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AO Spine Clinical Practice Recommendations for Interbody Fusion at the Lumbo-Sacral Junction

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Abstract

Study Design: Literature review with clinical recommendation. **Objective:** Provide a concise curation of recent literature in interbody fusions at the lumbo-sacral junction. **Methods:** Literature is graded based on the integration of scientific methodology and expert opinion. **Results:** Article 1: *ALIF with and without posterior instrumentation,* **Conditional**

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recommendation: ALIF is comparable to 360 fusions in well selected patients. **Article 2:** *ALIF+Perc Screws v. MIS TLIF at L5-S1,* **Conditional** recommendation: use ALIF in cases where higher lordosis correction is needed, **Article 3:** *L4-S1 ALIF v. TLIF with grade 1-2 osteotomy,* **Conditional** recommendation: use ALIF in cases where higher lordosis correction is needed. **Article 4:** *The Deformity TLIF,* **Conditional** recommendation: additional corrective maneuvers (grade 2 osteotomy, rod compression, anterior placement of the cage in the disc, hinged motorized operative table) can aid in achieving lordosis correction. **Article 5:** *Revision rates in isthmic spondylolisthesis,* **Conditional** recommendation: interbody use and 360 fusions decrease revision rates. **Article 6:** *ALIF v. TLIF for isthmic spondylolisthesis*, **Conditional** recommendation: use ALIF+Perc screws when an anterior approach is feasible. **Conclusions:** Segmental alignment matters, even in short segment constructs. Patients who require large magnitude correction are likely better served with an anterior approach as the literature consistently shows greater lordosis change with ALIF compared to TLIF. Appropriate lordosis is possible with TLIF, but surgeons must implement additional technical steps. For anterior fusions, supplemental fixation reduces the nonunion risk, but may not be necessary in a narrow subset of stable listhesis with good bone quality.

Keywords
degenerative, lumbosacral, interbody, fusion, outcomes

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Introduction

Degenerative pathology in the lumbar spine most typically involves the L4-S1 levels, and fusions across these segments are amongst the most common surgeries in our field. Historically, little attention has been paid to lordosis in short segment constructs. Emerging evidence indicates that lordosis does matter, even in short segment constructs, particularly for fusions at the lumbo-sacral junction. This evidence comes from biomechanical and finite element studies showing increased adjacent segment strain in patients with under-corrected fusions,[1] as well as from clinical studies showing higher rates of adjacent segment disease and pain.[2] In spite of its ubiquity, significant controversy exists across multiple topics, including the best approach (anterior v. posterior), the importance of segmental alignment and how best to achieve lordosis, and whether or not an anterior interbody requires supplemental posterior instrumentation. The purpose of this literature review is to discuss recent articles in this important topic area and to use this information to provide updated expert level clinical recommendations regarding best practices for interbody fusions at the lumbo-sacral junction. Particular emphasis is given to the importance achieving segmental alignment goals, even in short segment fusions.

Methods

The steering committee from the AO Spine Knowledge Forum Degenerative selected 6 key articles on the topic of interbody fusion at the lumbo-sacral junction. Articles were chosen at the discretion of the knowledge forum steering committee based on the quality of the included data, recency, and topic relevance. The strength of evidence and recommendations were determined using the GRADE approach.[3] Each article was summarized by a small group of three Knowledge Forum members. The summaries were incorporated into a single document by the first author, and all 23 members of the knowledge

forum reviewed the final manuscript. Consensus was obtained for the final clinical recommendations after a virtual meeting reviewing the summaries. The suggested recommendations and manuscript were circulated to the group prior to meeting. Each member was given a chance to respond to the recommendations and revisions were made to the wording of the recommendations until unanimous consensus was achieved.

Article 1

Laiwalla AN, Chang RN, Harary M, Salek SA, Richards HG, Brara HS, Hirt D, Harris JE, Terterov S, Tabaraee E, Rahman SU.

Primary Anterior Lumbar Interbody Fusion, with and without Posterior Instrumentation: A 1,377-Patient Cohort from a Multicenter Spine Registry

Spine Journal, 2024[4].

Clinical Rationale

The necessity of supplementing an anterior lumbar interbody fusion (ALIF) with posterior fixation is frequently debated, with some authors arguing the posterior fixation (PSF) is unnecessary and morbid and others arguing that it improves fusion rates and allows for earlier mobilization. This registry-based cohort study aimed to shed light on this controversy by comparing stand-alone ALIF against 360 fusions in which the ALIF was supplemented by posterior pedicle-screw fixation (ALIF + PSF). Adults who underwent ALIF between 2009-2021 were identified; cases involving trauma, tumor, infection, decompression, prior fusion, non-contiguous levels, or non-ALIF interbodies were excluded. Primary end points were reoperation for non-union and adjacent segment disease (ASD), analyzed as time-to-event outcomes; secondary 90-day events included emergency-department (ED) visits and readmissions.

Study Summary

The final sample comprised 307 stand-alone ALIF procedures and 1,070 ALIF + PSF procedures, with a mean follow-up of 4.5 ± 3.2 and 5.9 ± 3.7 years, respectively. At 5 years, the crude incidence of operative nonunion was 2.4% for ALIF only vs 0.5% for ALIF + PSF, while the incidence of operative ASD was 4.3% for ALIF only vs 6.2% for ALIF + PSF. After adjustment for baseline imbalances (age, BMI, sex, race, ASA class, smoking, comorbidities), ALIF + PSF was associated with a significantly lower risk of reoperation for non-union (HR 0.22, 95% CI 0.06-0.76). The incidence of operative ASD was 4.3% for ALIF vs 6.2% for ALIF + PSF, which was not statistically significant (HR 0.96, 95% CI 0.54-1.71). Operative time (mean 244 vs 158 min) and length of stay (3.8 vs 3.1 days) were greater with ALIF + PSF, yet 90-day adjusted odds of an ED visit (OR 0.74) or readmission (OR 0.55) were lower compared with ALIF alone. The authors concluded that posterior instrumentation modestly decreases the already low reoperation rate for non-union while not increasing the risk of ASD; therefore, supplemental fixation may be reserved for patients judged at higher biologic or mechanical risk of non-union.

Methodological Review

This investigation draws its strength from a prospectively maintained, integrated-health-system spine registry that captures virtually all operations and re-interventions performed within a large, demographically diverse patient population. Because membership status and electronic health-record linkage are preserved over time, differential loss to follow-up is minimal and reoperation status determination is highly reliable. Each putative outcome was verified by manual review of the chart and the statistical models accounted for clustering by surgeon, both of which improve internal validity (Paxton EW, Kiley ML, Love R, Barber TC, Funahashi TT, Inacio MC. Kaiser Permanente implant registries benefit patient safety, quality improvement, cost-effectiveness. Jt Comm J Qual Patient Saf. 2013 Jun;39(6):246-52).).

However, the study remains a retrospective observational comparison in which the decision to add PSF was left entirely to the operating surgeon. As a result, the two groups differed in ways that are only partly measurable: patients who received PSF were slightly older, more often women, and more likely to undergo multilevel fusion or receive bone-morphogenetic protein (BMP). The multivariable Cox models adjusted for these observable differences, but important unrecorded factors, such as bone mineral density, sagittal alignment, cage size, and other osteobiologics applied, could still influence both the choice of construct and the likelihood of non-union. Residual confounding by indication therefore cannot be excluded. Event scarcity further limits precision. Across 1,377 procedures the authors documented only 13 reoperations for non-union, producing wide confidence intervals around the hazard ratio and precluding meaningful subgroup analyses by level or number of segments fused. ASD was somewhat more frequent, but its definition was also restricted to cases that progressed to surgery.

Radiographic or symptomatic failures treated non-operatively were not captured, so the biological incidence of both non-union and ASD is likely underestimated.

The extensive use of BMP (>75% of patients) and predominance of fusions at L5–S1 (80%) may impact external generalizability to higher lumbar levels or settings with restricted BMP use. Despite these limitations, the findings align with existing literature indicating that stand-alone ALIF can achieve low rates of symptomatic nonunion, and additional posterior fixation may be reserved for higher-risk patients. However, the results may not equally apply to upper-lumbar levels, long-segment deformity, or health-care systems where BMP use is restricted.

Recommendation for Integrating into Your Clinical Practice

For adult patients undergoing one- or two-level primary ALIF in L4–S1 for degenerative lumbar pathology, standalone ALIF is a reasonable surgical option with a low absolute risk of reoperation for symptomatic nonunion over 5 years. PSF reduces this risk further, but adds operative time and hospital stay. The clinical trade-off involves balancing the modestly lower risk of nonunion with increased surgical complexity and recovery burden. We find the quality of the evidence of this article to be **low to moderate** and provide a **conditional recommendation** that a stand-alone ALIF is an appropriate option for carefully selected patients with adequate anterior column support, favorable bone biology, and minimal intraoperative instability. Supplemental posterior instrumentation may be considered when patient-specific factors (eg osteoporosis, multi-level constructs, high shear forces, smoking, or revision surgery) place the fusion at higher risk of non-union.

Article 2

Farber SH, Dugan RK, White MD, Walker CT, O'Neill LK, Alan N, Zhou JJ, Turner JD, Tumialán LM, Uribe JS. **A comparison of modern-era anterior lumbar interbody fusion and minimally invasive transforaminal lumbar interbody fusion at the lumbosacral junction.**

Journal of Neurosurgy Spine, 2023.[5]

Clinical Rationale

Both anterior and posterior approaches are frequently utilized in interbody fusion surgeries at the lumbo-sacral junction. While numerous previous comparisons have been published, there are few direct comparisons of the anterior and posterior minimally invasive approaches with percutaneous screws. In this study, the authors conducted a single-center retrospective cohort study among 108 consecutive patients who underwent ALIF (49 patients) or MIS-TLIF (59 patients) procedures at the L5-S1 level with percutaneous pedicle screw fixation without direct decompression over a 6-year period (from January 1, 2016 to November 30, 2021). The purpose was to report differences in clinical and radiographic outcomes including ODI, SF-36, total lumbar lordosis, segmental L5-S1 lordosis, neuroforaminal height and cage subsidence, and the presence of intraoperative and postoperative complications.

Study Summary

The authors reported that both ALIF and MIS-TLIF resulted in a significant increase in segmental lordosis, disc angle, and neuroforaminal height, as well as significant improvement of postoperative ODI compared to pre-operative values. However, the ALIF cohort achieved significantly greater increase in segmental lordosis, L5-S1 disc angle, and neuroforaminal height compared to MIS-TLIF, while MIS-TLIF was associated with significantly shorter mean hospital length of stay compared to ALIF. The interbody subsidence rates, revision rates, complications rates, and improvement in PROMS were comparable between the two methods.

Methodological Review

Given the small sample size, the study may be under powered. The radiographic analysis was not blinded and there was no inter or intra-observer reliability reported. There was variability amongst the two cohorts in interbody material, and no information was provided on smoking status. A further significant limitation of the study is also the short follow-up period: on average for the ALIF group – 1.6 years, for the MIS-TLIF group – 2.2 years, which limits the reporting of adjacent segment disease. In addition, the study includes a heterogeneous patient population without separation into type of spondylolisthesis (isthmic, degenerative), which may limit generalizability.

Notably, 96% of ALIF group used hyper-lordotic cages (15 degrees or more), while the MIS-TLIF group used implants with only a 6-degree angle, which is a significant confounder, and confusing in part because higher lordosis and expandable TLIF cages are available for MIS approaches. In addition, the cage heights were not reported, which would seemingly have relevance to the achieved foraminal height.

Recommendation For Integrating Into Your Clinical Practice

Overall, we consider the quality of evidence in this study to be **low** and make a **conditional recommendation** that in patients with single-level degenerative disease at the L5-S1 level, either ALIF or MIS-TLIF may be used, but ALIF is more capable of achieving segmental lordosis correction than a standard MIS-TLIF with a flat bullet style cage. Given the importance of segmental lordosis at L5-S1, surgeons wishing to utilize a posterior approach should take additional technical steps to ensure that alignment goals are reached, such as using higher lordosis cages, placing the cage anterior in the disc space to allow cantilever, and wide release or resection of the facet joints to allow posterior compression. Surgeons should be aware of the importance of segmental alignment even in short segment fusions.

Article 3

Zhang Y, Vengsarkar VA, Chi J, Yang H, Goudarzi A, Shen M, Jin L, Cho SK, Yoon ST, Li X
L4-S1 ALIF restores and maintains lordosis while minimizing adjacent segment disease compared to L4-S1 TLIF. Spine Journal, 2025.[6]

Clinical Rationale

The majority of studies comparing ALIF and TLIF have reviewed cases of TLIF with unilateral facetectomy. The Zhang et al. study is a single-center retrospective study comparing patients who underwent L4-S1 fusion for degenerative lumbar disease utilizing an open TLIF with grade 1 or grade 2 posterior osteotomy with static cages versus a similar cohort who underwent ALIF with percutaneous instrumentation. Given that TLIF is historically regarded as a kyphosing procedure, and the importance of segmental alignment in the L4-S1 levels, this study aimed to determine whether the addition of the posterior osteotomies would allow the TLIF cohort to achieve similar radiographic parameters as the ALIF patients.

Study Summary

The authors retrospectively studied a total of 155 patients, consisting of 102 who underwent TLIF and 53 who underwent ALIF, with an average follow-up of 45.8 ± 13.2 months. While both groups exhibited improvement in L4-S1 segmental lordosis compared to pre-operative measurement, the ALIF group resulted in a significantly greater increase in L4-S1 lordosis compared to TLIF (6.5° vs 1.3°). ALIF also reduced lordosis and compensatory changes at L3-L4 compared to the TLIF group (-2.4 ° vs 0.2 °). However, at final follow-up, the TLIF group's L4-S1 lordosis decreased by an average of 1.2 degrees compared to its preoperative value, likely due to cage subsidence and other causes of loss in correction. In contrast, although the ALIF group also experienced some loss of lordosis at final follow-up compared to immediate follow-up, it still maintained 72% of its immediate postoperative improvement. In addition to the significant differences in the alteration of radiological parameters, ALIF had lower incidences of ASD (3.8% vs. 15.7%, $p = 0.034$) and significantly lower reoperation rates (7.5% vs. 25.5%, $p = 0.009$). To further support the finding of lower ASD associated with ALIF, the authors found that in a binary logistic regression analysis, an increase in postoperative L4-S1 lordosis (OR 0.903 (95% CI: 0.820 – 0.994)) and a decrease in delta L3-L4 (OR 0.757, 0.597 – 0.961) were significantly associated with a reduced risk of ASD.

Methodological Review

The study is a single-center retrospective case study that evaluated patients who underwent L4-S1 ALIF with percutaneous instrumentation versus open TLIF with grade 1 or 2 osteotomy using static cages for the treatment of degenerative lumbar disease between 2017 and 2021. Enrolled subjects consisted of patients with degenerative lumbar disease who were older than 18 years and were followed for at least 2 years. Radiological assessment of preoperative, immediate postoperative, and 2-year follow-up, including bilateral femoral heads, sacral endplates, and all lumbar vertebrae. Patients who had undergone previous lumbar fusion surgery were excluded from the study. ASD was defined as a degenerative pathologic condition

observed on follow-up radiographs in conjunction with clinical symptoms requiring additional surgical intervention to treat neurological symptoms at the level L3-L4.

Radiological analyses were performed by two independent raters, employing standing lateral lumbar X-rays to assess pelvic tilt (PT), pelvic incidence (PI), sacral slope (SS), lumbar lordosis (LL), L1-L3 lordosis, L3-L4 disc angle, and L4-S1 lordosis. The accuracy and reliability of these measurements, as assessed by intra- and inter-observer comparisons, were evaluated in 50 randomly selected patients using intraclass correlation coefficients (ICC).

Univariable logistic regression analysis was performed to determine which baseline characteristics and radiologic parameters would be included in the multivariable binary logistic regression analysis. Variables that met the criteria for $p<0.05$ were included, and binary logistic regression analysis was conducted to determine independent risk factors for predicting the incidence of ASD.

Notably, the TLIF group included a mix of both grade 1 and grade 2 osteotomies. We suspect that that a grade 2 osteotomy, particularly when combined with additional corrective maneuvers such as rod compression and in-situ rod bending or cantilever, would have increased lordosis correction relative to a grade 1 osteotomy, and thus the lumping of both grade 1 and grade 2 osteotomies likely results in an under-estimation of the true lordosis correction available. Specifically, Grade 1 osteotomies involve a limited facetectomy. Bony impingement from the facets and spinous processes creates a physical block to lordosis achievement after TLIF, and Grade 1 osteotomies are therefore significantly less powerful for lordosis creation. The article on the "Deformity TLIF" included in this review focused only on grade 2 osteotomies and report greater lordosis correction with TLIF. Surgeons choosing to do a posterior approach should take additional technical steps to ensure that appropriate lordosis is obtained, such as grade 2 osteotomies and on table correction maneuvers with rod compression and table extension.

Recommendation Regarding Impact on Clinical Practice

Even with only percutaneous instrumentation and no facet osteotomies reported in the ALIF group, the authors still found superior lordosis correction in the ALIF group compared to the TLIF group, which included grade 1 or 2 osteotomies. The findings of this study are intuitive and biomechanically sound, as the ALIF enables the surgeon to cut the anterior longitudinal ligament, perform a more thorough discectomy, and place a larger interbody cage, which typically allows for greater lordosis. Overall, we find the quality of the evidence in this study to be **moderate** and provide a **conditional** recommendation that patients who require a large magnitude lordotic correction would likely benefit from an anterior approach. Surgeons choosing to do a posterior approach should take additional technical steps to ensure that appropriate lordosis is obtained.

Article 4

Polly DW Jr, Holton KJ, Haselhuhn JJ, Soriano PBO, Jones KE, Sembrano JN, Martin CT.

Does A Hinged Operating Table Facilitate Sagittal Correction in Transforaminal Lumbar Interbody Fusion With Smith-Peterson Osteotomy? A Radiographic Analysis.

Clinical Orthopedics and Related Research, 2024.[7]

Clinical Rationale

This prospective, single-center study aimed to quantify segmental lordotic changes with intraoperative spinal extension through a motorized hinged operating table in patients undergoing transforaminal lumbar interbody fusion (TLIF) combined with Smith-Petersen osteotomy (SPO). The theorized benefit of utilizing a motorized hinged operating table for this specific indication lies in the potential of achieving the desired segmental lordosis correction without relying solely on instrumentation-based closure techniques, which can risk screw loosening, especially in patients with compromised bone quality. This study investigates whether controlled table flexion and extension might offer a viable adjunct in achieving segmental lordosis correction.

Study Summary

Between October 2019 and March 2022, 61 patients were initially enrolled. After exclusions related to pandemic-related research disruptions, absence of intra-operative table extension, or cancelled surgeries, the final cohort consisted of 50 patients (24 male, 26 female) spanning 73 osteotomy levels. Patients were placed on the ProAxis motorized surgical table in the prone position, initially flexed to 10° to facilitate decompression, osteotomy, and interbody cage placement. Following TLIF completion, the table was extended in 5° increments from 10° degrees of flexion up to 10° of extension, with

radiographic assessment at each step. Segmental lordosis was measured between the upper and lower instrumented vertebrae, and additional radiographs were taken after final rod placement and compression.

The study found that table-facilitated extension from 10° of flexion to 10° of extension yielded an average of 5.6° correction in segmental lordosis. Specifically, angular changes from in the first 10° to 5° of flexion accounted for approximately 1.9°, with subsequent increments delivering progressively less correction. Final rod placement and compression an additional 1.8° of further correction. Inter-rater agreement in radiographic measurements was excellent, with intraclass correlation coefficients (ICCs) ranging between 0.97 and 0.98. No intraoperative neurological injury or hardware failure occurred. Notably, these measurements were taken after interbody placement, and thus represent additional regional deformity correction above and beyond what is achieved from the interbody alone.

Methodological Review

This is a prospective cohort of Level III evidence. Conducted at a tertiary academic institution, it evaluates a novel intraoperative mechanical approach using quantified radiographic endpoints. Four fellowship-trained spinal surgeons contributed to the measurements and procedures using consistent surgical techniques and equipment. All patients underwent bilateral TLIF with SPO, performed with patients placed on a motorized hinged operating table capable of intraoperative spine flexion and extension. Patient selection included those aged 18 or older undergoing primary lumbar fusion surgery using the specified techniques and approach. Of 61 initially enrolled, 50 completed protocol-compliant procedures with usable intraoperative radiographic data. Exclusions were largely due to pandemic-related disruptions and instances where table extension was not used due to complete osteotomy closure before reaching full table motion.

The study's radiographic protocol included a lateral radiograph at each position as the table angle changes were introduced in 5° increments. Measurements of segmental lordosis, defined as the angle from the superior endplate of the upper-instrumented vertebra to the inferior endplate of the lower-instrumented vertebra, were independently evaluated by two surgeons. Data integrity was supported by ICC values in the range of 0.97 to 0.98, however, segmental lordosis changes were only 1-2° and previously reported human measurement error with lumbar lordosis quantification is historically thought to be 1-3°. Blinding was not feasible during this study and the radiographic reviewers were also the surgeons performing the surgery, potentially introducing bias in measurement.

Additional study limitations stem from its sample size, exclusion of patients due to external constraints, and absence of a control group using only manual compression methods. The decision to exclude patients who underwent full osteotomy closure prior to full table extension creates some selection bias, particularly if those patients exhibited anatomical differences that influenced outcomes. Additionally, the inability to directly compare outcomes using manual compression limits the broader applicability of findings in clinical settings. Lastly, the authors maximized segmental lordosis correction with instrumentation based compression after the final table manipulation and without the aforementioned comparison group it is not possible to determine whether table manipulation plus instrument based compression is safer than instrument based compression alone.

Recommendation regarding Impact on Clinical Practice

Multiple other studies have shown that TLIF alone, even with a posterior osteotomy, is limited in its lordosis correction. This study indicates that the use of additional corrective maneuvers can increase the total lordosis achieved. Specifically, the use of the hinged operative table and rod compression achieved an additional 5.6 degrees correction beyond what was obtained with the interbody alone. Given that this is a small single center study, we find that the quality of evidence is **low**, and provide a **conditional** recommendation that surgeons performing TLIF at the lumbo-sacral junction consider using additional deformity correction maneuvers such as rod compression and table extension to ensure adequate lordosis is achieved.

Article 5

Durand WM, Quan T, Parekh Y, Yoon ST, Hsieh PC, Le H, Louie PK, Corluka S, Singh H, Cho SK, Muthu S, Buser Z, Hamouda W, Demetriades AK, Vadalà G, Jain A; AO Spine Knowledge Forum Degenerative.

A Comparative Analysis of Revision Rates in Surgical Treatments for Lumbar Isthmic Spondylolisthesis. *Global Spine Journal, 2025.*[8]

Clinical Rationale

The best surgical approach (anterior v. posterior) and whether or not to add posterior fixation to an ALIF are frequently debated topics in Isthmic Spondylolisthesis. This is a retrosepctive data-base study that attempted to answer these questions by reporting on the incidence of revision surgery with each approach.

Study Summary

The authors utilized the Market-Scan Research Database (IBM Health, Ann Arbor, MI) which is a collection of >300 billion claims records from private insurance carriers. Patients (n=1,014, Females = 525, 51.8%) included were less than 65 years of age with a diagnosis of lytic/isthmic spondylolisthesis and had undergone single-level arthrodesis from 2015 to 2020. Patients were grouped as ALIF alone (n=66, 6.5%), PLF alone (n=146, 14.4%) PLIF/TLIF (n=614, 60.6%), and ALIF+PSF (n=188, 18.5%). The primary outcome measure was revision surgery consisting of either arthrodesis or decompression, as defined by CPT codes.

The follow up averaged 637.6 days (SD+/-512.9 days). Revision surgery was performed in 4.2% of patients (n = 43), on average 441 days (±574) after the index surgery, of which 49% had decompression, and 79% had arthrodesis CPT coding. Decompression alone was coded in 21%, while 56% had fusion alone coding. The rate of decompression alone didn't differ significantly across surgical approach.

In unadjusted Cox regression, patients with ALIF-alone had a higher risk of revision compared to ALIF+PSF (HR 4.8), PLIF/TLIF (HR 5.5), and PLF-alone (HR 2.6). After adjusting for confounders such as age, sex, region and decompression at index surgery via multivariate analysis, a similarly increased risk of reoperation rate in the ALIF group was seen. In addition, after these adjustments, PLF alone was associated with a higher revision rate compared to PLIF/TLIF (HR 2.4), whereas the other comparisons did not reach statistical significance.

Methodological Review

Any administrative claims study is likely to carry significant limitations. Reliance on coding information is prone to coding errors, and variations in billing practices may affect cohort assignment and revision outcome identification. Specifically, the current study has identified revision surgeries using CPT codes that broadly incorporate various indications such as non-union, implant-related complications, ongoing neurologic stenosis, and adjacent segment disease, but information regarding the anatomical level/site of revision surgeries remains lacking. It is not clear whether the revisions were performed at the same primary level or at different/adjacent levels. A multivariable analysis adjusted for confounding factors was applied by taking decompression at index surgery, age, sex, and geographic region as covariates, but variation in clinical findings such as pain severity, functional & neurological status, fusion level, or implant type were not available for further adjustments.

However despite these limitations, 1,014 lytic spondylolisthesis patients were followed for up to 5 years and revision-free survival was assessed using Kaplan-Meier analysis. Through this approach a temporal increase in revision risk across surgical cohorts was identified, which was only 1.4% in 6 months, increasing to 2.8% at 1 year, became 5.9% at 2 years, and further increased to 11.0% at 5 years. These findings indicate that the early revision rates are low, but risk accumulates steadily over time. Notably, long term outcome is influenced by the type of index surgery performed as significant differences were seen in revision-free survival between surgical groups ($P < 0.0001$).

The mean time of revision was 441 days (SD 574) with a wide range from 0-59 months indicating substantial variability of timings in revision surgeries, and likely reflects the heterogenous indications for revision. The 95% CI for the mean revision was approximately 326 to 558 days. While looking at the distribution of revision surgeries (Table 1) it is indicated that majority of revisions occurred within the first 23 months after surgery, with a notable peak in the 6 to 11-month range (Table 1). Arthrodesis was found more common than decompression alone in follow up revision surgery, which implies that revision may have been primarily driven by nonunion, rather than recurrent stenosis.

Recommendation Regarding Impact on Clinical Practice

This study implies that adding posterior fixation to an ALIF, and adding an interbody to PLF are both associated with lower risk of revision. This is consistent with previously published systematic reviews showing that ALIF alone is inadequate for lytic spondylolisthesis [doi 10.1177/2192568217699210]. Overall, we find the quality of evidence in this study to be **Moderate** and provide a **Conditional** recommendation that posterior-based interbody or combined anterior-posterior approaches (such as PLIF/TLIF or ALIF+PSF) may be preferred over ALIF or PLF alone when aiming to reduce the likelihood of revision in single-level isthmic spondylolisthesis.

Table 1. Showing distribution of revision surgeries by months

Range of Months Post-Operative	Frequency of Revision Surgeries
0-5	9
6-11	13
12-17	8
18-23	7
24-29	2
30-35	1
36-41	1
42-47	0
48-53	1
53-59	1

Article 6

Lightsey HM 4th, Pisano AJ, Striano BM, Crawford AM, Xiong GX, Hershman S, Schoenfeld AJ, Simpson AK. **ALIF Versus TLIF for L5-S1 Isthmic Spondylolisthesis: ALIF Demonstrates Superior Segmental and Regional Radiographic Outcomes and Clinical Improvements Across More Patient-reported Outcome Measures Domains**. Spine (Phila Pa 1976), 2022.[9]

Clinical Rationale

This study provides additional perspective on the pros and cons of anterior compared to posterior approaches in treating isthmic spondylolisthesis at L5-S1.

Study Summary

The study included 70 patients (38 ALIF, 32 TLIF) treated between 2016 and 2020 at Mass General Health System (MGH). Pre- and post-operative radiographs and Patient-Reported Outcomes Measurement Information System (PROMIS) scores were evaluated between the groups. The authors aimed to assess which surgical approach yielded superior radiographic correction and functional outcomes in well-defined pathology. ALIF was associated with significantly greater improvements in segmental and L4-S1 lordosis compared to TLIF at both early (11.3° vs. 1.3°; 6.2° vs. 0.3°, $P < 0.005$) and final follow-up (9.6° vs. 0.2°; 7.9° vs. 2.1°, $P < 0.005$). Disc height restoration was also superior with ALIF (9.6 mm vs. 5.5 mm early; 8.7 mm vs. 3.6 mm final; $P < 0.001$), and notably, disc height was maintained over time in ALIF but declined in TLIF (ALIF 9.6 vs. 8.7mm, $P<0.01$; TLIF 5.5 vs. 3.6mm, $P < 0.001$), both findings reaching statistical significance. Both groups improved in pain-related PROMIS scores, but ALIF demonstrated additional benefit in Physical Function and Global Health-Physical domains. The authors concluded that ALIF, when supplemented by posterior fixation, may provide superior restoration of sagittal parameters and broader improvements in patient-reported outcomes as compared to TLIF.

Methodological Review

This retrospective case series utilized data from the MGH system, extracted through the Research Patient Data Registry (RPDR), a secure clinical data repository. Following IRB approval, the authors identified all single-level ALIF and TLIF procedures performed for L5-S1 isthmic spondylolisthesis between January 2016 and October 2020 across four affiliated institutions. Procedures were selected using CPT and ICD codes, with exclusion of revision cases and isolated ALIFs without posterior instrumentation. Both open and minimally invasive techniques were included. While not randomised, the authors matched baseline characteristics and performed appropriate statistical comparisons to minimise confounding. Radiographic outcomes, including segmental and regional lordosis, disc height, and anterolisthesis, were measured at three standardized intervals: preoperative, early postoperative (<6 weeks), and final postoperative (>1 year). A single rater performed all measurements, and inter- and intra-rater reliability was confirmed via intraclass correlation coefficients (ICCs) across five reviewers using 10 representative x-rays. This demonstrated strong agreement. Furthermore, the study employed validated, patient-centered outcome tools (PROMIS) to assess clinical improvements across multiple domains.

Table 2. Summary Recommendations

Article	Recommendation
Article 1: ALIF with and without posterior instrumentation[4]	Conditional recommendation: ALIF is comparable to 360 fusions in well selected patients.
Article 2: ALIF+Perc Screws v. MIS- TLIF at L5-S1[5]	Conditional recommendation: Use ALIF in cases where higher lordosis correction is needed.
Article 3: L4-S1 ALIF v. TLIF with grade 1-2 osteotomy[6]	Conditional recommendation: Use ALIF in cases where higher lordosis correction is needed.
Article 4: The Deformity TLIF[7]	Conditional recommendation: Additional corrective maneuvers (grade 2 osteotomy, rod compression, anterior placement of the cage in the disc, hinged motorized operative table) can aid in achieving lordosis correction.
Article 5: Revision rates in isthmic spondylolisthesis[8]	Conditional recommendation: Interbody use and 360 fusions decrease revision rates.
Article 6: ALIF v. TLIF for isthmic spondylolisthesis[9]	Conditional recommendation: Use ALIF+Perc screws when an anterior approach is feasible.

The study's limitations include its inherent retrospective design. The relatively small sample size (N=70) limits the statistical power for subgroup analyses. A very important point is that both open and MIS TLIF were combined into one group, and these two groups could have different outcomes. It is also unclear how many TLIFs involve bilateral facetectomy or the degree of decompression, both of which could alter the segmental lordosis. This may further reduce the generalizability of the findings across broader populations. Although the follow-up period extended to one year, it does not capture longer-term outcomes beyond one year, such as pseudoarthrosis status, adjacent segment degeneration, or implant failure rates. Additionally, the absence of complication data (e.g., vascular injury, neurologic deficits, infection) precludes a comprehensive risk-benefit comparison between ALIF and TLIF.

Recommendation Regarding Impact on Clinical Practice

Overall, the study found that ALIF provides significantly greater improvements in segmental alignment, disc height preservation, and regional lordosis compared to TLIF, with these gains maintained at one-year follow-up. Moreover, ALIF was associated with broader improvements across PROMIS domains, including physical function and overall health perception. We find the quality of evidence to be **moderate** and provide a **conditional** recommendation that for patients undergoing surgical treatment for L5-S1 isthmic spondylolisthesis, ALIF with supplemental posterior instrumentation should be considered the preferred interbody fusion technique when feasible, particularly when restoration of segmental and regional lordosis is a surgical priority.

Discussion

Each of these 6 articles were related to optimizing surgical alignment and outcomes at the lumbo-sacral junction and the consistency across studies increases confidence despite the limitations present in each study (Table 2). This, along with our consensus opinion based on clinical experience and expertise, allowed us to arrive at the following conditional recommendations. Patients who require large magnitude lordotic correction at the lumbosacral junction are likely better served with an anterior approach as the literature consistently shows greater lordosis change with ALIF compared to TLIF. Patient factors and logistics may make an anterior approach undesirable. In these cases, appropriate lordotic corrections are possible posteriorly, but surgeons must implement additional technical steps in their TLIF surgery to ensure that segmental alignment goals are attained. For anterior fusions, supplemental fixation reduces the nonunion risk in patients with isthmic spondylolisthesis, but may not be necessary in a narrow subset of patients without instability and with good bone quality.

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Ethical Considerations

Institutional Review Board approval was not required for this study as it did not meet the standards for human research.

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Declaration of conflicting interests

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References

1. de Andrada Pereira B, Wangsawatwong P, Lehrman JN, et al. Subtle segmental angle changes of single-level lumbar fusions and adjacent-level biomechanics: cadaveric study of optically measured disc strain. *J Neurosurg Spine*. 2022;37(4):525-534.
2. Pizones J, Hills J, Kelly MP, et al. Alignment Goals in Adult Spinal Deformity Surgery. *Global Spine J*. 2025;15(3_suppl):108S-122S.
3. Atkins D, Best D, Briss PA, et al. Grading quality of evidence and strength of recommendations. *BMJ*. 2004;328(7454):1490.
4. Laiwalla AN, Chang RN, Harary M, et al. Primary anterior lumbar interbody fusion, with and without posterior instrumentation: a 1,377-patient cohort from a multicenter spine registry. *Spine J*. 2024;24(3):496-505. doi:10.1016/j.spinee.2023.10.003. Epub 2023 Oct 22. PMID: 37875244.
5. Farber SH, Dugan RK, White MD, et al. A comparison of modern-era anterior lumbar interbody fusion and minimally invasive transforaminal lumbar interbody fusion at the lumbosacral junction. *J Neurosurg Spine*. 2023;39(6):785-792. doi:10.3171/2023.5.SPINE221224. PMID: 37548527.
6. Zhang Y, Vengsarkar VA, Chi J, et al. L4-S1 ALIF restores and maintains lordosis while minimizing adjacent segment disease compared to L4-S1 TLIF. *Spine J*. 2025;4(25):S1529. doi:10.1016/j.spinee.2025.06.001. Epub ahead of print. PMID: 40480521.
7. Polly DWJ, Holton KJ, Haselhuhn JJ, et al. Does A Hinged Operating Table Facilitate Sagittal Correction in Transforaminal Lumbar Interbody Fusion With Smith-Peterson Osteotomy? A Radiographic Analysis. *Clin Orthop Relat Res*. 2024;482(6):1065-1070. doi:10.1097/CORR.0000000000002910. Epub 2023 Dec 1. PMID: 38038970; PMCID: PMC11124653.
8. AO Spine Knowledge Forum Degenerative. Durand WM, Quan T, Parekh Y, et al. A Comparative Analysis of Revision Rates in Surgical Treatments for Lumbar Isthmic Spondylolisthesis. *Global Spine J*. 2025;12:21925682251326914. doi:10.1177/21925682251326914. Epub ahead of print. PMID: 40077922; PMCID: PMC11907570.
9. Lightsey HM 4th, Pisano AJ, Striano BM, et al. ALIF Versus TLIF for L5-S1 Isthmic Spondylolisthesis: ALIF Demonstrates Superior Segmental and Regional Radiographic Outcomes and Clinical Improvements Across More Patient-reported Outcome Measures Domains. *Spine (Phila Pa 1976)*. 2022;47(11):808-816. doi:10.1097/BRS.0000000000004333. Epub 2022 Feb 3. PMID: 35125462.