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Review Article

Restoration of lumbar lordosis after minimally invasive transforaminal lumbar interbody fusion: a systematic review

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ABSTRACT

BACKGROUND: Transforaminal lumbar interbody fusion (TLIF) is a well-accepted surgical technique for the treatment of degenerative spinal conditions and spinal deformity. The TLIF procedure can be performed open or using minimally invasive techniques. While several studies have found that minimally invasive TLIF (MI-TLIF) has advantages over open TLIF procedures with less blood loss, postoperative pain and hospital length of stay, opponents of the minimally invasive technique cite the lack of restoration of lumbar lordosis as a major drawback. With the increasing awareness of restoring sagittal alignment parameters in degenerative and deformity procedures, surgeons should understand the capabilities of different procedures to achieve surgical goals. To our knowledge, few studies have specifically studied the radiographic restoration of lumbar lordosis after MI-TLIF procedures. The purpose of this study was to perform a systematic review of the literature describing the sagittal lumbar radiographic parameter changes after MI-TLIF.

METHODS: Following PRISMA guidelines, systematic review was performed. With the assistance of a medical librarian, a highly-sensitive search strategy formulated on 1/19/2018 utilized the following search terms: "minimally invasive procedures," "transforaminal lumbar interbody fusion," "lumbar interbody fusion," "diagnostic imaging," "radiographs," "radiography," "x-rays," "lordosis," "lumbar vertebrae," "treatment," "outcome," and "lumbosacral" using Boolean operators 'AND' and 'OR'. Three databases were searched (PubMed/Medline, Embase, and Cochrane Library). An online system (www.covidence.org) was used to standardize article review. All studies were independently analyzed by two investigators and discrepancies mitigated by a third reviewer. Study selection for each cycle was Yes/No/Maybe. Cycles were: (1) (Title/Abstract); (2) (Full Text); (3) (Extraction). Inclusion criteria were: (1) All study designs, (2) MI-TLIF procedures, (3) Reporting total lumbar lordosis (LL) and/or segmental lordosis (SL) pre- and postoperatively. Exclusion criteria were: (1) non MI-TLIF procedures (ALIF, XLIF, LLIF, conventional TLIF, OLIF), (2) No reported LL or SL.

RESULTS: The search yielded 4,036 results with 836 duplicates leaving 3,200 studies for review. Cycle 1 eliminated 3,153 studies as irrelevant, thus, 47 were eligible for full-text review. Cycle 2

FDA device/drug status: Not applicable.

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excluded 31 studies for No English full text (9), Oral/Poster (8), Wrong intervention/outcome (10), Duplicate listing (2), Full text not available (1), Literature review (1) resulting in 16 included studies. Study designs were: Randomized-controlled trial (3), Case series (6) and Retrospective (7). Mean # of subjects were 32.0 (range 8–95). Weighted-mean LL was 39.6°±9.2 (range 28–57) and postoperative LL was 45.0°±7.4 (range 36–67) with a LL post-pre difference of 5.2°±5.9 (range −7 to 15). Weighted-mean preoperative SL was 12.7°±4.3 (range 5–21) and postoperative SL was 15.0°±4.5 (range 5–22) with a SL post-pre difference of 2.1°±1.7 (range 0–8).

CONCLUSIONS: The current literature on MI-TLIF and restoration of LL/SL is limited to 16 published studies, 44% of which are retrospective. The published evidence supporting LL and SL restoration with MI-TLIF is sparse with variable results. This systematic review demonstrates the need for future high-level studies to fully elucidate the capabilities of MI-TLIF procedures for restoring lumbar and segmental lordosis.

Keywords: Expandable; Foraminal decompression; Lordosis; Minimally invasive; Radiographic; Sagittal alignment; Segmental lordosis; TLIF.

Background

Lumbar spinal interbody fusion is a surgical technique utilized for many spinal conditions. Multiple interbody fusion surgical approaches exist including posterior (PLIF), transforaminal (TLIF), lateral (LLIF), and anterior (ALIF) [1]. Each approach has advantages and disadvantages and may be preferentially used by surgeons based on training, experience, the spinal pathology, and surgical goals. In addition to achieving a fusion, an interbody graft allows for indirect foraminal decompression, disc height (DH) restoration, and correction of radiographic spinopelvic alignment, especially lumbar lordosis (LL).

Minimally invasive techniques are gaining popularity in spinal surgery. In 2002, Foley et al. first described the minimally invasive TLIF (MI-TLIF) [2]. Since that time, the frequency of these procedures has increased across the world. MI-TLIF offers potential advantages over open TLIF procedures with decreased blood loss [3], decrease hospital length of stay [4], decreased narcotic use [5], faster time to ambulation [3,6,7], faster return to work [3,5], and lower infection rates [] [4,7,8,9,10]. However, there is a significant learning curve for minimally invasive procedures. Complications, operative time, and radiation exposure may be higher until surgeons perform enough procedures and achieve procedural proficiency [6,11].

Studies exist examining the ability of interbody fusion techniques (PLIF/TLIF/LLIF/ALIF) to restore lumbar lordosis and impact spinal pelvic parameters [1,12–16]. Uribe and colleagues performed a literature review on this topic in 2016 [16]. They studied all interbody techniques, including PLIF, TLIF, LLIF, and ALIF. Six of the 23 included studies examined TLIF procedures. With recent literature emphasizing the importance of restoring lumbopelvic balance, surgeons need to understand the abilities and limitations of different surgical techniques to achieve the intended surgical goals.

To our knowledge, the currently available literature has not clearly defined the ability of MI-TLIF to restore lumbar lordosis and/or segmental lordosis. The purpose of this effort was to perform a systematic review of published literature reporting outcomes after MI-TLIF procedures and the impact on lumbar lordosis and/or segmental lordosis. With previous literature reviews studying all interbody techniques, we believe this is the first systematic review isolating and analyzing only MI-TLIF procedures.

Methods

A review of published literature was performed. The study was designed using a PRISMA guidelines [17,18] and is summarized in Fig. 1. With the assistance of a medical librarian, search criteria were formulated to achieve a highly sensitive search. Three databases were selected: Medline via PubMed (1946 – date of search), Embase (1947 – date of search), and Cochrane library including Cochrane Central Register of Controlled Trials (CENTRAL), Cochrane Methodology Register (CMR), Database of Abstracts of Reviews of Effects (DARE), Health Technology Assessment Database (HTA), and NHS Economic Evaluation Database (EED) (Inception to date of search). The search strategies for each database are listed below. Searches were performed on January 19, 2018.

The results from each database search were compiled and transferred to specialized online systematic review software (Covidence Software, Veritas Health Innovation, Melbourne, Australia, available at www.covidence.org). Covidence is a software that standardizes systematic review methodology using a web-based interface. Inclusion criteria were as follows: All study designs, at least 1 study group including MI-TLIF procedures, reporting lumbar lordosis and/or segmental lordosis and/or changes in lumbar lordosis or segmental lordosis. Studies not including MI-TLIF cases or lacking radiographic data were excluded.

Two investigators independently reviewed each Title and Abstract for the inclusion criteria and selected “Yes,” “No,” or “Maybe” as the first level of selection. Any conflicts or

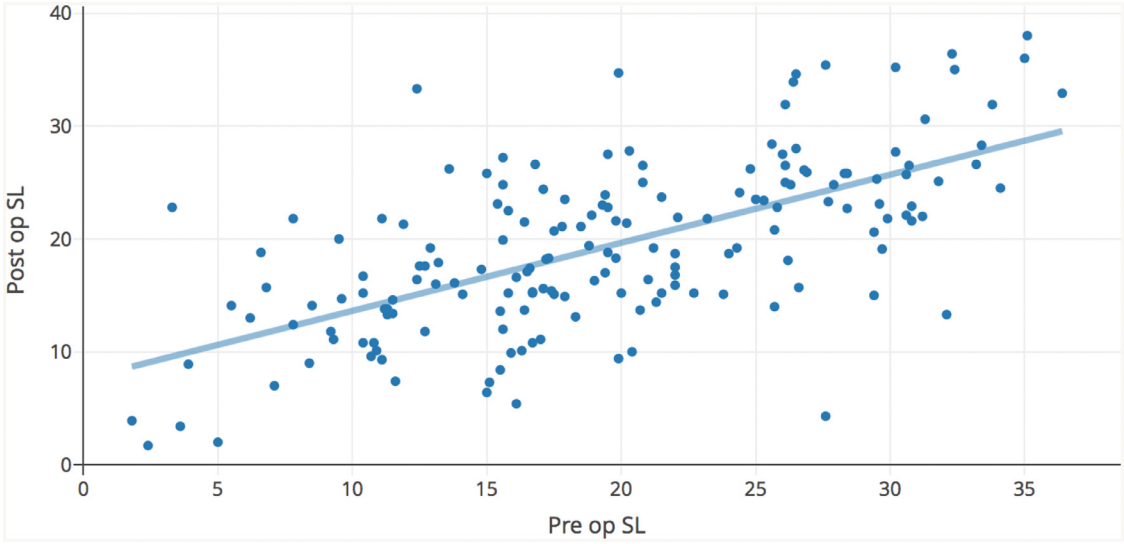

Fig. 1. Effect of preoperative segmental lordosis on postoperative segmental lordosis (R^2=0.41, p<.0001).

references selected as "Maybe" were resolved with a third investigator review. The same two initial investigators then independently reviewed the full text of all studies included from round one to confirm inclusion. Conflicts were again resolved by the third investigator. Studies lacking radiographic measurements, nonminimally invasive procedures, studies without English full text versions, references from conference proceedings, and duplicate references not previously identified were excluded. Literatures reviews that summarize studies already included and did not provide new or different information were also excluded from this study.

References selected for inclusion are summarized in Table 1. Descriptive statistics for LL and SL are reported. For consistency within this report, the terms "whole lordosis," "total lordosis," "global lordosis," and "lumbar lordosis" are reported as "lumbar lordosis" (LL). The terms "focal lordosis," "fused segment lordosis," "index level lordosis," "disc space lordosis," and "segmental lordosis" are reported as "segmental lordosis" (SL). For studies reporting groups based on single-level or multi-level measurements, single-level values were used. For studies reporting multiple postoperative radiographic measurements or time points, data from the final follow-up were selected and summarized in this study.

Table 1
Segmental lordosis

	Static (n=111)	Expandable (n=60)	p value[#]
Low lordosis	n=27	n=21	
• Preoperative	10.35±3.33	9.39±3.55	.350
• Postoperative	13.76±6.16	14.91±6.65	.406
• p value*	**p=.001**	***p=.001***	
Moderate lordosis	n=48	n=24	
• Preoperative	19.05±2.68	18.59±2.54	.444
• Postoperative	17.33±5.40	20.36±5.50	.036
• p value*	***p=.026***	*p=.247*	
High lordosis	n=36	n=15	
• Preoperative	29.44±3.07	28.62±2.79	.457
• Postoperative	25.32±6.98	25.91±5.87	.901
• p value*	***p=.001***	*p=.078*	

Bolded text shows statistical significance.
Results are reported as mean ± SD.
[#] p value for difference between static and expandable cages.
* p value for change from pre-operatively to post-operatively.

Descriptive statistics were calculated. Weighted means and standard deviations with weighting based on number of study subjects were calculated. A meta-analysis was unable to be performed due to the high variability in data, measurement methods, follow-up intervals, and differences in radiographic parameters reported between studies.

Results

Initial search resulted in 4,036 references. With careful review, 836 duplicates were removed leaving 3,200 studies available for screening. After both investigators completed title and abstract screening and conflicts were resolved, 3,153 studies were excluded, and 47 studies were eligible for inclusion. Thirty-one studies were excluded due to: no English full-text manuscripts (9), Oral presentations or meeting proceedings (8), incorrect intervention (7), incorrect outcome variables (3), duplications not previously identified (2), full-text unable to be obtained (1), and previous literature review without new data (1). The remaining 16 reports were included in this review (Fig. 1).

There were three prospective randomized controlled trials [19–21], five case series [22–26], and eight retrospective reviews [27–34]. Studies were published between 2008 and 2017. Mean number of patients with MI-TLIF procedures was 32.0 (range 8–95). Mean follow-up period was 23.3 months (range 6–52). All MI-TLIF procedures were performed between L1–L5, with the majority occurring at L4–L5, followed by L5–S1. Eleven of 16 (69%) studies had

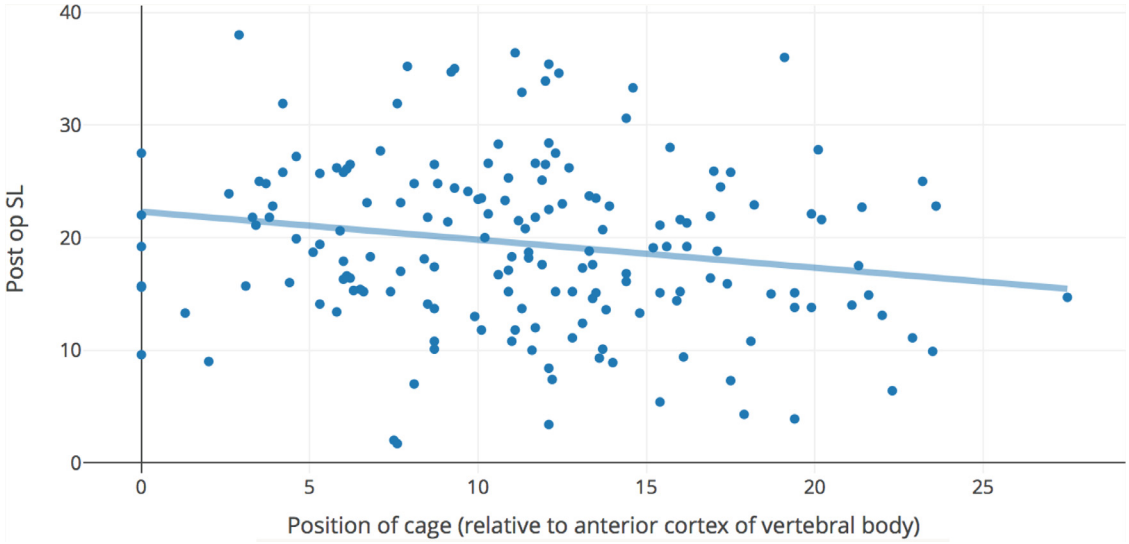

Fig. 2. Effect of cage-position on postoperative segmental lordosis (R^2=0.02, p=.067).

comparison groups. Comparison studies were based on several different study goals including: unilateral versus bilateral screw fixation (2), unilateral versus bilateral tubular access/decompression (1), MI-ALIF versus MI-TLIF (2), MI-LLIF versus MI-TLIF (1), different interbody device designs (2), and MI- versus Conventional TLIF (3) (Fig. 2).

Eleven of the 16 included studies reported on only 1-segment procedures. The remaining five studies included 2-segment and 3-segment procedures as well. One of these five studies reported their data separated by number of segments fused [33] and for the purposes of this study we reported only the 1-segment data. Three other studies appear to have the majority of their results from 1-segment disease. Kim et al. [23] had 38 out of 50 (76%) 1-segment procedures and the remainder were 2-segment. Hawasli et al. [27] had only 4 out of 44 (9%) 2-segment procedures and the remainder were 1-segment. Lindley et al. [26] reported doing 35 interbodies in 25 patients but do not specify how many segments were fused. Lastly, there was one study that included only 2- and 3-segment procedures [31].

Lumbar lordosis and segmental lordosis

Nine studies reported both LL and SL, three studies reported only LL, three studies reported only SL and one study reported only the LL and SL post-pre difference. Radiographic data from each study are summarized in Table 1. All studies except for one used lateral plain radiography for lordosis measurements. One study utilized plain radiographs or CT scans at final follow-up [25]. Weighted-mean preoperative LL was 39.6°±9.2 (range 28−57) and postoperative LL was 45.0°±7.4 (range 36−67) with a LL post-pre difference of 5.2°±5.9 (range −7 to 15). Weighted-mean preoperative SL was 12.7°±4.3 (range 5−21) and postoperative SL was 15.0°±4.5 (range 5−22) with a SL post-pre difference of 2.1°±1.7 (range 0−8) (Tables 2, 3, 4, 5, 6).

Discussion

Interbody fusion is a common procedure used to treat various spinal pathologies. Previous literature has demonstrated notable differences between interbody techniques for restoring lumbar lordosis or segmental lordosis [1]. Recently, Uribe et al. published a literature review of studies reporting preservation and restoration of spinal lordosis after various types of minimally invasive interbody procedures, including MI-ALIF, LLIF, PLIF, and TLIF [16]. Their conclusions suggest that minimally invasive procedures can impact local and regional lordosis alignment. We believe our study expands on theirs by isolating only MI-

Table 2
Lumbar lordosis

	Static (n=111)	Expandable (n=60)	p value
Low lordosis	n=27	n=21	
• Preoperative	46.86±12.64	49.27±13.27	.442
• Postoperative	48.25±11.50	48.20±12.02	.876
• p value*	p=*.773*	p=*.543*	
Moderate lordosis	n=48	n=24	
• Preoperative	56.69±9.85	56.63±10.02	.783
• Postoperative	54.70±10.74	52.33±9.48	.239
• p value*	**p=*.037***	**p=*.004***	
High lordosis	n=36	n=15	
• Preoperative	62.11±12.82	59.20±10.25	.450
• Postoperative	57.94±13.68	56.86±10.28	.634
• p value*	**p=*.003***	p=*.334*	

Bolded text shows statistical significance.
Results are reported as mean ± SD.
#p value for difference between static and expandable cages.
* p value for change from preoperatively to postoperatively.

Table 3
Posterior disc height

	Static (n=111)	Expandable (n=60)	p value
Low lordosis	n=27	n=21	
• Preoperative	6.66±1.48	3.69±1.89	**<.0001**
• Postoperative	8.36±1.91	6.78+2.35	**.022**
• p value*	**p=*.001***	**p<*.0001***	
Moderate lordosis	n=48	n=24	
• Preoperative	5.62±2.07	3.42±1.82	**<.0001**
• Postoperative	8.07±2.26	7.73±2.02	.671
• p value*	**p<*.0001***	**p<*.0001***	
High lordosis	n=36	n=15	
• Preoperative	5.76±1.80	3.77±1.68	**.001**
• Postoperative	8.52±2.47	7.95±2.09	.463
• p value*	**p<*.0001***	**p=*.001***	

Bolded text shows statistical significance.
Results are reported as mean ± SD.
#p value for difference between static and expandable cages.
* p value for change from preoperatively to postoperatively.

Table 4
Repeated measures ANOVA

	p value
Segmental lordosis	
• Low lordosis	.203
• Moderate lordosis	**.010**
• High lordosis	.476
Regional ordosis	
• Low lordosis	.393
• Moderate lordosis	.175
• High lordosis	.485
Posterior disc height	
• Low lordosis	**.035**
• Moderate lordosis	**.001**
• High lordosis	**.020**

Bolded text shows statistical significance.

TLIF procedures only and systematically analyzing all published research related to this particular technique.

This study identified 16 published reports of patients treated with MI-TLIF procedures that include radiographic LL and SL analyses. There is a high degree of heterogeneity between these studies based on design, number of patients, comparison groups, and type of interbody device used. This makes direct comparison or performing a statistical meta-analysis not feasible. Instead, this review summarizes the currently available literature and can be used as a benchmark for future study comparisons.

To our knowledge, the first report on LL and SL changes after MI-TLIF was published in 2008 by D.Y. Lee et al. [30]. They studied 27 patients retrospectively and reported 1.5° LL increase and 2.0° SL increase after MI-TLIF. In 2009, J.S. Kim studied 46 MI-TLIF cases and compared them to MI-ALIF. They reported MI-TLIF had 1.4° LL increase and 2.5° SL increase at 29.7-month follow-up [28]. In 2011, M.C. Kim et al reported on 56 patients with 32-month follow-up and demonstrated 7.4° increase in LL and 1.2° increase in SL [29]. In 2013, Min et al. reported on 69 patients at 25-month follow-up and showed a 6.6° increase in LL and 2.9° increase in SL [33]. The next year, Min and colleagues published another study on 30 patients (20 unilateral approach/decompression, 10 bilateral approach/decompression) with 18.6-month follow-up and reported an LL increase of 6.0° and SL increase of 2.6° in the unilateral group and 3.5° LL, and 0.8 SL increases in the bilateral approach group, however, these differences were not statistically significant [34]. More recently, Shen et al. published a randomized controlled trial looking for differences between unilateral versus bilateral percutaneous screw fixation [21]. Both randomized groups had MI-TLIF performed and the difference between groups was based on the type of posterior percutaneous fixation. The unilateral fixation group (31 patients) had a decrease in LL by −6.8° with a SL increase of 1.2°. The bilateral fixation group (34 patients) had a similar LL decrease of −6.1° with SL increase of 1.5°. There was no statistical difference between these groups for either LL or SL changes. In 2016, Isaacs et al. published a report comparing MI-LLIF to MI-TLIF cases and showed MI-TLIF improved LL by 2.6° and SL improved 0.3° [20]. This was not statistically different than their comparison LLIF group.

Two studies published in 2017 reported both LL and SL after MI-TLIF. Hawasli et al. conducted a study to investigate the impact of expandable interbody devices compared to static cages on lordosis, disc height, foraminal height, and pelvic parameters [27]. MI-TLIF procedures were performed in 44 subjects; 16 static cages and 28 expandable cages. They reported 4.4 LL increase and 2.3 SL increase

Table 5
Multiple regression analysis for predictors of postoperative posterior disc height (Adjusted R-square=0.247, p<.0001)

	B	S.E beta	Beta	t	p
Cage type (0=Static, 1=Expandable)	0.915	0.433	0.195	2.114	**.036**
Pre-Op total lordosis	0.007	0.021	0.038	0.328	.744
Pre-Op segmental lordosis	0.062	0.028	0.218	2.223	**.028**
Pre-Op posterior disc height	0.534	0.084	0.511	6.329	**<.0001**
Post-Op total lordosis	0.007	0.022	0.037	0.327	.744
Post-Op segmental Lordosis	−0.024	0.029	−0.080	−0.825	.411
Post-Op anterior edge of vertebra to anterior border of cage	0.042	0.033	0.111	1.265	.209

Bolded text shows statistical significance.

Table 6
Multiple regression analysis for predictors of postoperative segmental lordosis (Adjusted R-square = 0.514, p<.0001)

	B	S.E Beta	Beta	t	p
Cage type (0=Static, 1=Expandable)	1.862	1.164	0.119	1.600	.112
Pre-Op total lordosis	−0.134	0.055	−0.223	−2.444	**.016**
Pre-Op segmental lordosis	0.583	0.060	0.618	9.720	**<.0001**
Pre-Op posterior disc height	−0.033	0.252	−0.010	−0.133	.895
Post-Op total lordosis	0.281	0.053	0.447	5.255	**<.0001**
Post-Op posterior disc height	−0.172	0.209	−0.052	−0.825	.411
Post-Op anterior edge of vertebra to anterior border of cage	−0.073	0.090	−0.057	−0.811	.418

Bolded text shows statistical significance.

after static cage procedures and 4.7° and 5.2° increases, respectively, with expandable cages. Their data illustrated no difference for either cage type for LL. Expandable cages showed significantly increased disc height, foraminal height, and SL compared to static cages and these three parameters correlated with improved quality of life outcome measures. Another study published in 2017 by Lv et al. critically analyzed LL, SL, and sacral slope in MI-TLIF (50 patients) versus open TLIF procedures (56 patients) with minimum 36-month follow-up [32]. They reported 6.1° LL difference and 4.9° SL difference in the MI-TLIF cases, which was significantly different pre- to post-Op at 36 months for both parameters. In their study, both MI and open procedures had significant radiographic improvement at final follow-up and were not different between procedure types.

Among the nine studies that reported both LL and SL, some interesting relationships between pre-post differences of LL versus SL were observed. Four studies reported larger increases in SL compared to LL. In three of these studies, the SL increase was less than 1° more than the LL increase. The fourth study reported decreases in LL in both study groups of ∼6° and increases in SL ∼1°, which seems counterintuitive. We speculate that the interrelationship between SL and LL is more complicated than is captured with these two measurements alone due to multiple motion segments and possible compensatory mechanisms due to spinal stenosis and/or maintaining sagittal balance. This could be one possible explanation for why SL would increase while LL stays the same or decreases in some patients. Lastly, due to the high variability in surgical techniques, types of cages used, and differences in follow-up periods statistical comparisons between these studies and their results are limited to descriptive results only. Detailing the relationship between SL and LL among patients undergoing MI-TLIF should be investigated in future studies.

Three studies were identified that reported LL changes alone and do not report SL changes. Barbagallo et al. reported on eight patients with lytic spondylolisthesis in 2014 and showed an LL increase of 9.6° after MI-TLIF [22]. A study from 2016 published by Lee et al. examined differences between MI- (26 patients) and open- (43 patients) TLIF procedures. They found no radiographic difference at final follow-up between procedure types with MI-TLIF achieving 5.5° of LL correction [31]. The most recent study reporting LL after MI-TLIF was by Li et al. in 2017 [24]. Similar to Lee et al.'s study, they compared MI- (95 patients) versus open- (79 patients) TLIF at 54.4 months follow-up. Li reports the largest total LL increase among the studies included in this review at 14.7°. They reported no differences in LL between the MI- and Open- groups preoperatively or at final follow-up. Li et al.'s study has the largest number of MI-TLIF subjects and reports the largest increase in LL of all studies in this review.

There are three studies reporting SL without analyzing overall LL. Dahdaleh et al. published a randomized controlled trial in 2013 comparing unilateral versus bilateral posterior percutaneous fixation (similar to Shen's study). The unilateral group (16 patients) had 2.1° increase in SL, while the bilateral group (20 patients) had only 0.4° and the difference between groups was not statistically significant [19]. Lindley et al. reported on 25 patients undergoing MI-TLIF procedures and compared two groups based on using a bullet cage through a unilateral approach versus steerable cage with bilateral facetectomies [26]. The steerable cage patients had significantly more SL than the bullet cage (7.7° vs. 0.0°), however, it is unclear from their findings whether the cage type and/or differences in surgical technique (unilateral vs. bilateral facetectomies) explain the differences between groups. Lim et al. published a study comparing MI-ALIF versus MI-TLIF in 2013 which included 19 patients in the TLIF group and 32-month follow-up [25]. While they reported overall pre- and post-LL and SL measurements for the combined cohort, they reported only the differences in LL (2.1°) and SL (0.7°) for the MI-TLIF subgroup. Lastly, Kim et al. published a report in 2016 on 50 patients with 18-month follow-up and reported only a 0.1° difference in SL at final follow-up [23].

The results of this systematic review are mostly homogenous with 75% of included studies reporting results for only 1-segment procedures. There were five studies including data from multisegment procedures and from those, we reported only the 1-segment data from one study [33]. Three additional studies reported majority of 1-segment procedures, but did not separate the data based on number of segments making isolation of the 1-segment data for our study impossible [23,26,27]. One study was identified that reported only 2- and 3-segment procedures and did not include 1-segment data

[31]. Certainly, this makes interpretation of the SL and LL differences challenging. To further compound this issue, the one report of multi-segment procedures only reported LL changes and did not study SL and two of the reports with mixed 1-segment and multi-segment procedures only report SL. While full statistical analyses between 1-level and multi-level procedures cannot be accomplished given data constraints, the one study with only multi-level procedures showed on 5.5° increase in lordosis which is <5° difference than all other studies except one (Li et al. [24], 14.7° LL difference). Inclusion of multi-segment and 1-segment procedures in the same study makes full understanding of SL and LL changes difficult. The discrepancies between studies further illustrate the heterogeneity among the literature reporting radiographic outcomes after MI-TLIF procedures.

This systematic review demonstrates several important points. It is clear there is high variability within the literature for how researchers study this topic. There is variation in reporting LL and/or SL when studying MI-TLIF procedures. Most researchers have isolated 1-segment procedures, however, some reports include 1-segment and multi-segment procedures in the same analysis. Based on these findings, future studies should aim to include all relevant radiographic measurements and report data for all groups to determine potential differences. This will further broaden the number of studies reporting these important measurements as well as allow future studies to be compared to previously reported literature.

Regarding our primary research question (do MI-TLIF procedures restore lordosis?), we are guarded in our conclusion based on the published research. For LL changes, the variation ranged from −6.8° to 14.7°, with many studies reporting between 1° and 7°. It could be argued many of these findings are within the measurement error for Cobb's lordosis and may not represent a true difference [35,36]. SL had similar variability ranging from 0.1° to 8.4°, and most reports between 0° and 3°.

This study highlights the need for further investigation regarding the how MI-TLIF affects LL and SL and the clinical impact these parameters have on patient outcomes. There is currently no consensus regarding the abilities of MI-TLIF for restoring LL and/or SL. In addition, implant technology and surgical techniques may have dramatic impact on postoperative lumbar radiographic alignment complicating outcomes interpretation between studies. The published reports identified in this systematic review are mostly retrospective, have a wide sample-size range and highly variable follow-up intervals. Future, high-quality studies should aim to better define how MI-TLIF impacts segmental and global lordosis using standardized surgical techniques and research methodologies.

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