Do intraoperative radiographs predict final lumbar sagittal alignment following single-level transforaminal lumbar interbody fusion?

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OBJECTIVE The study aimed to determine if the intraoperative segmental lordosis (as calculated on a cross-table lateral radiograph following a single-level transforaminal lumbar interbody fusion [TLIF] for degenerative spondylolisthesis/low-grade isthmic spondylolisthesis) is maintained at discharge and at 6 months postsurgery.

METHODS The authors reviewed images and medical records of patients ≥ 16 years of age with a diagnosis of an isolated single-level, low-grade spondylolisthesis (degenerative or isthmic) with symptomatic spinal stenosis treated between January 2008 and April 2014. Age, sex, surgical level, surgical approach, and facetectomy (unilateral vs bilateral) were recorded. Upright standardized preoperative, early, and 6-month postoperative radiographs, as well as intraoperative lateral radiographs, were analyzed for the pelvic incidence, segmental lumbar lordosis (SLL) at the TLIF level, and total LL (TLL). In addition, the anteroposterior position of the cage in the disc space was documented. Data are presented as the mean ± SD; a p value < 0.05 was considered significant.

RESULTS Eighty-four patients were included in the study. The mean age of patients was 56.8 ± 13.7 years, and 46 patients (55%) were men. The mean pelvic incidence was 59.7° ± 11.9°, and a posterior midline approach was used in 47 cases (56%). All TLIF procedures were single level using a bullet-shaped cage. A bilateral facetectomy was performed in 17 patients (20.2%), and 89.3% of procedures were done at the L4–5 and L5–S1 segments. SLL significantly improved intraoperatively from 15.8° ± 7.5° to 20.9° ± 7.7°, but the correction was lost after ambulation. Compared with preoperative values, at 6 months the change in SLL was modest at 1.8° ± 6.7° (p = 0.025), whereas TLL increased by 4.3° ± 9.6° (p < 0.001). The anteroposterior position of the cage, approach, level of surgery, and use of a bilateral facetectomy did not significantly affect postoperative LL.

CONCLUSIONS Following a single-level TLIF procedure using a bullet-shaped cage, the intraoperative improvement in SLL is largely lost after ambulation. The improvement in TLL over time is probably due to the decompression part of the procedure. The approach, level of surgery, bilateral facetectomy, and position of the cage do not seem to have a significant effect on LL achieved postoperatively.

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KEY WORDS TLIF; transforaminal lumbar interbody fusion; lordosis; sagittal profile; postoperative correction

In degenerative spondylolisthesis/low-grade isthmic spondylolisthesis, surgical goals are to achieve neural decompression, bony fusion, and restoration of lumbar lordosis (LL). The transforaminal lumbar interbody fusion (TLIF) technique is widely used for these objectives. However, the correction/restoration of sagittal balance has been inconsistently reported and has varied from modest or insignificant at the levels instrumented to substantial corrections of up to 20°. Intraoperatively, surgeons typically rely on a cross-table lateral radiograph to determine
the sagittal alignment of the spinal segment in question. However, the amount of correction retained following surgery remains undetermined.

Factors such as the patient’s age and achieving an interbody union have been suggested to affect the outcomes of a TLIF intervention. This study was designed to investigate the sagittal plane radiological changes in the perioperative and early postoperative periods, as summarized in the following objectives. The primary objective was to determine if the intraoperative segmental lordosis calculated on a cross-table lateral radiograph following a single-level TLIF for low-grade degenerative/isthmic spondylolisthesis with symptomatic spinal stenosis is maintained at discharge and at 6 months postsurgery. The secondary objectives were to achieve the following: 1) determine the surgical variables affecting the degree of segmental lordosis achieved from a single-level TLIF; and 2) investigate the effect of a single-level TLIF on total LL (TLL) at discharge and at 6 months postsurgery.

Methods

During the period between January 2008 and April 2014, the radiographic images and operative records of patients who underwent a single-level primary TLIF for an isolated single-level low-grade spondylolisthesis (degenerative or isthmic) with symptomatic spinal stenosis were reviewed. Patients were included if they were ≥ 16 years of age with a minimum follow-up of 6 months. Patients were excluded if the surgery was a revision procedure, the patient had a previous lumbar fusion, or there was evidence of rotational deformity on standing standardized radiographs of the lumbosacral spine.

Data were collected on patients’ age, sex, level of surgery, surgical approach (midline or Wiltse), and whether a unilateral or bilateral facetectomy was performed. The final intraoperative lateral cross-table plain radiograph or lateral fluoroscopy image taken with the patient prone on an operative table, and standardized standing radiographs of the lumbosacral spine obtained prior to surgery (pre-op), before discharge from the hospital (postop–0), and 6 months after surgery (postop–6) were reviewed to make the following measurements (Fig. 1).

Segmental LL (SLL) of the index segment was measured by calculating the angle between the line tangent to the superior endplate of the upper vertebral body and the line tangent to the inferior endplate of the inferior vertebral body in that segment.

TLL was measured by calculating the angle between a line tangent to the superior endplate of L-1 and a line tangent to the superior endplate of S-1.

The pelvic incidence (PI) was measured by calculating the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral head axis.

Intraoperative images were used to determine the final intraoperative SLL and the position of the intervertebral cage within the index disc space. The latter was calculated as a ratio of the endplate posterior to, and not covered by, the cage relative to the total diameter of the endplate. The cage position was calculated for the endplates above and below the cage separately, as outlined in Fig. 2. At 6 months postsurgery, radiological evidence of construct loosening and cage subsidence was collected.

All images were reviewed on WebDI (version 3.6.1), which allows for measurement of the angle and distance. All measurements were performed by 2 of the authors (K.M.I.S. and A.P.E.). Two weeks after the completion of data collection, 30% of the sample was randomly selected and the measurements were repeated to confirm measurement reliability using the interclass correlation statistic.

Surgical Intervention

A single-level TLIF was performed under general anesthesia with the patient prone on a Jackson spinal modular table (MIZUHO OSI). The approach was based on the surgeon’s preference (midline posterior or Wiltse approach9). O-arm surgical imaging with StealthStation Navigation was used in the majority of cases to guide the insertion of poly-axial pedicle screws into the motion segment of interest. Once the desired posterior decompression was achieved (with unilateral or bilateral facetectomy based on surgeon’s preference), an annulotomy was created and...
the disc space was prepared to allow for the insertion of a bullet-shaped cage (CAPSTONE PEEK Spinal System for TLIF; Medtronic Sofamor Danek). The cage was then packed with local bone graft and inserted as anterior as possible in the disc space before compression was applied through the posterior instrumentation.

**Statistical Analysis**

Institutional review board approval was obtained prior to starting this study. Data were stored in an Excel spreadsheet and exported for final analysis to an SPSS version 23 platform (IBM SPSS Statistics). After exploring data normality (using the Shapiro-Wilk test), we used paired t-test, ANOVA, and linear regression analysis where appropriate. Data are presented as the mean ± SD. A p value < 0.05 was considered significant. Two weeks after the completion of data collection, 30% of the sample was randomly selected and measurements for SLL and TLL were tested using interclass correlation, which produced a coefficient > 0.8 and confirmed data measurement reliability. When calculated, the delta values were defined as the measurement change at a given point compared with baseline (preoperative measurement).

**Results**

During the study period, 84 patients (46 men [55%]) met inclusion criteria and were included in the study. The mean age of patients was 56.8 ± 13.7 years, and the mean PI was 59.7° ± 11.9°. The surgery was performed through a Wiltse approach in 37 patients (44%). The index level was at L1–2 in 1 case (1.2%), at L2–3 in 1 case (1.2%), at L3–4 in 7 cases (8.3%), at L4–5 in 55 cases (65.5%), and at L5–S1 in 20 cases (23.8%). A bilateral facetectomy was performed in 17 patients (20.2%). At 6 months, 13 patients (15.5%) showed evidence of subsidence, whereas radiographic imaging did not identify any evidence of implant loosening.

Data shown in Table 1 and Figs. 3 and 4 demonstrate a significant increase in SLL as measured on intraoperative radiographs, which was largely lost at discharge from the acute-care hospital (that is, after patients started ambulating). At 6 months postsurgery, the mean SLL increase at the index level was modest but statistically significant (1.8° ± 6.7°; p = 0.025 [paired t-test]), whereas the mean increase in TLL at 6 months postsurgery was larger (4.3° ± 9.6°; p < 0.001 [paired t-test]).

Improvements in SLL were not significantly different when various index levels were compared (Table 2). In addition, a bilateral facetectomy did not significantly increase the degree of SLL achieved compared with a unilateral facetectomy (Table 3). Similarly, there was no significant difference between the Wiltse and midline posterior approaches when SLL and TLL were compared at 6 months (Table 4). A linear regression model using delta values for SLL change (as the dependent variable) at 6 months against the position of the cage (relative to the rostral and caudal endplates) did not identify a significant effect of the cage position on the achieved degree of SLL (p = 0.93 and 0.79 for the superior and inferior endplates, respectively). In ad-

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**TABLE 1. LL measured before, during, and after surgery**

<table>
<thead>
<tr>
<th></th>
<th>LL Preop (°)</th>
<th>Intraop (°)</th>
<th>Early Postop (°)</th>
<th>6 Mos (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLL</td>
<td>15.8 ± 7.5</td>
<td>20.9 ± 7.7</td>
<td>17.8 ± 7.2</td>
<td>17.5 ± 7.6</td>
</tr>
<tr>
<td>TLL</td>
<td>48.5 ± 11.9</td>
<td>47 ± 11.3</td>
<td>52.9 ± 11.7</td>
<td></td>
</tr>
</tbody>
</table>

Values are presented as the mean ± SD.
Discussion

Heterogeneity in published TLIF studies creates difficulty when describing the effectiveness of the procedure in achieving or restoring SLL. The following variables represent some of the challenges in interpreting the literature on this topic as it pertains to sagittal alignment: cage position within the disc space, shape (bullet vs crescent), height, type of cage (synthetic vs bone graft), degree of subsidence, surgical technique (monoblock vs poly-axial screws, bilateral instrumentation vs unilateral screw fixation, bilateral vs unilateral facetectomy, extent of the associated decompression), and patient- or pathology-related factors (associated lumbar deformity, number of levels involved, a history of surgery or fusion).

In this study, we examined changes in SLL and TLL following TLIFs in the setting of routine and isolated lumbar pathology. Our findings indicate that the SLL correction achieved intraoperatively using a bullet-shaped TLIF cage is largely lost after the patient ambulates following surgery and is not influenced by the surgical approach, performing a bilateral versus unilateral facetectomy, the segment fused, or the position of the cage within the disc space (measured relative to the endplate above or below it). The overall significant improvement in TLL seems to be the result of a natural reconstitution of LL secondary to the decompression part of the surgery.

There are a limited number of studies investigating the effect of the bullet-shaped cage on SLL following TLIF. Lee et al. performed a retrospective review of SLL and TLL comparing a direct lateral lumbar interbody fusion (106 levels in 81 patients) with a bullet cage TLIF (136 levels in 98 patients) in a heterogeneous cohort (mixed primary pathology, multilevel surgery) and concluded that both procedures had an insignificant effect on SLL and TLL at 12 months, although it was not clear whether the measurements were performed on standing films. The authors reported significantly better segmental distraction using the larger direct lateral lumbar interbody fusion cages, as expected. The insignificant postoperative improvement in TLL was also described by Takahashi et al., who published their experience with an open TLIF using a bullet-shaped cage for lumbar degenerative spondylolisthesis in 41 patients with 24-month follow-up. SLL was not assessed in this study. Similarly, Shen et al. performed minimally invasive TLIF in 61 patients to treat single-level degenerative neural compression with no instability; these authors described no improvement in TLL.

Cage design has evolved over time. “Crescent” or “crescent-shaped” interbody cages have become more popular in an effort to place the cage more anteriorly within the disc space and to potentially achieve more segmental lordosis. The improvements in SLL and TLL with such curved cages are also not uniformly reported. Yson et al. reported excellent SLL restoration using a crescent-shaped interbody cage in 32 single-level TLIFs and 10 multilevel TLIFs (25 levels). The authors used bilateral facetectomy with bilateral disc exposure before a single large interbody cage was inserted into the disc space. The mean SLL correction achieved per level measured on standing radiographs obtained 6 weeks postsurgery was 5.2° ± 4.2° for a single-level TLIF. The authors reported maximal corrections in kyphotic segments and at the L5–S1 level.

Similarly, Ould-Slimane et al. described a significant SLL correction (preoperative 7.9° ± 6.6° to 17.2° ± 7.4° following surgery; p < 0.001) and TLL correction (preoperative 29.6° ± 6.3° to 40.1° ± 4.3° following surgery; p < 0.001) using monoblock pedicle screws, rod contouring, and a crescent-shaped TLIF cage (93% of cages had a 9° lordotic profile) in 45 patients who underwent single-level surgery with a mean follow-up of 35.1 ± 4.1 months. Jagannathan et al. also reported a significant improvement in LL following a 1- to 3-level TLIF using crescent-shaped cages, poly-axial screws, and a bilateral facetectomy. These authors reported SLL improvement of 11.3° ± 5.5° at L4–5 and an impressive 22.3° ± 4.3° improvement at L5–S1 using crescent-shaped cages in 87 patients, of whom 52% were undergoing revision surgery (80% of whom had a previous fusion).

Not all authors have reported such impressive sagittal profile corrections with a crescent-shaped TLIF cage. This
TABLE 3. PI, SLL, and TLL for bilateral compared with unilateral facetectomy cases

<table>
<thead>
<tr>
<th>Facetectomy</th>
<th>No.</th>
<th>PI (°) Preop</th>
<th>Intraop</th>
<th>Early Postop</th>
<th>6 Mos Postop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SLL  TLL</td>
<td>SLL  TLL</td>
<td>SLL  TLL</td>
<td>SLL  TLL</td>
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<tr>
<td>Yes</td>
<td>17</td>
<td>64.5 ± 11.7</td>
<td>15.3 ± 7.2</td>
<td>51.9 ± 15</td>
<td>23.06 ± 7.1</td>
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<tr>
<td>No</td>
<td>67</td>
<td>58.7 ± 11.3</td>
<td>15.2 ± 7.5</td>
<td>47.7 ± 11.7</td>
<td>20.6 ± 8.05</td>
</tr>
<tr>
<td>p value</td>
<td>0.06</td>
<td>NS</td>
<td>NS</td>
<td>0.25</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS = not significant. PI, SLL, and TLL values are reported as the mean ± SD.

was reflected in a study by Kida et al., who reviewed 23 patients who underwent a single-level TLIF using a crescent-shaped cage for degenerative spondylolisthesis. The authors described an initial improvement in SLL based on standing lumbar spine radiographs obtained 2 weeks postsurgery, which was lost at a mean final follow-up of 62 months, whereas TLL was significantly improved at the final follow-up by a mean of 4°. This was also the experience of Sembrano et al., who compared the change in SLL following 4 single-level fusion techniques (anterior LIF, TLIF; instrumented posterolateral spinal fusion, and lateral LIF). These authors reported a modest yet significant (1.9° ± 3.9°) change when using a crescent-shaped TLIF cage.

In our study, we observed that the anteroposterior position of the cage within the disc space did not have a significant effect on SLL. In a cadaveric study, 6 lumbar motion segments were instrumented with bilateral poly-axial pedicle screws and a crescent-shaped cage after a unilateral facetectomy. Radiographs were obtained of the segments with the cage positioned anterior and then posterior on the endplate. The authors concluded that the position of the cage did not influence SLL. In a radiographic review of 30 patients who underwent TLIFs for grade 1 or 2 isthmic spondylolisthesis, Kwon et al. reported that the improvement in SLL was positively correlated with how far anteriorly the interbody device had been pushed. The authors used the definition of the slip angle as the angle measured between a perpendicular to the line drawn against the superior endplate of the rostral vertebral body and a line drawn against the posterior border of S-1 and a line drawn against the superior endplate of the rostral vertebral body and used it to evaluate segmental lordosis on various levels. Our method of measuring segmental lordosis is a more direct representation of SLL and may explain the discrepancy in findings.

Our study has limitations, some which are directly related to the narrow scope of its research questions. To that effect, long-term changes in the local and global sagittal profiles (that is, beyond the study period) could not be commented on. We also acknowledge the effect of osteoporosis on the long-term correction outcome. With this in mind, the authors thought that with the relatively young mean age of our sample (56.8 years), the male predominance (55%), and the relatively short postsurgery target period the significance of osteoporosis as a confounding factor for the purposes of this study was limited. Our radiological cutoff at 6 months was an arbitrary estimate of when patients had completed their postoperative phototherapy and recovered from their spinal surgery. The authors acknowledge that during this period, it was too early to estimate a definitive fusion rate; however, this was not our research question from the onset. A longer follow-up is undoubtedly of value in reporting on fusion rates and further subsidence. However, the emphasis of this study was on the important surgical planning issue of segmental and total lordosis following the TLIF procedure as described.

Conclusions

To our knowledge, this study is the largest series of single-level TLIFs that specifically reviews changes in sagittal alignment induced by a bullet-shaped interbody cage. Our findings suggest that the majority of SLL achieved intraoperatively is lost once the patient ambulates. The improvement in TLL over time is probably due to intraoperative decompression. Final SLL was not influenced by various surgical factors, such as unilateral versus bilateral facetectomy or types of screws used. This result from our detailed radiographic review comes as some surprise, because we had expected to find considerably better lordosis at the operative level. It certainly helps in our surgical planning to have a reasonable expectation of what can be realistically achieved with this technique and interbody device in terms of sagittal correction. In general, the re-

TABLE 4. Effect of surgical approach on PI, SLL, and TLL

<table>
<thead>
<tr>
<th>Wiltse</th>
<th>No.</th>
<th>PI (°) Preop</th>
<th>Intraop</th>
<th>Early Postop</th>
<th>6 Mos Postop</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>SLL  TLL</td>
<td>SLL  TLL</td>
<td>SLL  TLL</td>
<td>SLL  TLL</td>
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<tr>
<td>Yes</td>
<td>37</td>
<td>64.5 ± 11.7</td>
<td>16.7 ± 7.8</td>
<td>48.7 ± 11.7</td>
<td>21.1 ± 7.2</td>
</tr>
<tr>
<td>No</td>
<td>47</td>
<td>58.7 ± 11.3</td>
<td>14.7 ± 8.2</td>
<td>48.6 ± 12</td>
<td>21.06 ± 8.5</td>
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<tr>
<td>p value</td>
<td>0.06</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

PI, SLL, and TLL values are reported as the mean ± SD.

* The TLL change was significantly different between the Wiltse and midline approaches in the early postop period (p = 0.024, t-test); however, it adjusted over time and was not significant at 6 months.
results highlight the potential overestimation of sagittal correction that can be achieved with this technique and warn of the potential for leaving initially kyphotic levels equally kyphotic postoperatively. We believe that the findings will be a useful adjunct, particularly in the setting of sagittal imbalance.

References

Disclosures
C.G.F. is a consultant for Medtronic and NuVasive. He receives royalties from Medtronic as well as fellowship program support that is paid by Medtronic to his institution. He also receives fellowship program support that is paid by AOSpine to his institution. He receives grant funding from OREF that is paid to his institution.

Author Contributions
Conception and design: Salem, Dvorak. Acquisition of data: Salem, Eranki, Paquette, Boyd, Street, Kwon, Fisher. Analysis and interpretation of data: Salem, Eranki. Drafting the article: Salem. Critically revising the article: Salem, Street, Kwon, Fisher. Reviewed submitted version of manuscript: Salem, Kwon. Approved the final version of the manuscript on behalf of all authors: Salem. Statistical analysis: Salem.

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