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Adult Spinal Deformity Surgeons Are Unable to Accurately Predict Postoperative Spinal Alignment Using Clinical Judgment Alone

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Abstract

Object: Adult spinal deformity (ASD) surgery seeks to reduce disability and improve quality of life through restoration of spinal alignment. In particular, correction of sagittal malalignment is correlated with patient outcome. Inadequate correction of sagittal deformity is not infrequent. The present study assessed surgeons' ability to accurately predict postoperative alignment.

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Methods: Seventeen cases were presented with preoperative radiographic measurements, and a summary of the operation as performed by the treating physician. Surgeon training, practice characteristics, and use of surgical planning software was assessed. Participants predicted if the surgical plan would lead to adequate deformity correction and attempted to predict postoperative radiographic parameters including sagittal vertical axis (SVA), pelvic tilt (PT), pelvic incidence to lumbar lordosis mismatch (PI-LL), thoracic kyphosis (TK).
Results: Seventeen surgeons participated: 71% within 0 to 10 years of practice; 88% devote >25% of their practice to deformity surgery. Surgeons accurately judged adequacy of the surgical plan to achieve correction to specific thresholds of SVA 69% ± 8%, PT 68% ± 9%, and PI-LL 68% ± 11% of the time. However, surgeons correctly predicted the actual postoperative radiographic parameters only 42% ± 6% of the time. They were more successful at predicting PT (61% ± 10%) than SVA (45% ± 8%), PI-LL (26% ± 11%), or TK change (35% ± 21%; $p < .05$). Improved performance correlated with greater focus on deformity but not number of years in practice or number of three-column osteotomies performed per year.
Conclusion: Surgeons failed to correctly predict the adequacy of the proposed surgical plan in approximately one third of presented cases. They were better at determining whether a surgical plan would achieve adequate correction than predicting specific postoperative alignment parameters. Pelvic tilt and SVA were predicted with the greatest accuracy.

Keywords: Adult spinal deformity; Surgical planning; Deformity correction; Adult scoliosis; Spinal alignment

Introduction

The goals of adult spinal deformity (ASD) surgery include reducing disability and improving quality of life through restoration of spinopelvic alignment and decompression of neural elements. Over the past decade, several studies have highlighted the importance of sagittal spinopelvic alignment in achieving optimal postoperative outcomes [1-3]. Specifically, Schwab et al. demonstrated significant correlations between specific radiographic parameters and standardized measures of health-related quality of life (HRQOL) [4]. It has become apparent that sagittal spinopelvic malalignment is a key factor influencing patient disability, with significant correlations reported between HRQOL and sagittal vertical axis (SVA), pelvic tilt (PT), and pelvic incidence to lumbar lordosis mismatch (PI-LL) [5,6]. Furthermore, it has been demonstrated that more complete sagittal plane deformity correction favors the greatest HRQOL benefit [7]. Determining the degree of correction required to restore sagittal alignment and, in turn, selection of suitable osteotomies, soft tissue releases, implants, and levels of instrumentation to achieve the desired correction, represents a significant challenge. Indeed, Moal et al. [8] demonstrated a relatively high rate of incomplete sagittal correction in ASD surgery of up to 50%.

The complexity of surgical planning, which must take into account radiographic and patient factors in addition to surgeon experience, has resulted in multi-faceted efforts to develop appropriate treatment strategies. Several authors have proposed mathematical models to facilitate accurate calculation of the angle required for spinal osteotomies to correct sagittal deformity [9-12]. Although these formulas represent an important step in improving prediction of postoperative alignment, they may be too complex and thus impractical for routine clinical use [9,10,13]. Alternatively, surgical planning software has been developed which allows simulation of a proposed plan and prediction of postoperative alignment. Such software allows the surgeon to measure spinopelvic, sagittal, and coronal alignment parameters. An osteotomy (or set of osteotomies) can then be simulated. Based on the surgical plan simulation, the software provides predicted values for postoperative radiographic parameters that allows surgeons to assess the adequacy of their plan [4,13].

The accuracy with which surgeons performing ASD are able to predict postoperative alignment in the absence of surgical planning software is currently unknown and represents the central question of the present study. In particular, we sought to determine the extent to which surgeons could judge whether a series of surgical plans would achieve adequate restoration of sagittal spinopelvic alignment without the use of surgical planning software or formula. We also assessed their ability to predict, within a range, the expected values of key postoperative radiographic alignment parameters based on preoperative images and proposed surgical plans. These data may prove useful in assessing the potential value of adjuncts to surgical planning as a means of optimizing the postoperative alignment and outcomes.

Methods

A survey that included 17 ASD cases was administered to surgeon members of the International Spine Study Group (ISSG). The survey was presented in PowerPoint (Microsoft, Redmond, WA) format and cases were prepared at a central location. Each case included a full-length (36-inch) lateral standing radiograph with standard preoperative radiographic measurements and a summary of the surgery performed by the surgeon who treated that patient. The surgical summary included the upper (UIV) and lower instrumented vertebrae (LIV), level of pedicle subtraction osteotomy (PSO), angle of resected wedge in PSO, and level of any interbody grafts (Figs. 1 and 2). Participants were first asked 6 questions to assess their training background and characteristics of their clinical practice, as well as whether they currently use surgical planning software and their beliefs regarding its value

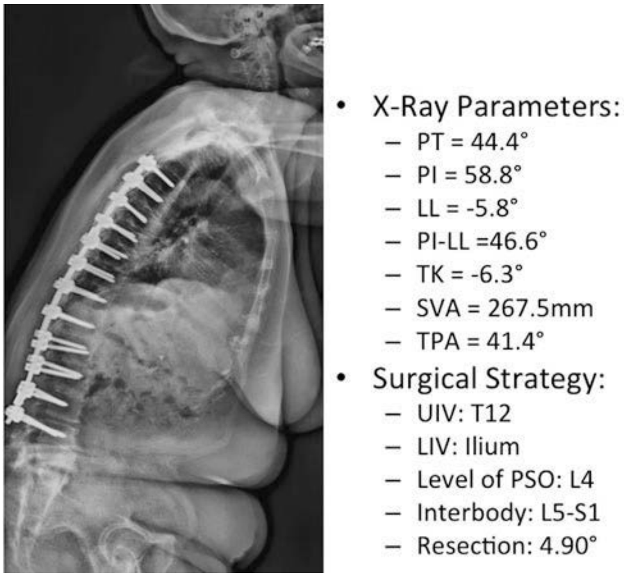

Fig. 1. Sample survey case presentation. Full-length radiograph presented with standard radiographic parameters and surgical plan. Resection reflects the angle of wedge resection of the planned PSO. PT, pelvic tilt; PI, pelvic incidence; LL, lumbar lordosis; TK, thoracic kyphosis; SVA, sagittal vertebral axis; TPA, T1 pelvic angle; UIV, upper instrumented vertebra; LIV, lower instrumented vertebra; PSO, pedicle subtraction osteotomy.

(Table). Participants completed all aspects of the survey on an individual basis.

Three questions were asked for each survey case and the results were tabulated. Question 1 required participants to predict whether the surgical plan would result in adequate deformity correction. Adequacy of correction was defined for each radiographic parameter based on established thresholds: SVA $\leqslant$ 50 mm; PT $\leqslant$ 22 degrees; PI-LL = $\pm$11 degrees [1]. Responses were compared to the actual correction achieved in the test case as measured 6 weeks postoperatively to determine if the participant accurately predicted adequacy (or inadequacy) of correction.

For Question 2, participants attempted to predict postoperative radiographic parameters, based on the given surgical plan. Three options each were provided for SVA, PT, PI-LL and thoracic kyphosis (TK) change. Each option represented a range of values for a given parameter; the correct response contained the postoperative value achieved in a given case whereas the other two options were distractors. Question 3 allowed participants to suggest modifications to the surgical plan that was performed in free text.

Statistical analysis

The mean number of correct responses for Questions 1 and 2 were determined. Normality of data was determined using the Shapiro-Wilk test. Percentage of correct responses was compared across the different radiographic parameters of interest using analysis of variance. Pairwise comparisons were also conducted between parameters using Tukey honestly significant difference test to control for Type I error. Correlation between surgeon practice characteristics and performance on survey questions was evaluated with Student *t* test for dichotomous variables and analysis of variance for

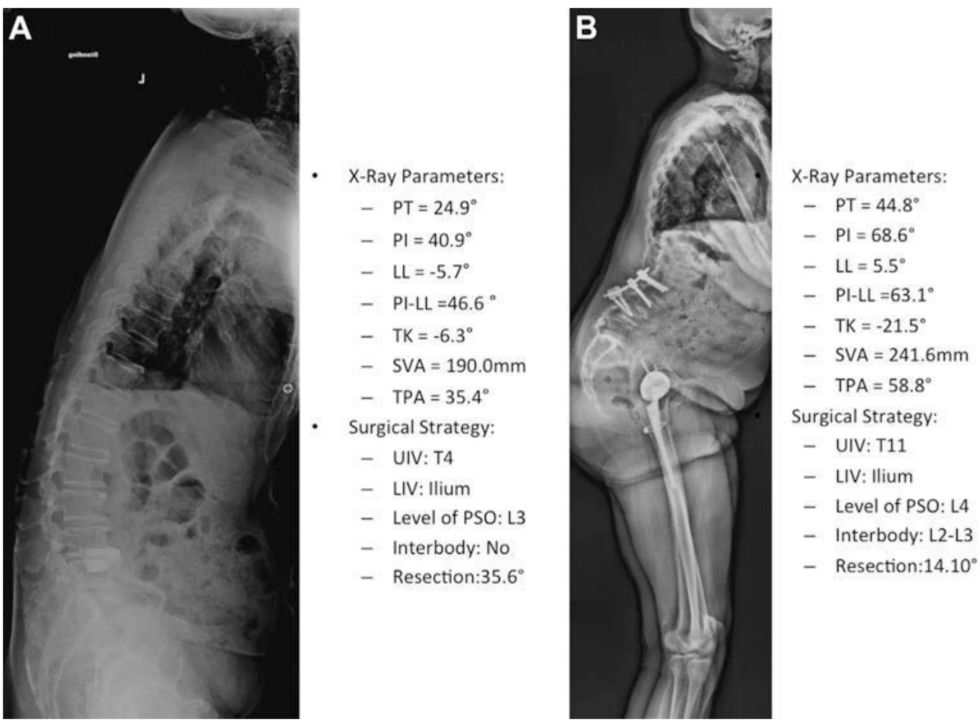

Fig. 2. Sample survey case presentations. (A) Example of surgical plan that resulted in adequate deformity correction. (B) Example of surgical plan that did not result in adequate deformity correction.

Table
Surgeon demographics and practice characteristics.

	n (%)
Years in practice	16
0−5	6 (37.5)
5−10	6 (37.5)
10−15	3 (18.8)
>15	1 (6.2)
Type of practice	16
Orthopedic	7 (43.8)
Neurosurgical	8 (50.0)
Combined	1 (6.2)
Percent of practice devoted to deformity	16
0−25	2 (12.5)
25−50	7 (43.8)
50−75	5 (31.2)
75−100	2 (12.5)
Number of three column osteotomies per year	17
0−10	3 (17.7)
10−25	7 (41.2)
25−50	5 (29.4)
>50	2 (11.8)
Use surgical planning software	17
Never	8 (47.1)
1−25% of cases	5 (29.4)
25−50%	1 (5.9)
50−75%	1 (5.9)
>75%	1 (5.9)
Believe planning software is important	16
Yes	14 (87.5)
No	2 (12.5)

categorical variables. To assess interrater reliability, Fleiss kappa values for multiple raters were determined.

Results

A total of 17 of 23 (74%) surgeon members of the ISSG completed the survey. Surgeon practice characteristics are shown in Table 1 along with their current use of and opinions regarding the utility of preoperative surgical planning software. The majority of participants were experienced surgeons with a significant focus on spinal deformity. Although most did not regularly use surgical planning software, 88% believed that its use is at least somewhat important.

On average, surgeons appropriately judged adequacy of the surgical plan to achieve correction of SVA 69% ± 8%, PT 68% ± 9%, and PI-LL 68% ± 11% of the time. There were no significant differences in the participants' ability to judge adequacy of correction of any of these parameters specifically ($p = .66$). Prediction of actual postoperative radiographic parameters proved a more difficult task, with correct prediction of change in SVA 45% ± 8%, PT 61% ± 10%, PI-LL 26% ± 11%, and TK 35% ± 21% of the time (Fig. 3). On average, they correctly anticipated radiographic parameters only 42% ± 6% of the time. Surgeons were significantly more successful at predicting PT than any of the other parameters and better at predicting postoperative SVA than either PI-LL or TK ($p < .05$ for all pairwise comparisons). Fig. 4 depicts a sample case and the rate of correct responses for predicting the adequacy of the proposed surgical plan. Interrater reliability was generally fair, except for TK, for which it was poor: overall (Kappa = 0.34), SVA (0.32), PT (0.46), PI-LL (0.32), and TK (0.05).

Number of years in practice was not predictive of ability to judge adequacy of correction. Mean correct prediction of postoperative radiographic parameters increased from 39% for 0 to 5 years in practice, to 42% for 5 to 10 years and 45% for more than 10 years in practice, however, this did not reach statistical significance ($p = .28$). Surgeons for whom deformity comprised more than half of their practice, accurately predicted postoperative radiographic parameters 45% ± 6% of the time as compared to 39% ± 5% of the time in those who devoted less than half of their practice to deformity ($p = .045$). The number of three-column osteotomies performed per year did not correlate with ability to determine adequacy of correction or to predict radiographic parameters ($p = .32$ and $p = .60$, respectively).

Participants recommended no change to the location or extent of osteotomy in 47% ± 23% of cases in which adequate sagittal correction was achieved and in 26% ± 14% of cases in which there was inadequate correction ($p = .044$). Similarly, for cases for which the surgical plan proved adequate, participants recommended no change to the levels of instrumentation 71% ± 21% of the time versus 39% ± 27% of the time when it was inadequate ($p = .04$). See Figure 2 for examples of survey cases with surgical plans that resulted in adequate versus inadequate correction of sagittal spinopelvic alignment. Surgeons were far more likely to suggest alterations to the osteotomy than the instrumentation levels ($p = .0069$). Proposed changes to the osteotomy were varied and included increasing the angle of resection, use of an extended osteotomy, omitting the three-column osteotomy in favor of multiple Ponte osteotomies and/or placement of hyperlordotic cages (lateral or anterior approaches), among others. Recommendations for changes to the instrumented levels included extension to the pelvis, and higher and lower termination levels of instrumentation.

Discussion

In the present study, surgeons were able to correctly judge the adequacy of a surgical plan to achieve global alignment in approximately two-thirds of survey cases. Thus, surgeons failed to correctly predict the adequacy of the surgical plan in approximately 1 in 3 cases. There was no difference in their success rate in predicting adequacy of correction for any specific radiographic parameter (SVA, PT, or PI-LL). The rate of correct responses was much lower (42% overall) when participants were asked to predict, within a range, the expected postoperative radiographic parameters. Poorer performance on the latter task likely reflects the fact that it is an inherently more difficult task to predict specific parameter values than judge whether adequate correction will be achieved. Interestingly,

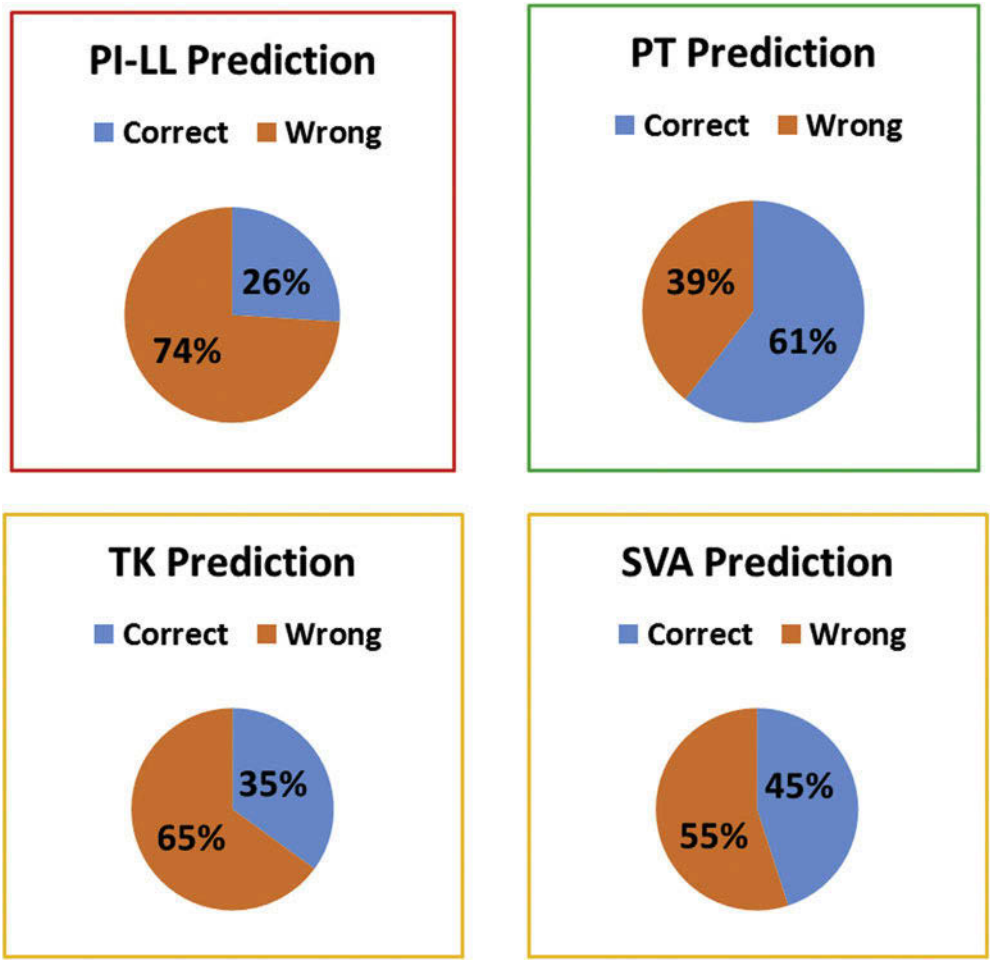

Fig. 3. Accuracy of prediction of postoperative radiographic parameters. PI-LL, pelvic incidence–lumbar lordosis mismatch; PT, pelvic tilt; TK, thoracic kyphosis; SVA, sagittal vertical axis.

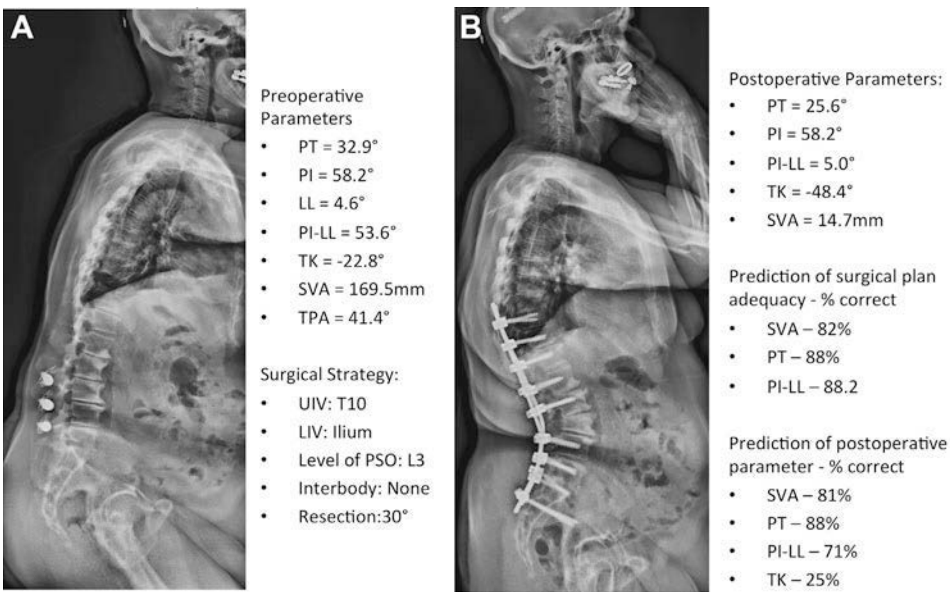

Fig. 4. Sample survey case. (A) Preoperative standing long-cassette radiograph with standard spinopelvic parameters and surgical plan. (B) Postoperative long-cassette radiograph (not part of survey) with spinopelvic parameters and correct response rate for predicting adequacy of surgical plan and values of individual parameters.

participants were significantly better at predicting postoperative PT (60%) and SVA (44%) than PI-LL (27%) and TK (35%). This may reflect the greater focus that surgeons place on these parameters in their clinical practice because of increased awareness of their importance in recent years. With greater experience and improved understanding of postoperative reciprocal changes, TK may be more accurately predicted in the future.

The only practice characteristic that correlated with performance on the survey case questions was percentage of practice devoted to deformity surgery: participants with greater than half of their practice spent on ASD were slightly better at predicting postoperative alignment. This is in keeping with the expectation that greater experience would result in improved ability to anticipate the results of a surgical plan for ASD. The lack of a correlation between survey performance, number of years in practice and number of three-column osteotomies performed per year in this study may represent type II error from small sample size and consequent inadequate power to detect differences for these parameters.

As expected, participants were more likely to recommend changes to the surgical plan when they judged it to be unlikely to provide adequate correction. The wide range of suggested alterations to different aspects of the surgical plan highlights the highly varied options employed by surgeons to correct spinal deformity. Furthermore, one might postulate that restricting participants to a specific surgical plan may have compromised their performance on the survey questions if the plan or elements thereof were outside their typical approach to such cases. In other words, surgeons may be better at creating a plan using their specific surgical skill set and predicting its outcome than one developed by another surgeon. This represents one potential limitation of the study and may have biased the results toward worse performance.

The spine deformity literature has established thresholds for key radiographic parameters that define optimal spinopelvic and global spinal alignment [1,5,6,14]. These thresholds serve as targets for postoperative alignment that in turn help to establish the degree of correction required for an ASD patient. Achieving adequate correction, as determined by such targets, has been correlated with improved patient outcome with respect to HRQOL and disability [3,4,7]. Conversely, failure to adequately correct deformity has been correlated with inferior overall clinical outcomes [5,7,15,16].

Determining the required amount of correction in ASD surgery is not necessarily straightforward and requires the surgeon to consider several factors. These factors include assessment of spinopelvic parameters, regional alignment measures, and sagittal and coronal global alignment. Furthermore, it is important to anticipate reciprocal changes in un-instrumented regions of the spine, which may occur postoperatively and compromise alignment [3,17]. Failure to achieve adequate correction occurs not infrequently, with rates ranging from 11% to 33% in the literature [15,16,18]. Insufficient correction may result in greater postoperative disability, and sometimes necessitates difficult and higher risk revision surgery. Despite the importance of assessing how and with what success spine surgeons are able to predict postoperative alignment, there is a paucity of studies on this topic. The results of this study highlight the challenging nature of determining the amount of correction that will be achieved based on a surgical plan.

This study must be interpreted within the context of its design and limitations. The survey was administered to a select group of surgeons with a fairly high level of spine deformity experience, which may limit its generalizability. Inclusion of a broader set of surgeons with less focus on spinal deformity may have resulted in even lower rates at which surgeons could successfully predict the adequacy of the surgical plan to achieve sufficient sagittal spinopelvic alignment without the aid of surgical planning software. The small sample size also limits the strength of conclusions that can be drawn; equally, it may have contributed to type II error as described above. Furthermore, participants were only provided a limited set of radiographic data and a brief description of the surgical plan without additional clinical information or additional imaging (computed tomography, magnetic resonance imaging, dynamic and/or supine radiographs) which may have compromised their performance. In particular, the lack of information on the flexibility of the deformity may have unduly biased the results toward poorer performance on the prediction tasks.

Even if surgeons were given a more complete set of preoperative clinical information, there are a multitude of factors that can influence the actual correction achieved intra-operatively during a given procedure. Many such factors cannot be anticipated, such as the amount of bone and soft tissue release achieved through osteotomies, failure of operative equipment or implants, and anesthetic and medical complications that prevent strict adherence to the preoperative surgical plan. These issues would not have been captured through the survey methodology we employed, which assumes optimal conditions and, as such, potentially biased the surgeons to overestimate the adequacy of the surgical plans.

Despite these limitations, this study demonstrates the significant challenges faced by surgeons attempting to design and implement a surgical plan that will achieve adequate correction of spinal deformity. These findings, in combination with previous reports that demonstrate the important relationship between sagittal spinopelvic alignment and clinical outcomes, suggest that there is substantial room for improvement in surgical planning that aims to achieve not only defined radiographic objectives but also optimal clinical outcomes.

Based on the present findings, we anticipate further study of adjuncts such as surgical planning software to aid the surgeon in predicting the desired postoperative sagittal spinopelvic alignment. The objective of studying and improving surgical planning is predicated on the assumption that achieving optimal radiographic correction will yield superior clinical outcomes. Although previous reports have demonstrated such an association, it will be important to directly incorporate HRQOL outcome assessment into future work on surgical planning and adequacy of deformity correction.

Conclusion

Accurate estimation of postoperative alignment after deformity correction represents a significant challenge. Surgeons failed to correctly predict the adequacy of the proposed surgical plan in approximately one in three of the presented cases. Surgeons were better at determining whether a surgical plan would achieve adequate correction than predicting specific postoperative alignment parameters. Pelvic tilt and SVA were predicted with the greatest accuracy. Future study is warranted to assess the incremental benefit of utilizing surgical planning software and a deformity treatment algorithm to facilitate improved radiographic and clinical outcomes.

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