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ORIGINAL ARTICLE

In vitro comparison of endplate preparation between four mini-open interbody fusion approaches

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Abstract

Purpose Discectomy and endplate preparation are important steps in interbody fusion for ensuring sufficient arthrodesis. While modern less-invasive approaches for lumbar interbody fusion have gained in popularity, concerns exist regarding their ability to allow for adequate disc space and endplate preparation. Thus, the purpose of this study was to quantitatively and qualitatively evaluate and compare disc space and endplate preparation achieved with four less-invasive approaches for lumbar interbody fusion in cadaveric spines.

Methods A total of 24 disc spaces (48 endplates) from L2 to L5 were prepared in eight cadaveric torsos using mini-open anterior lumbar interbody fusion (mini-ALIF), minimally invasive posterior lumbar interbody fusion (MAS PLIF), minimally invasive transforaminal lumbar interbody fusion (MAS TLIF) or minimally invasive lateral, transpsoas interbody fusion (XLIF) on two specimens each, for a total of six levels and 12 endplates prepared per procedure type. Following complete discectomy and endplate preparation, spines were excised and split axially at the interbody disc spaces. Endplates were digitally photographed and evaluated using image analysis software. Area of endplate preparation was measured and qualitative evaluation was also performed to grade the quality of preparation.

Results The XLIF approach resulted in the greatest relative area of endplate preparation (58.3 %) while mini-ALIF resulted in the lowest at 35.0 %. Overall, there were no differences in percentage of preparation between cranial and caudal endplates, though this was significantly different in the XLIF group (65 vs 52 %, respectively). ALL damage was observed in 3 MAS TLIF levels. Percentage of endplate that was deemed to have complete disc removal was highest in XLIF group with 90 % compared to 65 % in MAS TLIF group, 43 % in MAS PLIF, and 40 % in mini-ALIF group. Endplate damage area was highest in the MAS TLIF group at 48 % and lowest in XLIF group at 4 %.

Conclusions These results demonstrate that adequate endplate preparation for interbody fusion can be achieved utilizing various minimally invasive approach techniques (mini-ALIF, MAS TLIF, MAS PLIF, XLIF), however, XLIF appears to provide a greater area of and more complete endplate preparation.

Keywords Endplate preparation · Minimally invasive · Lumbar · Interbody fusion

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Introduction

Lumbar interbody fusion can be an effective treatment for a variety of spinal conditions and pathologies. Typically, the goal of interbody fusion is to eliminate motion at painful segments through the placement of a cage or graft in the intervertebral disc space, which can also lead to a restoration of foraminal height, improvement in sagittal alignment, and increase in arthrodesis rates compared to instrumented posterior fusion alone [1, 2]. This ability to insert an adequately large cage or graft and have a large potential fusion mass area is highly dependent upon the amount and quality of discectomy and endplate preparation that is performed [3]. Thus, proper endplate preparation for interbody fusion typically entails thoroughly removing the disc and endplate cartilage, exposing the underlying bleeding cortical bone, while avoiding gross violation of the endplate and surrounding ligamentous structures [4].

Minimally invasive approaches for lumbar interbody fusion have been developed as an alternative to conventional, open approaches that are often associated with high rates of morbidity, as well as damage to surrounding non-pathologic soft-tissue structures. A recent study by Rihn et al. [4] found that a minimally invasive approach for transforaminal interbody fusion (TLIF) was similar to an open approach with regards to the adequacy of disc space preparation. However, with endplate preparation (both area and quality of preparation) being such an important factor to successful healing, concerns remain about the adequacy of disc space and endplate preparation possible in a variety of modern minimally invasive approaches. Thus, the goal of this study was to evaluate (both quantitatively and qualitatively) and compare disc space and endplate preparation achieved with four modern, less-invasive approaches for lumbar interbody fusion.

Methods and materials

Four less-invasive techniques for lumbar interbody fusion were evaluated in a laboratory setting on cadaveric specimens by four experienced spine surgeons, each performing disc and endplate preparation on all levels using one interbody technique. The techniques included mini-open anterior lumbar interbody fusion (mini-ALIF), minimally invasive posterior lumbar interbody fusion (MAS® PLIF; NuVasive, Inc. San Diego, CA), minimally invasive transforaminal lumbar interbody fusion (MAS TLIF; NuVasive, Inc.) and minimally invasive lateral, transpsoas interbody fusion (XLIF®, NuVasive, Inc.). Intervertebral disc spaces from L2 to L5 were prepared on eight cadaveric torsos for a total of 24 levels and 48 vertebral endplates (cranial and caudal). Each surgeon used a single interbody technique to prepare three levels each on two cadavers, for a total of six levels and 12 endplates to evaluate for each approach.

Surgical technique

Mini-ALIFs were performed using a standard Brau technique [5]. Cadaveric torsos were placed in the supine position and the spine was accessed using a midline incision. The peritoneum was mobilized and retracted to expose the anterior spinal column. Iliac vessels were separated away from the spine and discectomy and endplate preparation were performed using standard techniques.

MAS TLIFs were performed using an oblique approach to the disc space with the cadaveric torso in the prone position [6]. A paramedian incision was made and retraction was extended just enough to expose the facet joints. Facetectomy, neural retraction, and disc space preparation were then performed.

MAS PLIFs were performed similarly to a conventional PLIF, though with a medialized posterior incision and muscle-splitting access corridor. Complete or partial facetectomies and laminotomies were performed to allow access to the disc space.

The XLIF surgical technique [7, 8] involves 90° off-midline lateral access to the anterior column. The approach involves development of the lateral retroperitoneal space and blunt passage to the lateral border of the iliopsoas muscle. Once the lateral disc space is accessed, discectomy and endplate preparation were performed using standard techniques.

Following completion of the disc space preparation, lumbar spines were excised from the torsos and examined to identify any violations of the anterior longitudinal ligament (ALL). The spines were then split in the axial plane at the center of each interbody space to expose the cranial and caudal endplates. Axial digital photographs were taken of each endplate to compare quantity and quality of preparation. Image analysis software was used by third party reviewers to measure total endplate area and quantify the percentage of area prepared during disc space preparation relative to the total area of the endplate.

Statistical analysis included analysis of variance (ANOVA) with post hoc Tukey's range test to evaluate overall and pair-wise differences in mean percentages of cross-sectional area prepared between surgical groups. Time taken to prepare each disc space and preservation of ALL were also evaluated.

Photographs of each prepared endplate were also qualitatively evaluated to identify the presence of endplate violations and to determine the quality of endplate preparation as it would relate to interbody fusion. For this evaluation, a 3×3 matrix was superimposed over each endplate image, dividing it into nine areas (Fig. 1). Each area was then scored on a 3-point scale of "no endplate exposure" (0 points), "incomplete endplate exposure" (1 point), and "total endplate exposure" (2 points) for a maximum of 18 points for complete vertebral endplate preparation. A

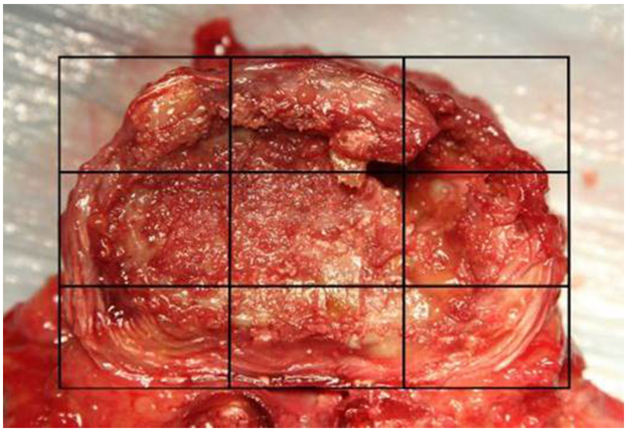

Fig. 1 Endplate 3 × 3 area subdivision

3-tiered grade of endplate preparation was given based on the combined score for each endplate. A score of 0–5 was considered “insufficient”, a score of 6–9 was considered “sufficient”, and a score of 10 and above was considered “complete” with more than half of the endplate well-prepared. Endplate violations were determined on a dichotomous scale, with an affirmative or negative assigned to each endplate with evidence of cancellous violation. Chi squared tests were performed to evaluate categorical differences between groups and alpha was set at 0.05.

Results

Quantitative results

A total of 24 levels and 48 endplates on eight specimens were prepared using four exposure techniques: MAS PLIF, MAS TLIF, mini-ALIF, and XLIF. Figure 2a–d shows the least and most prepared endplates from each approach technique. Quantitative evaluation of endplate preparation showed XLIF led to the largest relative area of preparation (58.3 %) compared to all other approach procedures, with mini-ALIF the lowest at 35.0 % (Fig. 3). Pair-wise comparisons showed that amount of endplate preparation was significantly higher for XLIF compared to all other approaches, as well as between mini-ALIF and MAS PLIF.

In general, caudal endplates were more extensively prepared (47.3 %) than cranial endplates (42.3 %). However, in mini-ALIF, MAS PLIF, and MAS TLIF groups, there were no differences in preparation between caudal and cranial endplates; however, a significant difference did exist in the XLIF group. Cranial endplates had an average of 65 % preparation compared to 52 % of caudal endplate ($p = 0.004$). Furthermore, amount of caudal and cranial endplate preparation was different between approach groups, with the highest amount of preparation achieved with XLIF and lowest with mini-ALIF ($p < 0.001$) (Fig. 4) (Table 1).

Mean disc space preparation time per level was highest for the XLIF group at 19 min, compared to 14 min for MAS PLIF, 12 min for MAS TLIF, and 8 min for mini-ALIF ($p < 0.001$). Correlation analysis showed significant correlation between percentage of endplate prepared and time spent ($R^2 = 0.275$, $p = 0.009$).

Qualitative results

ALL damage was observed in three of the 6 MAS TLIF levels. Less than 50 % of the ligament was damaged in two levels (both at L3–4) and greater than 50 % in the third

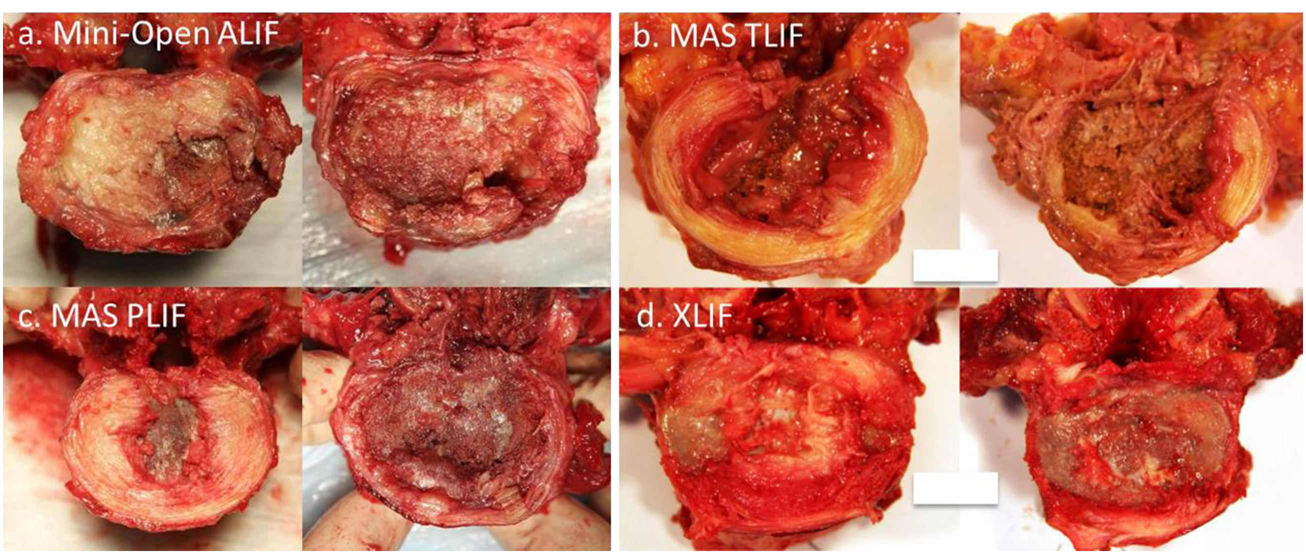

Fig. 2 Least (*left*) and most (*right*) extensively prepared endplates for each approach

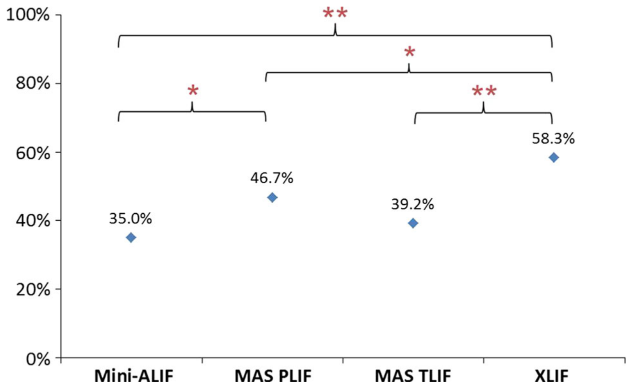

Fig. 3 Mean total endplate preparation by approach

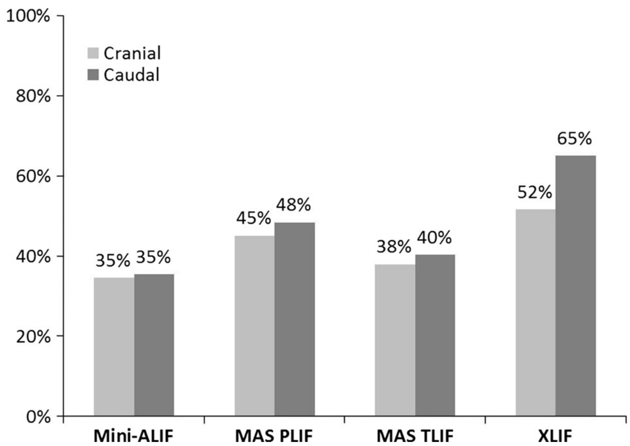

Fig. 4 Cranial versus caudal endplate preparation by approach

level (L4–5). No ALL damage was found in any of the mini-ALIF, MAS PLIF, or XLIF groups.

Percentage of endplates that were deemed to have complete disc removal was highest in the XLIF group with 90 % of endplates compared to 65 % in MAS TLIF group, 43 % in MAS PLIF, and 40 % in mini-ALIF group ($p = 0.003$) (Fig. 5). Endplate damage was highest in the MAS TLIF group at 48 % of relative endplate area damaged and lowest in XLIF group at 4 % ($p < 0.001$) (Fig. 6).

Discussion

Lumbar interbody fusion was first described for the treatment of degenerative disc disease via the anterior (ALIF) approach [9]. ALIF, while allowing for extensive access to the disc space for preparation at the lower lumbar levels, can be associated with vascular, visceral, and reproductive risks [10, 11]. It also tends to be more difficult to access from a direct anterior corridor above the L5–S1 level. The posterior approach for interbody fusion (PLIF), as originally described by Cloward, was developed as an alternative approach to the disc space by avoiding the morbidity associated with an anterior abdominal exposures. While PLIF allows for single-position decompression, interbody fusion, and supplemental fixation, the approach requires extensive muscular, bony, and ligamentous dissection and is associated with relatively high rates of postoperative neural deficits and wound complications [12]. As such, an alternative to the traditional PLIF approach was developed to utilize a unilateral transforaminal approach (TLIF) technique and reduce the morbidity associated with the open midline PLIF exposure [13]. Though the TLIF technique has grown in popularity, disadvantages of the approach include the limited access to the disc space allowing for placement of a relatively small intervertebral implant, which may not be able to resist subsidence due to a low endplate cage interface ratio [14, 15]. Restoration of lordosis can also be difficult via posterior approaches (both PLIF and TLIF) unless the interbody cage is placed far anterior, which increases the risk of ALL damage and subsequent vascular injury.

Modern minimally invasive approaches have increased in popularity in the past decade, as early proliferation of endoscopic approaches have been replaced by small incision, muscle-splitting approaches that use direct visualization and standard surgical techniques following pathologic exposure. These modern approaches include less-invasive alternatives for PLIF and TLIF, and ALIF (mini-ALIF and XLIF).

Table 1 Comparison of percent endplate exposed between approaches

	Mini-ALIF ($n = 12$)	MAS PLIF ($n = 12$)	MAS TLIF ($n = 12$)	XLIF ($n = 12$)	p-value
Endplate exposed (%) − mean ± SD					
Cranial	34.5 ± 12.2	45.1 ± 16.7	38.0 ± 7.9	51.6 ± 25.0	0.324
Caudal	35.4 ± 12.1	48.4 ± 12.4	40.3 ± 12.0	65.0 ± 5.9	**<0.001***
Endplate exposed (%) − mean ± SD					
L2-3	25.8 ± 3.5	44.9 ± 17.8	32.0 ± 7.0	69.2 ± 4.4	**<0.001***
L3-4	32.6 ± 6.1	47.8 ± 18.5	40.3 ± 9.2	65.1 ± 8.9	**0.011***
L4-5	46.6 ± 12.2	47.5 ± 8.4	45.2 ± 9.8	40.5 ± 21.0	0.906

Asterisks indicate statistically significant difference ($p < 0.05$)

SD, standard deviation; n, number of patients

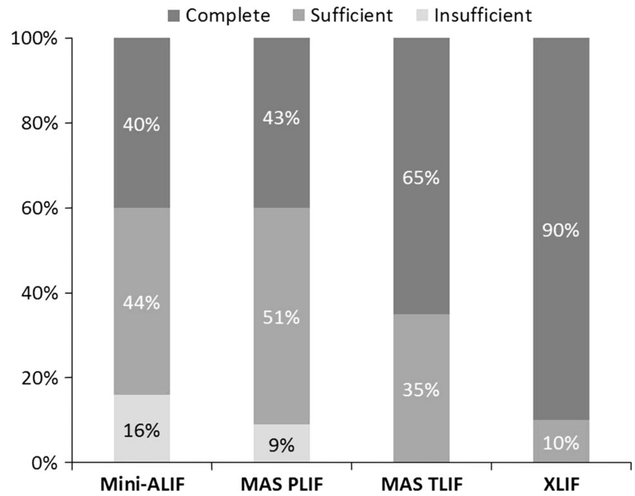

Fig. 5 Quality of endplate preparation by approach

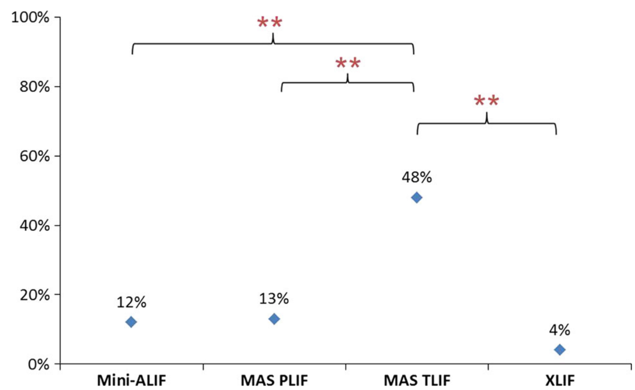

Fig. 6 Percentage endplate damage by approach

It has been well documented that the cross-sectional endplate area available for the placement of an interbody graft is an important factor for successful interbody fusion [16]. In addition to the increased surface area for the biological fusion process to occur, a greater discectomy and endplate preparation area allows for a larger bed upon which to place larger intervertebral spacers to reduce the risk of subsidence (and subsequent loss of disc height and correction), per the allowance of the surgical exposure. Despite the importance of these factors, few previous studies have directly quantitatively and qualitatively compared disc space preparation achieved with various minimally invasive or less-invasive approaches for fusion to gain information on endplate preparation characteristics.

The results of this study demonstrate that a higher percentage of disc space preparation is achieved with XLIF compared to all other approaches studied. In addition, quality of prepared endplate was also higher using XLIF, as all levels had either complete or sufficient preparation, with 90 % completely prepared. In comparison, 9 % of MAS PLIF and 16 % of mini-ALIF levels were deemed to have insufficient (<30 %) disc space preparation. Physical examination of the endplates prepared using the XLIF technique demonstrated consistent preparation of the central and lateral regions of the endplates. Furthermore, the bilateral margins of the apophyseal rings were exposed, which may allow for better implant support and prevention of graft subsidence [17]. In the current study, the XLIF, mini-ALIF, and MAS PLIF groups had similarly low incidences of endplate violation compared to the MAS TLIF group, which could translate clinically to a lower rate of graft subsidence as well as disc height and alignment maintenance. On this point, the TLIF approach had a significantly higher rate of endplate damage (48 %) and was the only procedure that demonstrated violation of the anterior longitudinal ligament. This presence of endplate and ALL violation in the MAS TLIF technique alone may suggest that an overly aggressive technique was undertaken, though may also suggest that the limited working window challenges maneuvering during the discectomy.

Limitations of the current study include the use of cadaveric torsos with varying degrees of bone quality and a relatively small sample size per procedural group. In the XLIF group, there were several specific limitations. First, the specimens studied did not have lower or upper extremities, nor did the tables have the ability to break, so taping and laterally bending the spine for exposure was not possible, which likely limited exposure to the L4–5 level. Also, at the time of the study angled surgical instruments—to facilitate a parallel working space at L4–5—had yet to be introduced so were not used. These factors may have negatively influenced the disc space preparation potential, and is likely why caudal endplate preparation was less extensive compared to cranial endplates. In the mini-ALIF group, L2–3 and L3–4 are not common levels to be treated. The position of the great vessels, even in a cadaveric setting, may have limited access to these disc spaces and, in turn, limited the ability of a more robust endplate preparation in this group. While choice of procedure performed by each surgeon was chosen based on individual skill and experience with each technique, differences between surgeons in surgical technique and thoroughness in endplate preparation likely exist and should also be considered. But as the intent of the study was to evaluate findings in surgeons with significant procedural experience (e.g., learning curve), we feel this consideration would have been a larger concern had surgeons been performing procedures not in their regular rotation. Finally, time to prepare endplates was positively correlated with extent of preparation achieved. This could be interpreted as a confounding factor (e.g., the more time spend preparing the disc space, the more disc is prepared), but also must be an artifact of the access corridor and disc space exposure afforded by each procedure. For instance, with an approach that allows for a broader disc exposure, it stands to reason that it would take longer to remove more disc. Unfortunately, decoupling of these two variables to examine whether or not time or procedure type were independently factors of endplate preparation was not possible and, given the results, appear to these authors that the approach used is the salient factor in the amount of (and time required for) disc space preparation. Despite these shortcomings, to our knowledge, this is the first study to directly and comparatively quantify and qualify endplate preparation between various modern less-invasive approaches for lumbar interbody fusion.

Conclusions

These results demonstrate that adequate endplate preparation for interbody fusion can be achieved utilizing various minimally invasive approach techniques (mini-ALIF, MAS TLIF, MAS PLIF, XLIF), however, XLIF provides a greater area and more complete endplate preparation.

Conflict of interest Dr Tatsumi is a consultant for NuVasive, Inc., Dr. Lee has no conflicts to report, Dr. Khajavi receives honoraria from and is a consultant for NuVasive, Inc., Dr. Taylor receives royalties from and is a consultant for NuVasive, Inc., Dr. Chen has no conflicts to report, and Dr. Bae is a consultant for and receives royalties from NuVasive, Inc.

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