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Accuracy of Rod Contouring to Desired Angles With and Without a Template: Implications for Achieving Desired Spinal Alignment and Outcomes

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Abstract

Study Design: Biomechanical Study.

Objective: The search for optimal spinal alignment has led to the development of sophisticated formulas and software for preoperative planning. However, preoperative plans are not always appropriately executed since rod contouring during surgery is often subjective and estimated by the surgeon. We aimed to assess whether rods contoured to specific angles with a French rod bender using a template guide will be more accurate than rods contoured without a template.

Methods: Ten experienced spine surgeons were requested to contour two 125 × 5.5 mm Ti64 rods to 40°, 60° and 80° without templates and then 2 more rods using 2D metallic templates with the same angles. Rod angles were then measured for accuracy and compared.

Results: Average angles for rods bent without a template to 40°, 60° and 80° were 60.2°, 78.9° and 97.5°, respectively. Without a template, rods were overbent by a mean of 18.9°. When using templates of 40°, 60° and 80°, mean bend angles were 41.5°, 59.1° and 78.7°, respectively, with an average underbend of 0.2°. Differences between the template and non-template groups for each target angle were all significant ($p < 0.001$).

Conclusions: Without the template, surgeons tend to overbend rods compared to the desired angle, while surgeons improved markedly with a template guide. This tendency to overbend could have significant impact on patient outcomes and risk of

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proximal junctional failure and warrants further research to better enable surgeons to more accurately execute preoperative alignment plans.

Keywords
biomechanics, proximal junctional kyphosis, rod bending, sagittal alignment, spinal alignment, spinal instrumentation, spine surgery

Introduction

Achieving appropriate sagittal alignment is considered one of the most important objectives in spinal deformity surgery in order to help optimize patient-reported outcomes and to reduce the risks of junctional failure and need for revision surgery.[1-6] This has led surgeons to pursue defined spino-pelvic targets in order to achieve the desired postoperative alignment for each patient. Restoration of known parameters such as pelvic tilt (PT), sagittal vertical axis (SVA), T1-pelvic angle (TPA) and pelvic incidence to lumbar lordosis mismatch (PI-LL) has been associated with improved functional status and walking tolerance, as well as reduced risk of requiring revision surgery.[2,5,7-9] Hence, sophisticated planning tools and software have been developed to simplify preoperative assessment of alignment and enable surgeons to create specific alignment plans for each patient.[10-12]

Spinal rod contouring and biomechanical properties are key components of posterior instrumentation outcomes.[13] Achieving target overall realignment and desired regional sagittal angles is dependent on adequate contouring of the rods, reflecting the critical importance of the intraoperative rod bending step. However, despite the available sophisticated planning tools and alignment objectives, surgeons often lack the means of ensuring their plans are appropriately executed in the operating room and end up estimating rod angles by subjectively contouring rods intraoperatively. This can lead to both over and under-bending the rods once in the operating room, despite knowing in advance the desired alignment measures.

Numerous studies have reported that both under- and over-correcting lumbar lordosis can have a deleterious impact on spino-pelvic alignment and patient-reported outcomes.[1,5,10] Identifying significant differences between desired angles and the actual rod curvature estimated by the surgeon could carry significant implications for in vivo spinal deformity correction. The purpose of this study was to assess how accurately surgeons can bend rods to specified angles. We then assessed whether providing surgeons with a rod template reflecting the desired angle would improve their ability to achieve the requested angular bend.

Materials and Methods

Ten experienced spine surgeons were requested to contour two 125 × 5.5 mm Ti64 rods using a French rod bender to 40°, 60° and 80° without templates. The same surgeons were then asked to bend 2 additional rods using 2D metallic templates that had been bent to the corresponding requested angles. Rods were photographed overhead next to an object of known size (coin) to calibrate measurements, and photos were imported into Surgimap (Nemaris, New York, NY, USA) for measurements (Figure 1).[14] The arc length of the rods was measured using the multi-line tool in Surgimap. The circle tool was used to overlay a circle of best fit to the center line of the bent rod and measure its radius. The angle of the bent rod was calculated using the

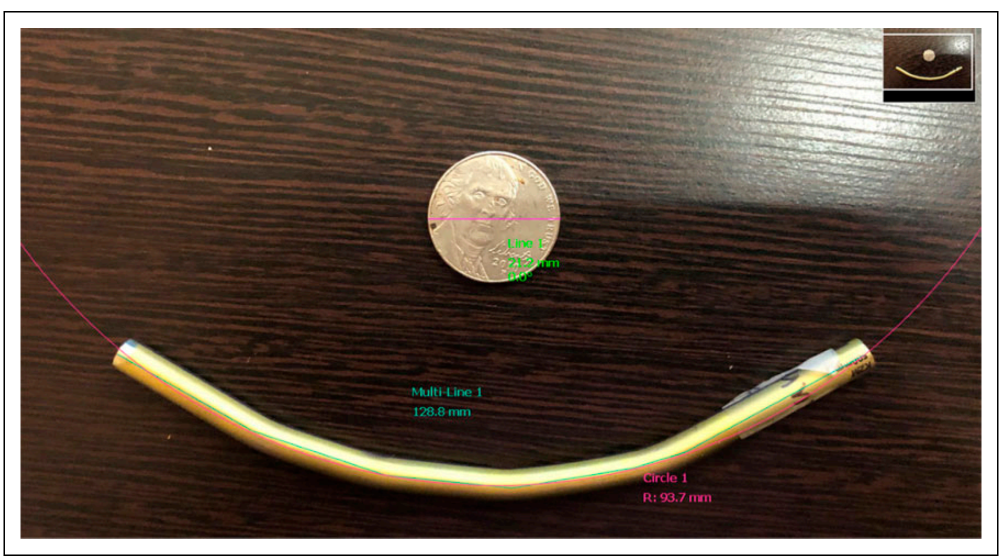

Figure 1. Rod photographed next to a coin for size calibration to facilitate angle measurement.

Table 1. Angular Measurements of Bent Rods With and Without a Template.

Target Angle	Template use	Average Bend Angle (°)	Standard Deviation (°)	Max Angle (°)	Min Angle (°)	Average Difference from Target Angle (°)	Error (%)
40°	With a Template	41.5	2.5	47.2	38.7	1.5	3.7
	Without a template	60.2	13.9	82.6	37.8	20.2	36.7
60°	With a Template	59.1	2.3	65.1	54.7	-0.9	1.4
	Without a template	78.9	12.8	98.4	56.8	18.9	31.4
80°	With a Template	78.7	2.7	82.2	72.5	-1.3	1.6
	Without a template	97.5	18.6	134.2	73.0	17.5	21.9

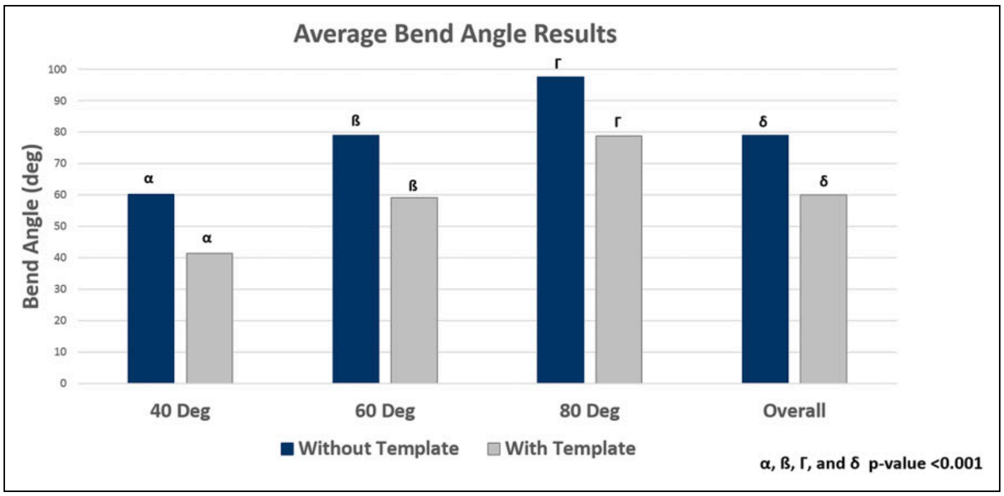

Figure 2. Average bend angle results. Comparison of achieved angular bends with and without a template for the 40°, 60°, 80° and overall groups.

formula $s = r\Theta$, where s is the arc length, r is the radius and Θ is the angle in radians converted to degrees. Rod angles were compared for average and absolute differences as well as error percentage between both groups. Descriptive statistics were performed using Minitab 17 (Minitab, State College, PA, USA), data was presented as mean value ± standard deviation, p-values were calculated using a 2-sample t-tests and $p < 0.05$ was considered to indicate statistical significance. Since this study was confined to biomechanical analyses without involvement of patients, patient material, or animals, Internal Review Board approval was not required and patient consent was not indicated.

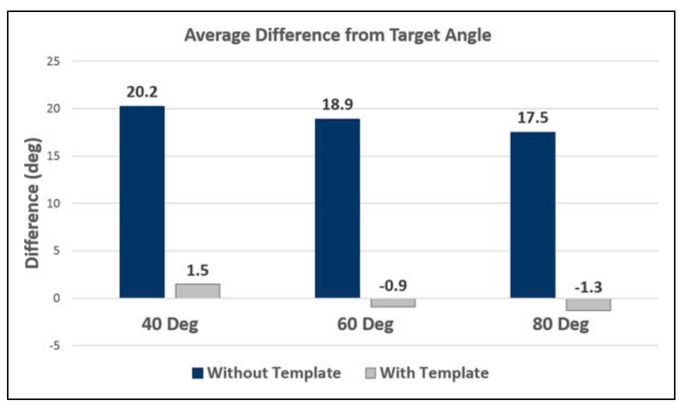

Figure 3. Average difference from target angle. Shown are mean differences from the target angle when surgeons were asked to bend rods to 40°, 60° or 80° with or without a template guide.

Results

A total of 120 rods were bent, one-half using 2D metallic templates of 40°, 60° and 80° as models and the other one-half were bent without a template. Mean angle values of the rods bent without a template to 40°, 60° and 80° were as follows: 60.2 ± 13.9° (range: 82.6°-37.8°), 78.9 ± 12.8° (range: 98.4°-56.8°), and 97.5 ± 18.6° (range: 134.2°-73°), respectively. Mean angle values of the rods bent using templates of 40°, 60° and 80° were as follows: 41.5 ± 2.5° (range: 47.2°-38.7°), 59.1 ± 2.3° (range: 65.1°-54.7°), and 78.7 ± 2.7° (range: 82.2°-72.5°), respectively (Table 1). For each of the desired angular bends, the differences between the achieved angular bends with and without a template were statistically significant ($p < 0.001$ for each, Figure 2).

The average overbend without a template was 18.9 ± 15.1°, which is an average error of 30% (Table 1). In contrast, when using the templates there was a relatively small underbend that averaged −0.2 ± 2.5°, with an average error of only 2.3% (Figure 3). The angular bends achieved without the use of a

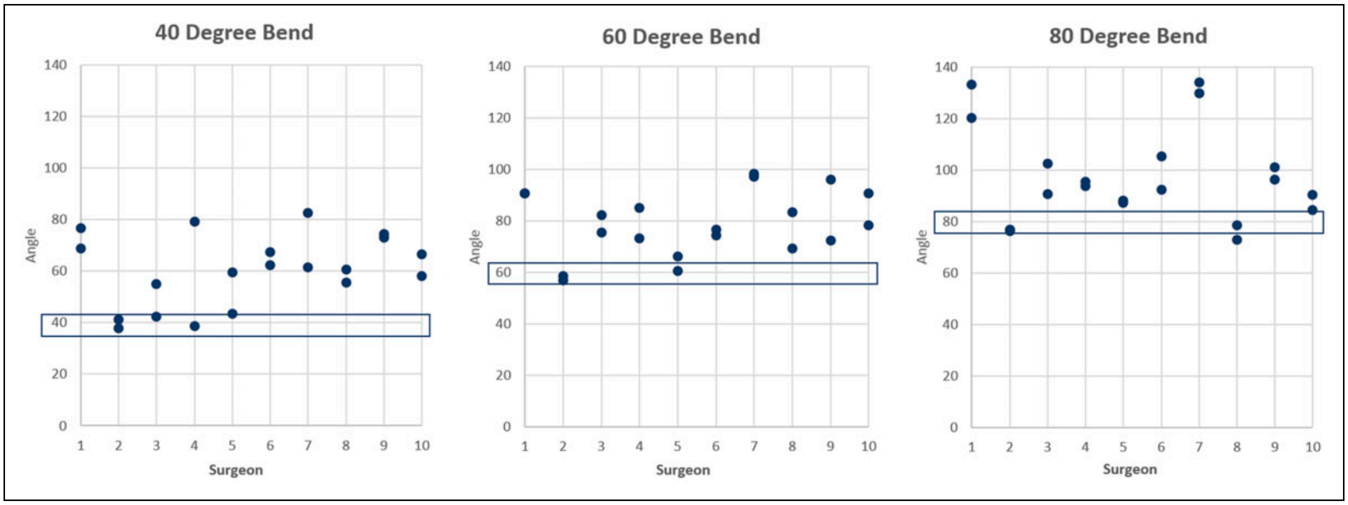

Figure 4. Angular bends achieved without the use of a template guide for each surgeon. Data is grouped by the requested angular bend (40°, 60° or 80°), 2 points are shown for each surgeon for each angle, since each bend was performed in duplicate.

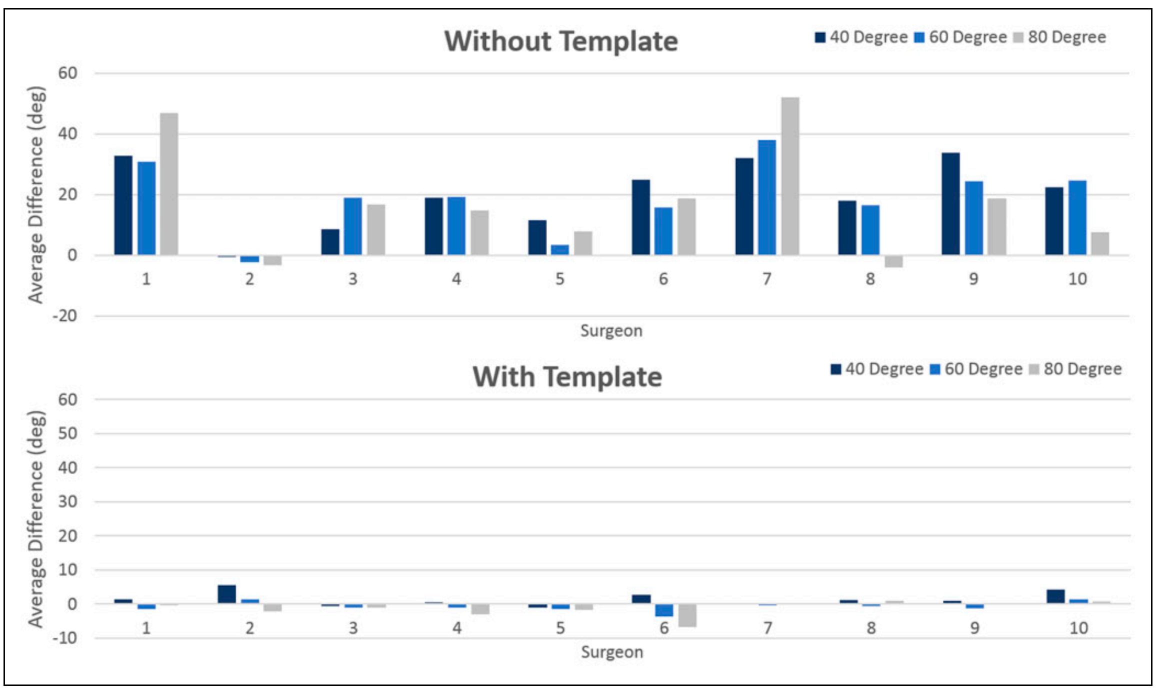

Figure 5. Average differences from target angular bends achieved without (upper panel) and with (lower panel) the use of a template guide for each surgeon.

template guide by surgeon are illustrated in Figure 4, and the average differences from the target angular bends achieved without and with the use of a template guide for each surgeon are graphically depicted in Figure 5.

Discussion

Adult spinal deformity (ASD) is a common disease that has progressively increased over recent decades, partly due to a rise in the elderly population.[15] Increasing prevalence of ASD has led to an upsurge in the number of spinal instrumentation procedures performed globally; and with them, greater attention has been directed at surgical outcome measures and goals. There is now substantial evidence that patient-reported outcomes measures correlate with sagittal alignment. Regardless of its etiology, sagittal malalignment implies alteration of spino-pelvic parameters that can compromise the ability to maintain an upright posture within the cone of economy, without significantly greater energy expenditure.[16,17] In particular, PI-LL mismatch, PT, and SVA are among the strongest radiographic predictors currently available that correlate with surgical outcomes, disability and quality of life.[1,3,18]

Operative treatment goals for ASD include restoration of appropriate spino-pelvic alignment. Correction of lumbar lordosis is especially critical, since it has direct impact on SVA and mismatch reduction, as well as an indirect effect on PT, which serves as a compensatory measure for sagittal malalignment. To directly address the mismatch between PI and LL, patients often require osteotomies, soft tissue releases, interbody implants and instrumentation to gain sufficient lordosis. To accurately plan desired corrections, sagittal alignment analysis is of vital importance and many digital tools have been designed to aid surgeons when making preoperative decisions. Computer-based measurements have been shown to be faster, more precise and most surgeons at least recognize their importance when determining the degree of correction required to restore sagittal alignment.[10,12,19,20] Nonetheless, despite optimal preoperative planning, surgeons often lack the means of ensuring that the desired plan is appropriately executed in the operating room.

In the present study, when surgeons were asked to bend rods without a reference template, not only was there considerable variation in the angles, but nearly all of them tended to overbend the rods, especially as the target angles decreased. When aiming for 40°, 60° and 80° without the template there were mean differences from the target angles of 20.2°, 18.9° and 17.5°, respectively. These discrepancies between planned curvatures and the actual achieved angles might be a major contributing factor to reports in the literature in which in vivo correction not uncommonly differs from the preoperative alignment plans. In a study that included 161 patients with ASD, Moal and colleagues found that 48% of patients had inadequate lumbar lordosis improvement after surgery and only 23% of patients had complete global radiographic correction of the deformity.[21] The arduous challenge to achieve desired angles could be explained, in part, by the difficulty in estimating rod curvatures intraoperatively, that when inadequate, can cause postoperative malalignment. Furthermore, accurate rod bending is not just critical for achieving appropriate lumbar lordosis, in procedures including the thoracic spine, there is also the need to contour the rod to facilitate achievement of appropriate thoracic kyphosis.

Proximal junctional kyphosis (PJK) is among the most common complications in patients who undergo long-segment spinal arthrodesis for ASD and arguably remains the biggest unsolved challenge with these procedures. PJK is associated with high rates of postoperative loss of sagittal alignment, pain, neurological deficit, instability and need for reintervention.[22-26] Although it is a complex, multi-factorial process not yet completely understood, there is evidence supporting a higher incidence of PJK in patients with significantly greater corrections in lumbar lordosis and sagittal vertical axis.[6,22] In a retrospective analysis of 679 ASD patients with fusions to the pelvis stratified by age group, Lafage et al assessed postoperative offsets from age-specific alignment norms and found that patients who developed PJK were significantly overcorrected when compared to age-adjusted sagittal alignment goals.[6] If one extrapolates to a surgical scenario the degree of overcorrection seen when the rods were bent without a template in the present study, this could mean patients are often receiving rods with more lordosis than they may actually need. Since theoretically, achieving the correct regional sagittal contour is dependent on the correct angle of the rod, this means patients could end up with more postoperative lordosis than expected and therefore worse postoperative outcomes and higher rates of revision surgery. This is particularly relevant to the elderly population, who are more prone to overcorrection associated complications due to poorer bone quality, weaker soft-tissue support, and overall increased frailty.[6] In contrast, when surgeons in our study were asked to bend the rods with the aid of templates, there was an average mean difference of just −0.2° from the target angle, which is only a 2.3% error.

Unless patient-specific rods are used, implanted rods are not in their originally straight manufactured form after in situ or French rod benders are used to contour them into the desired shape; causing defects or notches that may ultimately lower their fatigue life.[21,27,28] In fact, this “notch sensitivity” may help to explain why rod failure typically occurs at the screw-rod junction or at the apex of the curve where greater contouring has been done.[28,29] Our study revealed that nearly all participating surgeons overbent the rods when they did not use a template. In fact, there was an overall 18.9° overbend for all angles, which translates into a 30% angular error. This means rods were potentially subject to an unnecessary greater number of notches by the French bender to deliver the curvature deformation. When translating this to an in vivo environment, the more notching caused by overbending could affect the fatigue life of the rods and contribute to implant failure. In addition, a previous biomechanical study from Tang and colleagues[30] demonstrated that rods bent to greater angles had lower fatigue life, suggesting that rods bent to angles greater than necessary may needlessly decrease the fatigue life of the rod and increase the risk of rod fracture.

The importance of appropriate rod contouring is not confined to ASD corrective surgeries or to long-segment instrumentation. As with long-segment fusions, the alignment achieved with shorter-segment fusions is impacted by rod contouring in addition to the bony, disc, and soft tissue releases. Achieving adequate lumbar lordosis for shorter-segment fusions has been shown to have significant impact on the occurrence of adjacent segment disease. Rothenfluh and colleagues[31] assessed 84 patients who had been treated with a short-segment (between 1 and 3 levels) posterior lumbar fusion. Patients with a postoperative PI-LL mismatch had a 10-fold greater risk of requiring revision surgery for adjacent segment disease.

Some limitations of this study should be noted. Rods were only bent in a single angular direction, however ASD patients often need rods to have both lordosis and kyphosis which could entail further discrepancies between desired contours and the actual rod curvature. Furthermore, surgeons were only asked to achieve a specific angle, but no information was given regarding the location of the rod or other specific visual cues that may be available intraoperatively; if surgeons were asked to bend rods to a certain degree of kyphosis versus lordosis, contouring estimates could change. However, this requires a larger sample and further research.

Conclusion

Obtaining adequate postoperative spinal alignment that matches preoperative planned alignment remains a challenge for surgeons. Analysis of angle difference between rods bent without a template versus rods bent with a template revealed significant improvement in accuracy when using the latter. Without the template, surgeons tended to overbend rods compared to the desired angle, while nearly all surgeons improved markedly with use of one. This overbending could have significant implications for patient outcomes and PJK risk and warrants further research to help enable surgeons to better execute preoperative alignment plans into the operative setting.

Declaration of Conflicting Interests

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