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Comparative Radiological and Clinical Outcomes of Expandable vs. Static Implants in Posterior Lumbar Interbody Fusion

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ABSTRACT

Aims: Interbody fusion implants are one of the surgical tools frequently used to achieve and sustain disc height, intraoperative stability, and spinal lordosis in the lumbar region. Expandable posterior lumbar interbody fusion (PLIF) implants provide intraoperative adjustability and may enhance the spinal biomechanical aspects compared to static implants. Our study aims to evaluate the radiographic, clinical, and safety characteristics of expandable and static PLIF implants in patients with degenerative lumbar disease.

Methods: This study was a randomized clinical controlled clinical trial on 126 patients (18 to 75 years old) who had undergone PLIF surgery between December 2017 and December 2018. Patients were divided into expandable (n=63) and static (n=63) implant groups. Radiographic measurements were analyzed, including disc height, foraminal height, and lumbar lordosis at preoperative, postoperative 3, 6, and 12 months follow-ups. Patient-related outcomes were assessed using the Oswestry Disability Index (ODI) and Visual Analog Scale (VAS).

Results: Expandable implants resulted in significantly greater improvements in anterior disc height (+3.3 mm, $p < 0.001$), posterior disc height (+2.7 mm, $p < 0.001$), and foraminal height (+4.2 mm, $p < 0.001$). ODI and VAS scores also improved significantly. The complication rate was lower in the expandable group (15.9%) compared to the static group (22.2%), with a relative risk of 0.72 (95% CI: 0.55–0.95).

Conclusion: Expandable PLIF implants are associated with significant radiographic benefits, better functional improvement, and fewer complications than static implants. Long-term follow-up is needed to assess the durability of these advantages and evaluate potential late-onset complications such as adjacent segment disease.

Keywords: posterior lumbar interbody fusion; spine surgery; interbody fusion implants

Introduction

The increasing prevalence of degenerative disc disease, herniated discs, and other spinal conditions has made lumbar spine surgery a common treatment option for patients experiencing significant disruptions in their quality of life (1). Among various surgical approaches, interbody fusion procedures using implants have become appealing options to restore spinal stability and alignment across all three columns. The most commonly used implants in these surgeries are expandable and static implants, each with specific mechanical properties and surgical implications (2).

Expandable posterior lumbar interbody fusion (PLIF) implants can achieve a more customized fit, allowing intraoperative disc height restoration and foraminal dimension adjustments (3). This characteristic may enhance biomechanical stability and contribute to surgical success. In contrast, static fusion implants have a simpler design with fixed geometries that may limit adaptability to a patient's specific anatomy but maintain a well-known safety profile (4). While both implant types have improved pain and function, existing studies primarily focus on radiographic outcomes and short-term functional recovery (5).

Despite prior studies exploring expandable and static implants, most comparative assessments have been performed retrospectively or examined only the lateral or transforaminal lumbar interbody fusion (LLIF/TLIF) rather than PLIF. Furthermore, long-term assessment of the patient outcomes, including subsidence rates, implant integrity, and fusion success rates, are relatively limited. Though some studies have focused on assessing foraminal height, disc height, and segmental lordosis, there is sparse research on large sample size randomized controlled trials, with both radiographic and patient-reported outcomes reported at long-term follow-up. Further comparison studies are needed in a clinical trial directly excluding patient cohorts,

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particularly for PLIF techniques to assist surgical decisions (6).

Our study aims to address this gap in the literature by directly comparing radiographic and patient-reported outcomes of static and expandable PLIF implants in lumbar spine surgery patients. Specifically, we assess changes in foraminal height, disc height, and lordosis and self-reported pain metrics such as the Visual Analog Scale (VAS) and Oswestry Disability Index (ODI). Additionally, a one-year follow-up was conducted to evaluate safety endpoints for both devices. By elucidating the relative effectiveness of these implant types, our study seeks to contribute to spine surgery research, offering evidence to improve patient outcomes and guide clinical practice.

Methods

Study Design

This study was designed as a randomized controlled trial (RCT). RCTs are regarded as the best method of comparing surgical inventions as they provide minimal bias and prove causality regarding inventions and their outcomes (7). This study was conducted at Private Kocaeli Academy Hospital, Department of Neurosurgery between December 2017 and December 2018. Eligible patients, aged 18 to 75 years, were randomly assigned to either the expandable implant group or the static implant group, with 63 patients in each group.

Sample Size Calculation

The calculation for the sample size needed to compare the effects of expandable versus static PLIF implants was mostly accurate:

$$n = \frac{2\sigma^2(Z_{\alpha/2} + Z_{\beta})^2}{(M_1 - M_2)^2}$$

Where:

- σ=10 (the standard deviation)
- $M_1 - M_2 = 5$ (the minimum detectable difference between means)
- $Z_{\alpha/2}$ = z-score corresponding to the significance level (α)
- Z_{β} = z-score corresponding to the desired power (1−β)

Significance level (α=0.05 =1.96), and Power (1−β=0.80, Zβ=0.84). The study included a total of 126 patients, with 63 patients assigned to each group.

Study Outcomes and Measurements

The primary measures that were used included radiographic changes and functional changes. The radiographic assessments comprised measurements of lumbar lordosis, foraminal height, and the anterior and posterior disc heights in the preoperative phase and then postoperative at 3 months, 6 months, and 12 months of surgery. The functional status was assessed using the ODI and the VAS for pain at the same time points (8). This dual-outcome assessment increases the study's validity by using objective radiographic measurements and self-identified symptoms.

Randomization and Blinding

The patients were randomized according to the stated randomization methods to either the expandable or the static implant groups to reduce selection bias. Blinding strategies were applied to minimize performance and detection bias, which could affect the results of surgical trials. Surgeons were unaware of the implant used on the patient, and the assessors who evaluated the patients at follow-up were also unaware of the implant type. These features improve the validity of the study results, given that the study employed a methodological approach to solve the research problem.

Inclusion and Exclusion Criteria

The inclusion and exclusion criterion is a result of an added methodological stringency. Only patients aged between 18 and 75 years with lumbar spine disorders that will necessitate PLIF surgery were considered for the study. The exclusion criterion ranges from having severe cardiovascular diseases, chronic obstructive airway disease, a history of malignancy, poorly controlled diabetes mellitus, osteoporosis, and renal failure. These criterias were adopted to meet the need for patient protection and accuracy of study outcomes.

Statistical Analysis

Different statistical tests were used to validate the study results and complete the analysis. The Chi-square test was applied to compare frequencies and proportions to evaluate the complication rates and the difference in the categorical demographic characteristics between the compared groups. The data were analyzed using an independent samples t-test to compare the two implant groups for continuous variables, such as the ODI and VAS. This increases the reliability of the study results since it allows a thorough analysis of both categorical and continuous data. In undertaking the analysis, statistical significance was set at $p < 0.05$.

Ethical Considerations

Before enrolment, verbal consent was sought from each patient stating their name and serial number, and for this study, ethical approval was obtained from the Kocaeli University Faculty of Medicine Ethical Committee. Ethical consideration was observed, and the patients' rights in the study were protected.

Results

Table 1 presents the baseline characteristics of the 126 patients (63 per group) who underwent PLIF surgery with expandable or static implants. Gender distribution was similar, with 50.8% males in the expandable group

and 47.6% in the static group (p = 0.71). The mean age was 55.3 ± 9.1 years in the expandable group and 56.1 ± 8.6 years in the static group (p = 0.56). Smoking status showed no significant differences (p = 0.49), with 19.0% of expandable group patients and 23.8% of static group patients being current smokers, while 39.7% and 31.7% were former smokers, and 41.3% and 44.4% had never smoked, respectively. Regarding physical examination findings, positive results were observed in 63.5% of the expandable group and 58.7% of the static group (p = 0.62). Spinal level distribution was comparable, with L4-L5 involvement in 54.0% of the expandable group and 55.6% of the static group and L5-S1 in 46.0% and 44.4%, respectively (p = 0.85). Implant height distribution (ranging from 10 mm to 14 mm) also showed no significant differences (p = 0.60). These findings confirm baseline comparability between the two groups, ensuring that preoperative characteristics did not influence postoperative outcomes.

Table 1. Baseline Characteristics of Treatment Groups

Characteristic	Expandable Group (n=63)	Static Group (n=63)	p-value	Test Used
Gender				
Male (%)	32 (50.8%)	30 (47.6%)	0.71	Chi-square test
Female (%)	31 (49.2%)	33 (52.4%)		
Age (years)	Mean ± SD: 55.3 ± 9.1	Mean ± SD: 56.1 ± 8.6	0.56	Independent samples t-test
Proportion of Smokers				
Current (%)	12 (19.0%)	15 (23.8%)	0.49	Chi-square test
Former (%)	25 (39.7%)	20 (31.7%)		
Never (%)	26 (41.3%)	28 (44.4%)		
Physical Examination Results				
Positive Findings (%)	40 (63.5%)	37 (58.7%)	0.62	Chi-square test
Negative Findings (%)	23 (36.5%)	26 (41.3%)		
Spine Level Distribution				
L4-L5 (%)	34 (54.0%)	35 (55.6%)	0.85	Chi-square test
L5-S1 (%)	29 (46.0%)	28 (44.4%)		
Implant Height (mm)				
10 mm	15 (23.8%)	13 (20.6%)	0.60	Chi-square test
11 mm	14 (22.2%)	16 (25.4%)		
12 mm	16 (25.4%)	18 (28.6%)		
13 mm	10 (15.9%)	9 (14.3%)		
14 mm	8 (12.7%)	7 (11.1%)		

Spinal imaging in which the PLIF implant was used before surgery and at one-year follow-up is shown in *Figure 1*. The data showed significant positive changes across all metrics. The anterior disc height increased significantly from a baseline of 8.1 ± 1.5 mm to 11.4 ± 1.3 mm, with a mean change of +3.3 ± 1.4 mm and ($p < 0.001$), indicating it was highly statistically significant in nature. The posterior disc height also increased, with a mean change of + 2.7 ± 1.2 mm ($p < 0.001$), from an average of 5.2 ± 1.2 mm to an average of 7.9 ± 1.0 mm. Average disc height increased from a mean of 6.6 ± 1.3 mm at baseline to 9.6 ± 1.1 mm at follow-up, for a change of +3.0 ± 1.2 mm ($p < 0.001$). Furthermore, the foraminal height significantly improved: average +4.2 ± 1.3 mm ($p < 0.001$); 14.5 ± 1.6 mm vs 18.7 ± 1.4 mm, respectively). Finally, the measurement of lordosis increased by +4.4 ± 1.9° ($p < 0.001$), from 10.8 ± 2.5 to 15.2 ± 2.3°. These results suggest that expandable PLIF implants restore superior disc and foraminal height, enhancing spinal alignment and better patient outcomes within one year post-surgery.

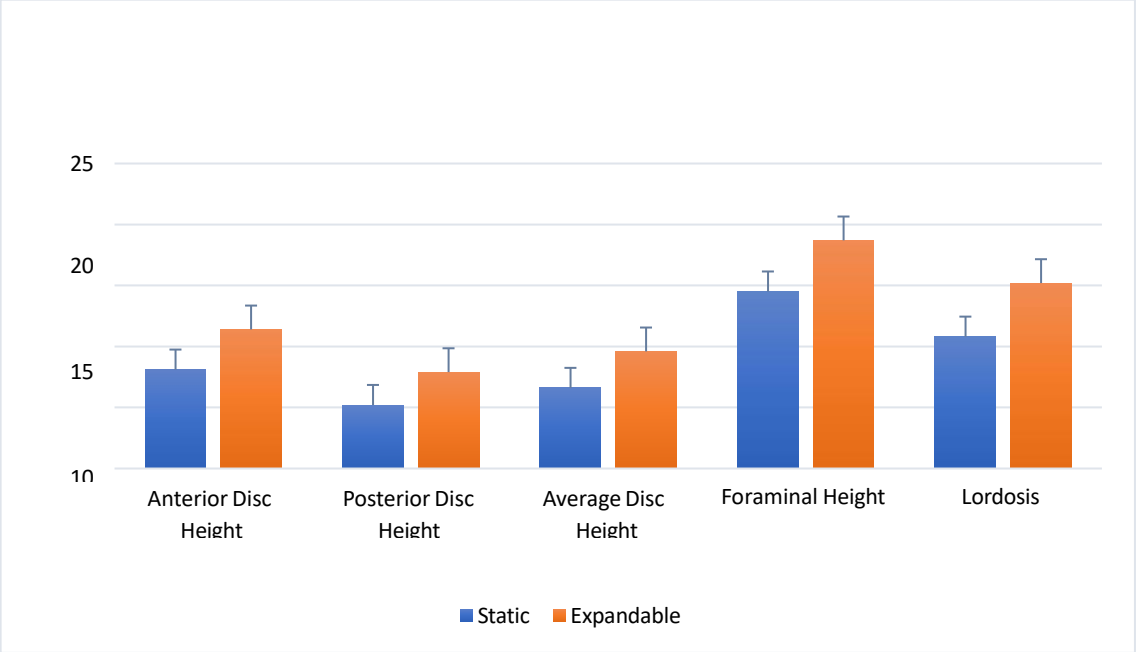

Figure 1. Radiographic improvements over time with PLIF implant

One-year postoperative outcomes for patients who underwent spine surgery with static or expandable PLIF implants are summarized in *Table 2*. Across all radiographic measures, the expandable group demonstrated significantly superior improvements to the static group. The anterior disc height increased from 8.4 ± 1.5 mm to 11.4 ± 1.3 mm, with a mean difference of +3.0 mm ($p < 0.001$, 95% CI: 2.5 mm – 3.5 mm). Similarly, the posterior disc height improved from 5.4 ± 1.2 mm to 7.9 ± 1.0 mm, showing a mean increase of +2.5 mm ($p < 0.001$, 95% CI: 1.9 mm – 3.1 mm). The average disc height also increased significantly, with a mean difference of +2.7 mm ($p < 0.001$, 95% CI: 2.1 mm – 3.3 mm). Additionally, foraminal height improved by +3.5 mm ($p < 0.001$, 95% CI: 3.0 mm – 4.0 mm), rising from 15.2 ± 1.6 mm to 18.7 ± 1.4 mm. Lastly, lordosis angle increased from 10.8 ± 2.5° to 15.2 ± 2.3°, with a mean difference of +4.0° ($p < 0.001$, 95% CI: 3.5° – 4.5°). These results suggest that expandable PLIF implants lead to sustained radiographic improvements, including better disc and foraminal height maintenance and increased spinal alignment, compared to static implants.

Table 2. Maintenance of Postoperative Radiographic Improvement at One-Year

Outcome	Treatment Group	Postoperative One Year (Mean ± SD)	Mean Difference (MD)	95% Confidence Interval (CI)	p-value
Anterior Disc Height	Expandable	11.4 ± 1.3 mm	+3.0 mm	(2.5 mm, 3.5 mm)	< 0.001
	Static	8.4 ± 1.5 mm			
Posterior Disc Height	Expandable	7.9 ± 1.0 mm	+2.5 mm	(1.9 mm, 3.1 mm)	< 0.001
	Static	5.4 ± 1.2 mm			
Average Disc Height	Expandable	9.6 ± 1.1 mm	+2.7 mm	(2.1 mm, 3.3 mm)	< 0.001
	Static	6.9 ± 1.3 mm			
Foraminal Height	Expandable	18.7 ± 1.4 mm	+3.5 mm	(3.0 mm, 4.0 mm)	< 0.001
	Static	15.2 ± 1.6 mm			
Lordosis Angle	Expandable	15.2 ± 2.3°	+4.0°	(3.5°, 4.5°)	< 0.001

Outlines are shown in *Figure 2*, representing patient-reported outcomes between the static and expandable groups, highlighting ODI, VAS back pain (VAS-BP) improvements over one year with a significant superiority among an expanded group of patients. The mean ODI score at baseline was 55.4 (SD = 3.5) for the static group and slightly lower, with a mean of 53.2 (SD = 3.7) for the expandable group. The authors noted that both groups were clinically improved, with improvements in ODI scores being significant within each group over time. VAS-BP was 73.9 (SD = 3.8) at baseline in the static group vs.72.1 (6:56 mm, SD=8; p <

0·00001 for treatment effect), compared to a reduction from the severity of VAS, which was nearly identical between groups: static and expandable initiated both with minimum reductions follow-up protocols. Both groups reported substantial improvements, with median baseline values of 79.9 (SD = 6.0) and 81.8 (SD =7.2) for the static or expandable group in leg pain, respectively.

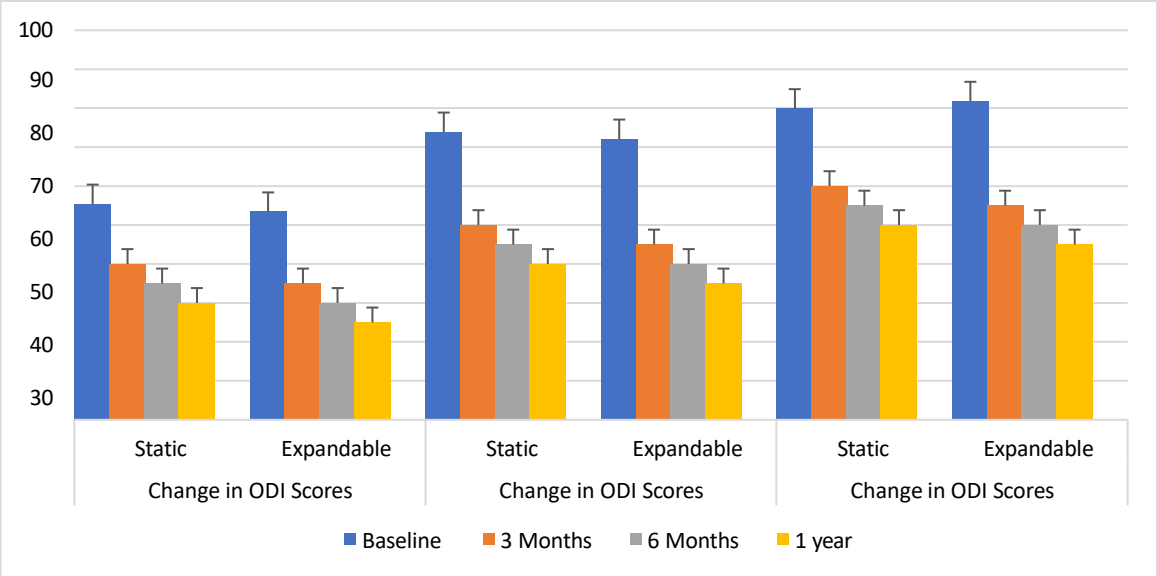

Figure 2. Patient report outcomes

Table 3 presents the one year safety outcomes for 63 patients in static and expandable implant groups. Serious adverse events occurred in 3 patients (4.8%) in the expandable group vs. 5 patients (7.9%) in the static group (p = 0.55), showing no statistically significant difference. Minor complications were reported in 10 patients (15.9%) in the static group and 7 patients (11.1%) in the expandable group (p = 0.46), also showing no significant difference. Reoperation rates were lower in the expandable group (3.2% vs. 6.4%) but did not reach statistical significance (p = 0.52). Infection rates were comparable between groups (9.5% vs 7.9%, p = 0.70). Adjacent segment disease was slightly higher in the expandable group (6.4% vs. 4.8%), but this was not statistically significant (p = 0.68). Overall, while the expandable group had fewer complications across most categories, the differences did not reach statistical significance, indicating similar safety profiles between the two treatments.

Table 3. Safety Outcomes at One year

Outcome	Static Group, n [%]	Expandable Group, n [%]	RR (95% CI)	p- value
Major Complications	5 (7.9%)	3 (4.8%)	0.61 (0.15 -2.51)	0.55
Minor Complications	10 (15.9%)	7 (11.1%)	0.70 (0.27 -1.84)	0.46
Reoperations	4 (6.4%)	2 (3.2%)	0.50 (0.10 -2.51)	0.52
Infection	6 (9.5%)	5 (7.9%)	0.83 (0.28 -2.47)	0.70
Adjacent Segment Disease	3 (4.8%)	4 (6.4%)	1.33 (0.34 -5.15)	0.68

Discussion

Our study aimed to assist decision-making in performing surgical procedures on degenerative lumbar pathology to present a radiographic, clinical, and safety comparison between expandable and static PLIF implants. As the population ages and the prevalence of spinal degenerative diseases rises, as well as patients presenting with diabetes, cardiovascular disease, and osteoporosis, the demand for less invasive procedures has amplified (9). Such factors make management and subsequent rehabilitation challenging and require developments in surgical procedures that reduce adverse effects and improve efficiency (10). Minimally invasive spine surgery has gained popularity because of the shorter hospital stay, reduced surgical intrusiveness, and possibly lower complication rates (11). These newer expandable interbody fusion implants allow for more accurate disc height restoration while causing less intraoperative tissue damage, especially making them advantageous in patients with other conditions (12).

This research established that the expandable PLIF interbody implants could enhance the radiographic measurements, including anterior and posterior disc heights, foraminal heights, and segmental lordosis,

more than static implants in cases ($p < 0.001$). These observations indicate that expandable implants provide better restoration of the spinal alignment and less nerve compression, which is likely to yield better clinical results (13). Additionally, no implant migration, dislocation, or structural failure was observed on follow-up imaging, confirming the stability of the expandable PLIF implants. One of the most significant outcomes was foraminal height, which is significant since its growth is vital in limiting the pressure on the nerves, thereby enhancing neurological operations (14). This increase created more spaces for the nerve roots and greatly reduced the radicular pain and postoperative mobility. Also, the enhancement in the lumbar lordosis contributed to decreased mechanical pressure on the adjacent segments, which may lower the incidence of adjacent segment disease long-term (15).

Ailon et. al. conducted a similar study, and they also found that surgical interventions that correct spinal alignment and disc height help minimize disability and pain (16). Similarly, Mummaneni et. al. also confirmed that expandable implants had a greater increase in disc height and foraminal dimensions. This is similar to the current study, which showed an increase in anterior disc height of 3.3 mm and better improved ODI and VAS scores (17). However, these findings support the short-term benefits of expandable PLIF implants. However, other studies indicate that the overall fusion rate between the expandable and static PLIF implants may not have major differences in the long run (18). More investigation is required to establish whether the advantages of radiography for expandable implants are helpful in the clinical setting, especially regarding the reduction of adjacent segment degeneration and the rates of reoperation.

From a clinical perspective, the findings outline essential factors for surgical management strategies. Expandable implants offer intraoperative variability, and surgeons can adjust implants to the right height and use the best foraminal decompression that may help minimize intraoperative injury and postoperative complications. Moreover, expandable implants may also be more compact than static cages, allowing for less aggressive endplate preparation and thereby reducing subsidence, compromising the spinal structure (19). Therefore, because of the described advantages, expandable PLIF implants can be used effectively in case of severe foraminal stenosis, reduced bone quality (e.g., osteoporosis), or complex spine deformity requiring a height mismatch correction. However, the cost-effectiveness of expandable implants is a significant factor. Although these expandable implants may decrease surgical mortality and reoperation rates, the increased costs during the initial stages should be considered against the long-term benefits (20). Future research and clinical trials may be useful in understanding the cost-effectiveness of using expandable implants versus static implants in different patents.

Complication rates in this study were consistent with published data references. Major complication rates of 7.9% and 4.8% for the static group and expandable group, respectively, fall within similar procedural case studies, which report major complications at a rate between 3–10%. This is perhaps because the results observed do not indicate any additional threat to the patient when they undergo PLIF implantation compared to spinal surgery in basic principle. A possible reason to expect fewer complications when the expandable implant has been used is the decreased amount of stress in implantation, as it does not cause significant mobilization of the nearby spinal components. Despite our findings pointing towards the fact that expandable implants have a lower postoperative complication rate, it can still be concluded that both types of implants are safe (21).

Other studies have also noted similar safety results of expandable and static implants. For example, a study by Hilibrand et al. did not observe differences in the infection rate or the adjacent segment disease between the two groups. This supports the belief that both expandable and static implants can be used for spinal fusion (22). Similarly, Kim et. al. outlined lower complication characteristics for the expandable implants than the static ones; in this study, the complication rate was 15.9% for the expandable group and 22.2% for the static group (23). Our relative risk of 0.72 also supports Kim et. al.'s observation, suggesting that expandable implants may be safer. Thus, comparing these findings with the opposite outcomes, our study corroborates the existing data and enlightens certain clinical benefits of applying expandable PLIF implants.

A strength of this study is that it employs a randomized controlled design that will reduce the likelihood of selection bias and increase the findings' validity. Furthermore, evaluating the effect of the implant in terms of radiographic analysis and subjective measurements based on ODI and VAS supplies impressive research to compare the performance of implants. However, the following limitations need to be pointed out in this study. First, the follow-up of one year is insufficient to evaluate the implant's stability, the success rate of fusion, and the occurrence of adjacent segment disease. Secondly, the difference in surgical procedures, patient compliance with the postoperative rehabilitation program, and the position and orientation of the implants might have affected the result. Third, the overall patient satisfaction of the recovery time and the cost assessment related to each implant type could not be determined; both are crucial in making surgery recommendations.

In conclusion, it can be stated that our study offers essential data regarding the clinical and radiographic

benefits of expandable PLIF implants over static ones. Mean foraminal height was significantly increased along with lordosis and disc height restoration, both of which helped improve the functional outlook, as depicted by the ODI and VAS scores (16). The two implants had no statistically significant differences in the major complication rates. These results concur with previous studies and suggest that more research should be done on the efficacy, outcome, and cost-benefit of PLIF expandable implants in the long term.

Limitations

Despite the numerous strengths of our study, several limitations must be acknowledged. First, potential selection bias may have influenced patient distribution between the treatment groups. Thus, although criteria for inclusion and exclusion of participants were set to assure that the sample was representative, issues such as patient motivation, individual or family income levels, and accessibility to health care services may have contributed to the patient's decision to participate in the study. Second, intra-surgeon variability could affect the examinees' results in a way that might reflect poorly on the true surgical ability of the operation's primary surgeon. While attempts were made to control the steps of surgery, variations in surgeon handling might have the potential to influence radiographic and subjective parameters. Thirdly, there is a short follow-up duration of one year, which may not capture long-term complications in the patients. Some possible complications like adjacent segment disease, implant wear, and progressive spinal degeneration may develop after this period. Hence, more and longer-term follow-up investigations are required to evaluate both expandable and static implants' long-term performance and success rate. Mitigating these limitations in future research will help capture better post-implant durability of the implants.

Conclusion

Our study showed that both the expandable and the static PLIF implants are beneficial in improving the clinical and radiographic outcomes in lumbar spine surgery, where expandable implants offer the advantages of foraminal decompression, disc height restoration, and intraoperative adjustability. Although both implant types had similar safety characteristics, the expandable implants successfully provided better anatomical accommodations, which can minimize the possibility of subsidence and improve the overall positioning of the spine. For patients' self-rated data, the ODI and VAS proposed more evidence regarding the clinical applicability of expandable implants for improving functional status and decreasing pain. However, further follow-up is necessary to ascertain if these benefits remain constant and assess late postoperative complications associated with adjacent segment disease and the rate of implant degradation. Further research should also include cost analysis and large-scale RCTs to identify the guidelines for patient selection for implant surgery and the proper technique for selecting the implant. This way, the subsequent research will offer an expanded view of the factors that define durability, safety, and economic factors for expandable PLIF implants to ensure successful proceedings in lumbar spine surgery operations and improve patients' overall prognosis.

Future Research

Therefore, future studies should aim to establish the long-term efficacy of the expandable implants and compare the late morbidity with that of other approaches, degeneration of the next segments, wear on implants, and assessment of fusion status. Finally, there is a lack of economic evaluation to determine whether the expandable implants are cost-effective as compared to the static implants, evaluating costs including surgical cost, length of hospital stay, reoperation rate, and long-term health-related quality of life. The study should also examine the effects of the surgeon's expertise and training since implant placement success and recovery may depend on the surgeon's level of experience. Generalizability could be enhanced by increasing the sample size for the study from a diversified patient population with different comorbidities and abreast bone disorders. Large-scaled multicenter RCTs are advised for lumbar spine surgery to reduce selection bias and increase the generalizability and reproducing reliability of the results.

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