobb (°)	21.3	14.6	0.63
Postop SS (°)	31.9	30.2	0.009
Postop PT (°)	19.9	24	0.029
Postop PI (°)	51.5	54.5	0.17
Postop PI-LL (°)	1.1	13.6	<0.001
Postop LL (°)	50.6	40.5	0.001
Postop SVA (mm)	1.3	49.7	<0.001

IBF = interbody fusion; SS = sagittal slope.

Values are presented as the means unless stated otherwise. Boldface type indicates statistical significance.

back and leg scores and ODI scores were similar between the AL and MAL subgroups. Postoperatively, the coronal Cobb angles were similar and, as expected, the MAL subgroup had significantly higher values for PT, PI-LL, and SVA. With regard to clinical outcomes, there were significant improvements within both the AL and MAL subgroups. Specifically, the VAS back and leg pain and ODI scores improved from 6.7, 6.1, and 51.4 to 3.8, 2.3, and 28.5, respectively, in the AL subgroup ($p < 0.001$). In the MAL subgroup, the VAS back and leg pain and ODI scores improved from 7.0, 5.5, and 54.5 to 4.2, 2.6, and 37.9, respectively ($p < 0.001$). For the comparison between groups, although the VAS scores were similar postoperatively, the mean ODI score was 37.9 in the MAL subgroup, which was significantly higher than that of 28.5 in the AL group ($p = 0.019$).

In the older cohort, patient and surgical characteristics

TABLE 2. Patient characteristics, and radiographic and clinical outcomes in the older (≥ 65 years) cohort

	AL	MAL	p Value
No. of patients	26	52	
Age (yrs)	70.7	70.4	0.459
BMI	27.3	28.1	0.793
Follow-up, mos	39.2	36.3	0.489
Approach, n (%)			0.026
Hybrid surgery	4 (15.4)	21 (40.4)	
MIS	22 (84.6)	31 (59.6)	
Staged, n (%)	12 (46.2)	33 (63.5)	0.145
Levels instrumented	6.3	6.6	0.49
IBF levels	3.6	3.4	0.759
Preop VAS back pain	6.9	7.1	0.656
Preop VAS leg pain	5.8	5.4	0.802
Preop ODI	48.1	48.2	0.992
Preop maximum Cobb (°)	34.8	32.1	0.564
Preop SS (°)	27.5	30.4	0.316
Preop PT (°)	20.9	27.8	0.005
Preop PI (°)	48.5	58.2	0.001
Preop PI-LL (°)	10.7	24.3	<0.001
Preop LL (°)	37.7	33.9	0.386
Preop SVA (mm)	39	73.5	0.043
Postop VAS back pain	2.8	3.9	0.079
Postop VAS leg pain	1.8	2.8	0.117
Postop ODI	27.7	32.2	0.338
Postop maximum Cobb (°)	18	15.6	0.213
Postop SS (°)	27.6	29.7	0.42
Postop PT (°)	21.1	29	0.001
Postop PI (°)	48.7	58.7	0.001
Postop PI-LL (°)	2.8	19.6	<0.001
Postop LL (°)	45.9	39.1	0.023
Postop SVA (mm)	13.9	64.8	<0.001

Values are presented as the means unless stated otherwise. Boldface type indicates statistical significance.

were similar except for the proportion of MIS versus hybrid approaches (Table 2). Given this significant difference, an additional analysis controlling for approach was performed, which resulted in similar significant differences in the postoperative radiographic parameters except for LL (Table 3). At baseline, the mean PI for the AL subgroup was 48.5°, which was significantly lower than that of 58.2° for the MAL subgroup ($p = 0.001$). Preoperative PI-LL and SVA also significantly differed, with means 10.7° and 39 mm in the AL subgroup versus 24.3° and 73.5 mm in the MAL subgroup, respectively ($p < 0.001$, $p = 0.043$). The remaining radiographic parameters as well as the VAS back and leg and ODI scores were similar between subgroups. As expected, the postoperative PT, PI-LL, and SVA were significantly higher in the MAL subgroup. Similar to the younger cohort, in regard to clinical outcomes, there were significant improvements within both AL and MAL subgroups. The VAS back and leg pain

TABLE 3. Postoperative radiographic parameters adjusted for approach in the older (≥ 65 years) cohort

	AL	MAL	p Value
No. of patients	26	52	
Postop PT ($^{\circ}$)	21.9	29.2	0.022
Postop PI ($^{\circ}$)	46.4	59.0	0.001
Postop PI-LL ($^{\circ}$)	3.2	19.2	<0.001
Postop LL ($^{\circ}$)	43.3	39.8	0.308
Postop SVA (mm)	14.3	64.9	<0.005

Values are presented as the means unless stated otherwise. Boldface type indicates statistical significance.

and ODI scores improved from 6.9, 5.8, and 48.1 to 2.8, 1.8, and 27.7, respectively, for the AL subgroup ($p < 0.001$, $p < 0.001$, $p = 0.001$). For the MAL subgroup, the scores improved from 7.1, 5.4, and 48.2 to 3.9, 2.8, and 32.2, respectively ($p < 0.001$, $p < 0.001$, $p = 0.001$). In contrast to the younger cohort, the VAS and ODI scores did not significantly differ postoperatively between the AL and MAL subgroups.

Discussion

One of the major concerns with the application of MIS to deformity has been the possibility of inadequate sagittal plane correction. This concern was related to the dependence of early-generation MIS techniques on standard interbody fusion techniques (i.e., TLIF or LLIF) without osteotomies or the extensive soft-tissue release that would occur with more traditional deformity surgery. In one of the few studies comparing MIS versus open deformity surgery, 38 patients who underwent circumferential MIS and 33 patients who underwent traditional open deformity surgery were analyzed.¹⁵ Preoperatively, the circumferential MIS and open groups had similar mean SVAs of 63.5 mm and 71.4 mm, respectively ($p = 0.60$). The baseline PI-LL, however, was significantly higher in the open group (26.8 $^{\circ}$) versus the circumferential MIS group (19.0 $^{\circ}$) ($p = 0.03$). Postoperatively, the open group had much better sagittal improvement with an SVA of 28.2 mm and PI-LL of 3.3 $^{\circ}$, whereas the circumferential MIS group had a worse mean postoperative SVA of 71.2 mm and little correction of the PI-LL, with a mean of 16.3 $^{\circ}$.¹⁵ These results suggest that traditional MIS approaches are not as effective in sagittal correction and are consistent with our study in which approximately two-thirds of the patients in both the younger and older cohorts did not achieve optimal spinopelvic parameters.

In the typical course of aging, there is the development and progression of kyphosis within the spine. In a study of 100 asymptomatic volunteers, age ≥ 40 years, increasing SVA was significantly correlated with age.⁵ Loss of total lumbar lordosis was also associated with age. Similar results were observed by Hammerberg and Wood,⁷ who analyzed 50 asymptomatic volunteers (age range 70–85 years, mean 76.3 years). They noted a positive correlation between age and SVA. In this investigation, the mean SVA was 40.4 mm with a range from –37 mm to 139 mm. More

recently, a much larger study of 1461 individuals also noted analogous findings with regard to SVA and age.³ In addition, thoracic kyphosis and PT were positively correlated with age. Based on these studies, it is apparent that some degree of spinopelvic mal-alignment is expected with aging and does not necessarily lead to symptoms.

In our study, there were no significant differences in VAS back and leg pain or ODI between the postoperative AL and MAL subgroups in the older (≥ 65 years) cohort. This lack of clinical difference was present despite the significant differences in postoperative SVA (13.9 mm vs 64.8 mm), PT (21.1 $^{\circ}$ vs 29 $^{\circ}$), and PI-LL (2.8 $^{\circ}$ vs 19.6 $^{\circ}$) of the AL and MAL subgroups, respectively. This is consistent with the aforementioned studies and suggests that the proposed optimal thresholds of SVA < 50 mm, PT $< 20^{\circ}$, and PI-LL within 9 $^{\circ}$ may not be applicable in the elderly. This is in contrast to the findings in the younger (< 65 years) cohort in which there was a significant difference in ODI between the AL and MAL subgroups. Specifically, the MAL subgroup patients had significantly worse disability with a mean ODI of 37.9 compared with a mean ODI of 28.5 in the AL subgroup postoperatively. Although the postoperative pain scores were similar between subgroups, this does suggest that an optimal spinopelvic alignment is more important in younger patients.

To date, there has been little analysis evaluating the influence of age on spinopelvic thresholds for surgical correction. In the one study specifically focusing on the impact of age, Lafage et al. analyzed 773 patients with ASD.⁸ Acknowledging the changes that occur with physiological aging of the spine, new radiographic thresholds were calculated based on age-specific ODI US norms, which were calculated from SF-36 Physical Component Summary US norms. These new spinopelvic parameters approximated the previous optimal thresholds with an SVA of 37 mm, PT of 22.1 $^{\circ}$, and PI-LL of 3.3 $^{\circ}$ for the 55- to 64-year age group but were progressively more liberal for older patients. Specifically, thresholds for SVA, PT, and PI-LL were 55.6 mm, 25.2 $^{\circ}$ and 7.5 $^{\circ}$ and 79.9 mm, 28.8 $^{\circ}$, and 13.7 $^{\circ}$ for the 65- to 74-year and ≥ 74 -year age groups, respectively. These new proposed age-specific radiographic targets would be more consistent with the findings in our study, in which the mean age of the MAL subgroup (≥ 65 years) was 70.4 years and the mean SVA, PT, and PI-LL were 64.8 mm, 29 $^{\circ}$, and 19.6 $^{\circ}$, respectively.

Limitations

Although the sample size of the older age group was relatively large, it is possible that a significant difference may have been present in the postoperative ODI score if a larger number of patients had been analyzed. The findings of this study should serve as the basis for larger investigations into the impact of age on target spinopelvic parameters.

Conclusions

Age appears to have an impact on the degree of sagittal plane correction needed to achieve symptomatic improvement. Likely due to the changes occurring with normal physiological aging, older patients tolerate some degree of

spinopelvic mal-alignment and are amenable to MIS approaches. More optimal spinopelvic parameters, however, are likely required in younger patients with ASD to optimize clinical outcomes.

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