CLINICAL ARTICLE

Factors Influencing Segmental Lumbar Lordosis After Lateral Transpsoas Interbody Fusion

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Objective: Although contributions to sagittal alignment have been characterized for anterior, posterior and transforaminal lumbar interbody fusion, sagittal alignment after lateral transpsoas interbody fusion (LTIF) has not yet been characterized. This study examined the ability of LTIF to restore lumbar lordosis and identified factors associated with change in sagittal alignment.

Methods: Twenty-nine patients and 67 levels were studied. Segmental lordosis, anterior-posterior cage position, and cage obliquity were measured on preoperative and postoperative radiographs and CT scans. Change in sagittal alignment was analyzed with respect to demographic information and measures of cage position and obliquity to identify factors associated with segmental alignment change.

Results: Mean lordosis increased 3.7° at instrumented segments, increasing from 4.1° preoperatively to 7.8° postoperatively. Although increases at each level were significant, there were no significant differences between levels. Lordosis increase was inversely-associated with preoperative lordosis; levels with the least preoperative lordosis gained the most lordosis. Cage obliquity and height were not significantly associated with lordosis change. Anterior cage placement resulted in the largest lordosis gain (+7.4°/level) while posterior placement was prokyphotic (–1.2°/level). There were no significant associations with age, sex or body mass index.

Conclusion: Anteroposterior cage placement is an important intraoperative determinant of postoperative alignment; anterior placement results in greater lordosis while middle/posterior placement has a minimal effect on sagittal alignment.

Key words: Interbody cage; Lordosis; Operative; Spinal fusion; Surgical procedures

Introduction

Restoration or maintenance of lumbar lordosis after fusion is a significant factor in optimizing surgical outcomes. In the degenerative spine, lumbar lordosis is often lost. This may result in sagittal imbalance, an important consideration in surgical treatment of patients with severe spinal spondylosis because of patient dissatisfaction associated with uncorrected sagittal imbalance after surgery[1–7]. In addition to improving patient satisfaction, the importance of restoration of lumbar lordosis in prevention of adjacent-level disease has been supported by both clinical and experimental studies[8–11]. Development of symptomatic flat-back deformity has also been associated with loss of lumbar lordosis and/or failure to recreate lumbar lordosis at the time of spinal fusion[12–14].

Interbody fusion has many advantages compared with posterior or posterolateral fusion alone, including higher fusion rates as demonstrated by a recent meta-analysis[15]. The same study also supported improved clinical outcomes scores after circumferential fusion when compared to posterior fusion alone in patients with grade I and II spondylolisthesis[15].

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Finally, in the setting of loss of anterior column height due to degenerative disc collapse and/or spondylolisthesis, anterior column support may improve the surgeon's ability to restore intervertebral height and indirectly decompress the neural foramen.

Several techniques have achieved widespread acceptance for interbody fusion, including anterior, posterior and transforaminal lumbar interbody fusion (ALIF, PLIF and TLIF, respectively). More recently, a novel technique utilizing a lateral approach has also been described.

Lateral transpsoas interbody fusion (LTIF), which is a minimally invasive surgical technique that permits anterior column lumbar interbody fusion via a direct lateral transpsoas approach, was described in a preliminary report that demonstrated a low complication rate in a small cohort of patients[16]. The polyether ether ketone cages used with the eXtreme Lateral Interbody Fusion (XLIF) system (Nuvasive, San Diego, CA, USA) were specifically developed for this approach. This cage, which is inserted from the lateral aspect of the vertebral body, is wide enough to span the entire width of the vertebra so that it rests on apophyseal bone on either side. This provides a potential biomechanical advantage because peripheral apophyseal bone is significantly stronger than central cancellous bone[17,18], the latter being used to provide support for other interbody fusion devices that are used in posterior or anterior approaches. In contrast to ALIF, PLIF, and TLIF techniques, LTIF allows preservation of the anterior and posterior longitudinal ligaments. It is unknown whether the unique biomechanical characteristics of LTIF influence the lordosis achieved after fusion. Although previous studies have evaluated the ability to restore lordosis using other interbody fusion techniques, no guidance is available regarding the amount of lordosis that can be expected after LTIF or the technical factors that are associated with more or less successful restoration of lumbar lordosis.

Our objective in this study was to describe a cohort of patients who underwent LTIF and were imaged preoperatively and postoperatively using CT scans and to answer the following research questions.

1. How does LTIF affect lumbar lordosis and does lordosis vary by spinal level?
2. How do the anteroposterior position of the cage and cage obliquity affect the amount of postoperative lumbar lordosis?
3. Do age, sex and body mass index affect the ability to restore lumbar lordosis?
4. Does use of larger cages result in greater restoration of lordosis?

Materials and Methods

Patients were eligible for inclusion if they had undergone LTIF for degenerative disc disease, spondylolisthesis or degenerative scoliosis with or without posterior instrumentation and had had both preoperative and postoperative standing radiographs and postoperative CT scans with multiplanar image reconstruction obtained either in the early postoperative period (<6 months) for evaluation of components' positions (8 patients) or later in the postoperative period (>6 months) to evaluate whether the operated levels had successfully fused (21 patients). Patients were excluded if they had undergone previous spinal instrumentation and/or fusion over any part of the spinal segment instrumented in the most recent surgery (the procedure being studied). LTIF was performed using 10° lordotic cages that ranged in height from 8 mm to 16 mm.

TABLE 1 Study patients' characteristics

Number of patients	29
Average age	69
Male : Female	12:17
Number of levels	
Overall	67
L_{1-2}	6
L_{2-3}	20
L_{3-4}	21
L_{4-5}	20

In these 29 patients, 67 levels were treated by LTIF and included in the study. These figures include 8 patients treated without, and 21 patients treated with, posterior instrumentation posterior instrumentation. Relevant patient variables, body mass index (BMI) and implants used were obtained from the patients' hospital charts (Table 1). Although a detailed analysis of postoperative surgical complications was beyond the scope of this investigation and surgical complications associated with such cohorts have been previously reported[19,20], new postoperative neurological deficits (thigh/groin numbness/pain and hip flexor weakness) were recorded for correlation with cage position. CT scans were obtained using a Phillips multidetector CT scanner with coronal and sagittal plane reconstructions. Preoperative and postoperative sagittal-plane images from radiographs and CT scans for each patient and each instrumented level, some of which had been subjected to subsequent pedicle screw instrumentation, were examined to record the following measurements: (i) sagittal plane instrumented level endplate angulation (lordosis) as measured on standing radiographs; (ii) global lumbar lordosis measured from L_1-S_1; (iii) sacral slope; (iv) obliquity of the cage as measured by the angle difference between the axis of the cage and a line defined by the bilateral transverse processes to account for residual spinal rotation on axial CT images; and (v) cage position as measured from the anterior and posterior border of the adjacent inferior vertebral body on midsagittal CT images. To standardize cage positions despite differing vertebral body sizes, the position of the anterior to posterior midpoint of the cage was assigned to one of three groups. Cages classified as anterior were centered in the anterior 40% of the vertebral body (14 cages), those classified as middle in the middle 20% of the vertebral body (43 cages) and those classified as posterior in the posterior 40% of the vertebral body (10 cages). Cage obliquity was analyzed in two ways: (i) with

TABLE 2 Change in lordosis by spinal level

Level	N	Preoperative lordosis (°)*	Postoperative lordosis (°)*	Change in lordosis (°)†
L_{1-2}	6	1.6 ± 3.1	6.0 ± 6.0	4.4
L_{2-3}	20	3.8 ± 5.1	6.6 ± 2.8	2.8
L_{3-4}	21	4.8 ± 6.0	7.9 ± 4.4	3.1
L_{4-5}	20	4.3 ± 6.2	10.0 ± 5.6	5.7
Overall	67	4.1 ± 5.7	7.8 ± 4.8	3.7

Preoperative and postoperative values are presented as mean ± standard deviation. *, significantly different at all spinal levels ($P < 0.05$); †, no significant difference between different levels ($P > 0.05$).

consideration of two groups (<5° obliquity and >5° obliquity); and (ii) with consideration of three groups (<5° obliquity, 5°–10° obliquity and >10° obliquity). Distances to determine cage position and all angles were measured using embedded Picture Archiving and Communications System workstation functions.

Statistical analysis was performed with SPSS 16.0 (SPSS, Chicago, IL, USA). When comparing preoperative and postoperative values in the same patients, comparison of means between more than two groups was performed using ANOVA, and comparison of means between two groups using Student's *t*-test or paired Student's *t*-test. Calculation of correlations between continuous variables was performed using Pearson's correlation coefficient as described below.

This study was approved by the Institutional Review Board.

Results

Preoperative lumbar lordosis averaged 4.1° at instrumented levels compared with 7.8° postoperatively ($P < 0.01$); thus, the mean increase was 3.7° per level. The average preoperative lordosis by spinal level was 1.6° at L_{1-2}, 3.8° at L_{2-3}, 4.8° at L_{3-4}, and 4.3° at L_{4-5}. Average postoperative lordosis was 6° at L_{1-2}, 6.6° at L_{2-3}, 7.9° at L_{3-4}, and 10° at L_{4-5}. The lumbar lordosis increases found at each spinal level were significantly different ($P < 0.05$). There were no statistically significant differences in the amount of increase in lordosis between spinal levels ($P > 0.05$ for all differences) (Table 2). Analysis of the correlation between preoperative and postoperative sagittal alignment at instrumented levels using Pearson's correlation coefficient (ρ) demonstrated that preoperative alignment was correlated significantly with postoperative lordosis ($\rho = 0.34$, $P = 0.003$) and correlated inversely with increase in lordosis ($\rho = -0.67$, $P < 0.001$), meaning that the levels with the least preoperative lordosis had gained the most lordosis after the procedure.

The increase in lumbar lordosis was greatest when the cage was placed in the anterior portion of the disc space (+7.4° lordosis per level) and less when it was placed in the mid-portion of the disc (+3.8° lordosis per level). When it had been placed in the posterior portion of the disc space, kyphosis was actually produced (−1.2° lordosis per level); these differences were statistically significant ($P = 0.017$). Analysis of cage obliquity did not reveal significant differences in postoperative lordosis based on cage alignment, regardless of whether the data was analyzed using two groups (<5° obliquity and > 5° obliquity, $P > 0.1$) or three groups (<5° obliquity, 5°–10° obliquity and > 10° obliquity, $P > 0.2$). There were no significant increases in lordosis based on the height of the interbody cage ($P > 0.2$). Analysis of the rate of new postoperative neurological symptoms (sensory or motor) demonstrated no differences between placement of the cage in the anterior/middle of the disc (rate = 22%) or the posterior part of the disc (rate = 33%, $P = 0.62$) Preoperative global lumbar lordosis averaged 43.5° compared with 48.4° postoperatively ($P = 0.14$) for an increase of 3° per level. Preoperative sacral slope averaged 32.5° compared with 34.5° postoperatively ($P = 0.19$) for an increase of 2° per level.

Age was not significantly correlated with change in segmental or global lordosis ($\rho = 0.09$, $P = 0.23$, $\rho = 0.12$, $P = 0.27$, respectively). Sex was not significantly associated with increase in segmental or global lordosis ($P = 0.8$, $P = 0.9$, respectively); nor was BMI ($\rho = -0.1$, $P = 0.24$, $\rho = 0.13$, $P = 0.25$, respectively).

Discussion

This is the first study to evaluate the restoration of lumbar lordosis after LTIF and to assess technique-dependent factors that optimize postoperative lordosis. We found that LTIF increases segmental lumbar lordosis in a level-independent fashion, anterior cage placement increases postoperative lordosis, and this technique is most successful at increasing lordosis in levels with low preoperative lordosis measurements. Although we found a trend toward overall increase in lumbar lordosis and increase in sacral slope, these differences were not significant. No patient variables were significantly associated with increase in lordosis. We feel this data will be useful to surgeons both in selection of interbody fusion technique and in optimization of postoperative lordosis after LTIF.

Lumbar lordosis increased an average of 3.7° per instrumented level with no significant difference in level instrumented. This increase in lordosis is less than that reported by Groth *et al.*, who reported average segmental lordosis increases of 5.3° after ALIF when a Harms-type cage was used but decreased lordosis when threaded cylindrical cages (–.5°) or structural allograft bone (–0.9°) were used[21]. Similarly, Hsieh *et al.*[22] reported segmental increases in lordosis of 8.3° after ALIF. Resection of the anterior longitudinal ligament and anterior annulus may result in greater lordosis after ALIF than after XLIF, PLIF, and TLIF.

Recent series in which segmental lordosis was measured after PLIF have reported increases in lordosis ranging from –2.4° to +1°[23,24]. Series studying sagittal alignment after TLIF from Hsieh *et al.*[22], Kim *et al.*[25] and Lee *et al.*[26] found segmental lordosis increases of –0.1°, 0° and +2°, respectively. Spinal levels with greater preoperative segmental lordosis are likely to achieve greater lordosis gains postoperatively, emphasizing the difficulty in restoring lumbar lordosis in those patients who have the greatest need for re-establishment of sagittal balance.

In contrast to previous reports on the relationship between lordosis and cage position using other implants[27,28], we found significant differences in the amount of lordosis achieved depending on the position of the cage with respect to its anteroposterior placement. Whereas anterior placement increased lordosis to 7.4°, on average posterior positioning of the cage was slightly prokyphotic. Based on these findings, surgeons may be able to achieve more or less postoperative lordosis by careful selection of cage position; this might allow them to compensate for other factors associated with restoring lordosis that are out of their control, such as preoperative alignment. The ability to adjust postoperative lumbar lordosis through cage placement would be an especially useful technique in patients undergoing multilevel surgeries with preoperative sagittal imbalance. On the other hand, cage obliquity did not affect postoperative lordosis, suggesting that the degree of lordosis built into the cages (which would be lessened by not placing them along a true coronal plane) is less important in establishing postoperative lordosis than is distraction of the anterior column by the cage; the latter is not affected by obliquity.

Age was not correlated with preoperative to postoperative changes in lumbar lordosis, which is surprising given previous studies that have established correlations between endplate failure and the decreased bone mineral density that often accompanies aging[29,30]. The wide footprint of the cages used in this study may have contributed to the lack of correlation with age, because they distribute the stress associated with intervertebral distraction over a larger portion of the vertebral body, including the peripheral cortical bone. Further studies, including more patients and biomechanical analysis, are necessary to investigate this possible correlation.

This study has several limitations. Because the studied patients had follow-up CT scans at varying times after surgery and cages can subside or migrate over time, it is possible that the distribution of the cage-position groupings would have been different if the follow-ups had been done at a uniform time. To assess this possible additional variable in our study, we compared cage position, intervertebral height and lordosis between early and late CT groups, who were imaged an average of 4 months and 18 months after surgery, respectively. These measurements were not significantly different between the two groups, suggesting that cage migration did not affect our analysis. Next, although other implants designed to be used with a lateral approach are available, we used a single type of implant in this study—other implant types with differing amounts of built-in lordosis or cage height may produce different results. Our study is relatively small and may be underpowered for analysis of some variables; in particular, the difference in rate of new neurologic deficits postoperatively after placement of the cage in the posterior part of the disc space may become significant with a larger sample size. Although we found significant increases in segmental lordosis at the instrumented levels, we did not find a significant increase in overall lordosis (3°), a finding consistent with that of Acosta *et al.*[31] This discrepancy could reflect greater error in measuring lordosis across a large segment than at a single level, the natural history of disc degeneration at noninstrumented levels or accelerated degeneration with loss of lordosis at noninstrumented levels related to the fusion; further investigation is warranted. Finally, evaluating a similar cohort in a prospective manner would eliminate many of the biases intrinsic to the retrospective study design used in this investigation.

In conclusion, we sought to identify patient-dependent and technique-dependent factors associated with increases in lumbar lordosis after LTIF to assist surgeons in preoperative planning of re-establishment of sagittal balance. We found increases in lumbar lordosis after LTIF to be significantly correlated with preoperative sagittal alignment and anteroposterior cage placement. Anteroposterior cage placement is within the control of the surgeon; anterior placement of the intervertebral cage may allow the surgeon to add lumbar lordosis as necessary while placement of the cage in the middle or posterior part of the intervertebral disc space has only a minimal effect on the segmental sagittal alignment. Comparison with previously published data suggests that the surgeon's ability to create lordosis after LTIF is intermediate between that observed after ALIF (more lordosis) and PLIF/TLIF (less lordosis).

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