Original Article

A single straight expandable cage via a hybrid posterior-transforaminal approach with rhBMP-2 or allograft provides high fusion rates with low risk of subsidence

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Background: Due to the ongoing debate surrounding the clinical impact of surgical technique; cage type (expandable *vs.* static), cage shape (straight *vs.* banana), or technique [posterior lumbar interbody fusion (PLIF) *vs.* transforaminal lumbar interbody fusion (TLIF)], the aim of this study was to evaluate the mid-term clinical and radiographic outcomes of patients who underwent a hybrid posterior-TLIF (P-TLIF) with a single straight expandable titanium cage using recombinant human bone morphogenetic protein-2 (rhBMP-2) or demineralised bone allograft (DBA) bone substitute.

Methods: A retrospective analysis of data from consecutive patients who underwent a hybrid P-TLIF by a senior spine surgeon between August 2017 and May 2022. A single straight expandable interbody cage was inserted obliquely after laminectomy and bilateral facetectomies. Cages were packed with either rhBMP-2 or DBA. Consecutive patients received rhBMP-2 prior to withdrawal (Australia, March 2020), and then DBA was used. Patient-reported outcome measures (PROMs) included visual analogue scale (VAS) back and leg pain, Oswestry disability index (ODI) and 12-Item Short Form Survey (SF-12) measured at preoperative, postoperative 6-week, 6-month, 12-month, and 24-month. Computed tomography (CT) imaging, assessed by an independent radiologist, was conducted postoperative day-2 for instrumentation positioning then at either 6-, 12-, or 24-month to assess subsidence and interbody/posterolateral fusion (Bridwell classification). If fusion was achieved no further CTs were undertaken.

Results: This cohort consisted of 81 (54.3% female) patients with a mean age of 57.3±12.5 years. rhBMP-2 was used in 60 (74.1%) and DBA in 21 (25.9%) patients. Total clinical complication rate was 27.2% including five patients requiring reoperation. Asymptomatic radiologic subsidence rate was 7.4% and clinical subsidence rate was 1.2%. Total (interbody and posterolateral) fusion was achieved at 6-month in 34.4% and 55.7%, 12-month in 76.8% and 88.4%, and 24-month in 86.3% and 93.2% of patients. There was a non-significant difference in fusion rates at each timepoint between rhBMP-2 and DBA. Preoperative pain, disability, and function all significantly improved postoperatively. Mean VAS back/leg (7.8±0.8,

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7.7±0.9), and ODI (35.8±6.6) significantly (P<0.001) decreased (2.7±1.8, 1.9±2.3, 13.6±5.8); SF-12 physical/mental (27.4±3.8)/(38.1±8.3) showed significant improvements (P<0.001) at 12-month follow-up (47.1±8.8, 52.1±8.7). The mean follow-up time was 20.3±6.1 [12–24] months.

Conclusions: A hybrid P-TLIF with a single straight titanium expandable cage permitted safe cage insertion, guided repositioning, and controlled expansion. Patients demonstrated significant improvements in pain, disability and function with low subsidence and high CT fusion rates over 24-month follow-up. The use of DBA in this cohort showed no significant difference in fusion rates across 24-month when compared to rhBMP-2.

Keywords: Computed tomography (CT); expandable cage; posterior; transforaminal; lumbar interbody fusion

Submitted Jul 10, 2024. Accepted for publication Nov 15, 2024. Published online Feb 12, 2025.
doi: 10.21037/jss-24-82
View this article at: https://dx.doi.org/10.21037/jss-24-82

Introduction

Degenerative disc disease (DDD) pathologies are a common cause of low back pain affecting up to 16% of the Australian adult population (1). Up to 5% of these patients do not respond to conventional treatment and may be candidates for appropriate surgical intervention (2).

Posterior lumbar interbody fusion (PLIF), first described in 1944, allows for open bilateral neural decompression and bilateral cage insertion for treatment of DDD (3-6). In 1982, transforaminal lumbar interbody fusion (TLIF) was first reported allowing for a unilateral facetectomy and decompression with a single interbody cage (7). Both PLIF and TLIF allow for potential 360° fusion using a single incision (5,7,8). There is also a contemporary hybrid posterior-TLIF (P-TLIF) with uni- or bilateral facetectomies and uni- or bilateral decompression using either a single straight or banana-shaped cage, with no consensus on cage shape superiority or technique (3,5,9).

Interbody devices promote fusion between vertebral endplates, contain graft and assist in restoring lumbar lordosis and anterior column support (10). Static cages with a fixed height and angle of lordosis created an appropriate scaffold for fusion. However, the insertion of static cages can cause iatrogenic endplate damage including microtrauma/fractures due to repeated trialling and the forceful impaction required at the time of insertion. The resultant damage to the endplate can then lead to subsidence or cage-migration post-surgery, potentially causing recurrent pain and re-operation (11,12).

New generation expandable titanium cages were designed to provide more individuality with correction of spinal alignment to reduce device related complications inherent with static cage design, while providing radiographic and clinical benefit (13,14). Multidimensional cage expansion optimises axial surface area. It also facilitates superior graft packing and permits backfilling of biologic material to optimise fusion (15). Insertion of expandable cages at a

Highlight box

Key findings

- Significant improvements in pain, disability and function.
- Low subsidence and high computed tomography fusion rates over 24-month follow-up.
- No significant differences in fusion rates across 24-month when demineralised bone allograft was compared to recombinant human bone morphogenic protein 2.

What is known and what is new?

- A straight expandable interbody cage has benefits of lower rates of iatrogenic endplate damage, subsidence, retropulsion, and better restoration of disc height.
- Our contemporary hybrid posterior-transforaminal lumbar interbody fusion (TLIF) approach inserting a single straight titanium expandable cage packed with bone graft after a laminectomy and bilateral facetectomies permitted safe cage insertion, guided repositioning, and controlled expansion. It combined the benefits of both a conventional posterior lumbar interbody fusion and TLIF approach, allowing for 360° fusion, bilateral neural decompression, positioning of an easily expandable straight cage.

What is the implication, and what should change now?

- Surgeons should consider the benefits presented in this paper using this specific surgical technique when planning surgical management for their patients.
- However, further investigation into the clinical relationship is needed to confirm this study's significance. Controlled and larger cohort studies are needed to determine further nuances in the relationship.

collapsed, smaller height, minimises nerve root retraction and subsequent risk of dural injury (16). Adjusted *in-situ*, controlled cage expansion restores individual intervertebral and foraminal height while allowing for optimal endplate-to-endplate contact and reduced risk of subsidence (10,16). Individualized patient-specific device customization of disc space height and lordosis can assist in restoring segmental and global lumbar lordosis, sagittal balance, and improve clinical outcomes post-surgery (10,12,15). Despite the functional benefits of expandable cages there is no consensus on whether these improve the clinical outcomes for patients undergoing PLIF or TLIF (9-13,15,16).

Due to the ongoing debate surrounding the clinical impact of cage design, surgical technique, and bone graft selection, the aim of this study was to evaluate the mid-term clinical and radiographic outcomes of patients who underwent a hybrid P-TLIF with a single straight expandable titanium cage using rhBMP-2 or DBA bone substitute. We compared the fusion outcomes using rhBMP-2 *vs.* DBA expecting that there would be no significant difference between fusion rates. We present this article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-24-82/rc).

Methods

Study design

A retrospective analysis of prospectively collected data of consecutive patients who underwent a hybrid P-TLIF with a single straight expandable interbody cage between August 2017 and May 2022 under a senior spine surgeon at a single private institution in Australia.

Inclusion criteria were patients who suffered persistent low back pain for at least 6 months; and had radiological evidence of grade 1–2 degenerative or isthmic spondylolisthesis, degenerative discopathy, canal/foraminal stenosis, or a combination as a cause of chronic back +/– leg pain. All patients had a single straight titanium expandable cage inserted as an interbody fusion device (RISE Globus Medical Inc., Audubon, PA, USA). If a patient did not attend to at least 6-month follow-up they were excluded from data analysis.

Data collection

Baseline patient characteristics of age, sex, body mass index (BMI) and smoking status were obtained preoperatively. The presenting pathology was recorded, and any previous spine operations were noted. Patients diagnosed with low bone mineral density by dual-energy X-ray absorptiometry (DEXA) were included in the study and referred to an independent endocrinologist for perioperative management. Intraoperative data included estimated blood loss (EBL), bone substitute used and operative levels.

Patient-reported outcome measures (PROMs) were collected preoperatively and postoperatively at follow-up time points of 6-week, 6-month, 12-month, and 24-month by face-to-face or video interview. Back pain visual analogue scale (VAS back) and leg pain visual analogue scale (VAS leg) assessed pain, Oswestry disability index (ODI) assessed disability, and the 12-Item Short Form Survey (SF-12) assessed physical and mental functional status (17-19). We defined clinical success as achievement of the minimal clinically important difference (MCID) by 24 months postoperatively. MCID was defined as a 1.2-point decrease in back pain (VAS back), 1.6-point decrease in leg pain (VAS leg), 12.8-point decrease in ODI, and 4.9-point increase in the physical component and 9.1-point increase mental component of SF-12 based on previously published thresholds (17-19). Intraoperative and postoperative complications to 24-month, including any reoperations and the indication were recorded.

Radiographic analysis

Radiographic outcomes were assessed via computed tomography (CT). Day-2 CT scan was conducted for instrumentation position check. A 6-, 12-, or 24-month CT scan was conducted to assess fusion and any radiological complications such as subsidence, cage migration, or adjacent segment disease. If fusion was reported as complete, defined as grade 1 or 2 using Bridwell classification, no more CT scans were undertaken and this was used in the calculation of the fusion score at final follow-up. The postoperative CT scans were not full diagnostic lumbar CTs but rather focused on the level of construct to determine instrumentation positioning and fusion status. Subsidence was defined as any compromise of either vertebral endplate (on InteleViewer software, Intelerad Medical Systems, Inc., Montreal, Canada). Fusion was assessed by a third-party independent radiologist. The Bridwell classification was used to report fusion status in the interbody space and posterolateral space separately (20).

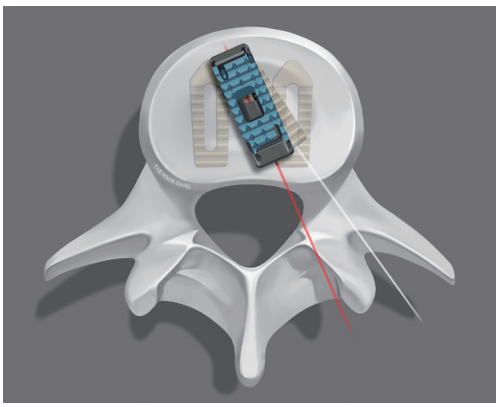

Figure 1 Axial image of lumbar disc space showing superimposed views of cages placed by transforaminal route (TLIF), conventional paramedian route bilaterally (PLIF), and our hybrid P-TLIF route. The white and red lines indicate TLIF and P-TLIF trajectories respectively. TLIF, transforaminal lumbar interbody fusion; PLIF, posterior lumbar interbody fusion; P-TLIF, posterior-TLIF.

Fusion was graded; grade I—fused with remodelling and trabeculae present; grade II—graft was intact, not fully remodelled and incorporated, but no lucency present; grade III—graft was intact, with potential lucency present at top and bottom of the graft; and grade IV—fusion was absent with collapse/resorption of the graft.

Surgical technique

Midline surgical incision was made with a subperiosteal dissection of the erector spinae muscles. Dissection was extended over the facet joints laterally and to the depth of the transverse processes of the planned instrumented pedicles. Transverse processes where then carefully decorticated with a high-speed drill. Pedicle screws were placed with image guidance (Brain Lab with 3D Ziehm). A midline laminectomy then bilateral facetectomies were performed resecting the inferior then superior facets and ligamentum flavum (type-2 Schwab osteotomy) (21). A microscope was introduced to optimise visualisation and illumination. On the symptomatic side of neural compression or the easier/safer side to access the disc space, a unilateral 10 mm annulotomy was performed from 5 mm medial to the lower pedicle and extending into the foramen. A total discectomy was performed and endplate shavers used as a guide for cage insertion height. Endplate decortication completed with curettes and rasps. No trials were used so as to minimise the risk of traversing/exiting nerve root and/or end plate injury. The disc space was filled with supplementary bone graft substitute (either recombinant human bone morphogenetic protein-2 (rhBMP-2; Infuse, Medtronic, Dublin, Ireland) or demineralised bone allograft (DBA; Allovance® Crunch, Australian Biotechnologies, Sydney, Australia). A single straight 26 mm long expandable cage was selected, cage width of 10 or 12 mm depending on access, and packed with bone graft substitute (either rhBMP-2 or DBA). This was inserted obliquely across the midline aiming at the contralateral anterolateral corner of the target disc space at minimum size (8 mm) then expanded based on tactile feedback to ensure a snug fit, without over-expansion. An illustration of cage positioning for this hybrid P-TLIF approach is shown in *Figure 1*. The fixed lordotic expandable cage height was adjusted *in situ*, then the position and height of the cage were checked with intraoperative fluoroscopy. Cages were inserted at either 8- or 10-mm height and expanded up to maximum 15- or 17-mm height respectively with corresponding fixed 10° or 15° of lordosis dependent on operative level. The posterolateral gutters were filled with a combination of harvested laminectomy bone graft (morselised in a bone mill) and either rhBMP-2 or DBA.

rhBMP-2 was the preferred bone graft substitute used in Australia to promote fusion prior to March 2020 but has been associated with adverse complications and cost concerns (22). Subsequently, private insurance companies in Australia restricted funding of rhBMP-2 hence Australian spine surgeons have since used the alternative DBA.

Ethical statement

Institutional approval was granted by Epworth HealthCare (No. EH2022-599). This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and the Australian, National Statement on Ethical Conduct in Human Research [2023]. This was a review of cases collected under a standard privacy disclosure to patients that their information will be used for ongoing evaluation of outcomes and their identity will be protected in any publication arising from this. Patients were verbally briefed on the research being conducted during their final follow-up, and these patient's verbal consent for their de-identifiable data to be used was granted.

Statistical analysis

Counts and percentages were reported for categorical

Table 1 Patient demographics (n=81)

Demographics	Results
Female, n (%)	44 (54.3)
Age (years), mean ± SD	57.3±12.5
BMI (kg/m^2), median [IQR]	28.8 [5.3]
Smoking status, n (%)	
Smoker	13 (16.0)
Ex-smoker	9 (11.1)
Non-smoker	59 (72.8)

SD, standard deviation; BMI, body mass index; IQR, interquartile range.

Table 2 Operative statistics (n=81)

Variables	Operative values
EBL (mL), median [IQR]	300 [305]
Biologic, n (%)	
rhBMP-2	60 (74.1)
Allograft	21 (25.9)
Operative levels, n (%)	
L2/3, L3/4	1 (1.2)
L3/4	8 (9.9)
L4/5	30 (37.0)
L4/5, L5/S1	14 (17.3)
L5/S1	28 (34.6)
Previous lumbar surgery, n (%)	
Yes	23 (28.4)
No	58 (71.6)

EBL, estimated blood loss; IQR, interquartile range; rhBMP-2, recombinant human bone morphogenic protein 2.

data, means and standard deviations for continuous data. If the latter appeared to be skewed or ordinal, medians and interquartile ranges (IQRs; difference between the 25th and 75th percentiles) were reported. Paired *t*-tests were used to compare PROMs between baseline and 12-month follow-up, these being the planned pairwise comparisons of greatest clinical interest. A grouped two sample *t*-test was used to assess the difference between interbody and posterolateral fusion rates at 6-, 12-, and 24-month between the application of rhBMP-2 or DBA. Statistical significance was assessed at P<0.05, two-tailed. Analyses were performed in Stata 18, Stata Corporation, College Station, TX, USA, 2021.

Results

This cohort of 81 patients was 54.3% female with a mean age of 57.3±12.5 years (*Table 1*). The mean follow-up time was 20.3±6.1 [12–24] months, with 55 (71.4%) patients available for 24-month follow-up. The operative levels and graft combinations used in this study are summarized in *Table 2*. A single-level procedure was conducted in 66 {expandable cage at L3/4 [8], L4/5 [30], L5/S1 [28]} patients and a double-level procedure was conducted in 15 patients {expandable cages at L2/3 and L3/4 [1], L4/5 and L5/S1 [14]}. Five patients had an extension or revision procedure on an existing lumbar spine construct {expandable cage at L3/4 [1], L4/5 [3], L2/3 and L3/4 [1]}.

PROMs showed stepwise continued improvement from baseline to 12-month follow-up (*Table 3*). There was a statistically significant difference (P<0.001) in all PROMs between baseline and timepoint of clinical interest (12-month). The largest difference in PROMs was seen between baseline and 12-month with counts plateauing out at 24-month follow-up.

Table 3 Comparison of PROMs data at baseline, 6-week, 6-month, 12-month, and 24-month

PROMs	Baseline	6-week	6-month	12-month	24-month	Baseline comparison to 12-month	
						Mean difference (95% CI)	P value
VAS back	7.8±0.8	5.1±1.6	3.9±1.4	2.7±1.8	2.1±1.6	5.2 (4.6–5.8)	<0.001
VAS leg	7.7±0.9	5.5±1.7	3.4±1.8	1.9±2.3	1.3±1.8	5.7 (5.0–6.4)	<0.001
ODI	35.8±6.6	22.5±9.7	15.2±6.8	13.6±5.8	9.7±5.5	19.2 (16.7–21.8)	<0.001
SF-12 physical	27.4±3.8	37.0±5.1	41.5±5.9	47.1±8.8	51.3±7.7	19.7 (16.9–22.6)	<0.001
SF-12 mental	38.1±8.3	45.8±9.3	47.4±7.6	52.1±8.7	61.1±6.1	14.0 (10.4–17.6)	<0.001

Data are presented as mean ± SD, unless otherwise stated. PROMs, patient-reported outcome measures; CI, confidence interval; VAS, visual analogue scale; ODI, Oswestry Disability Index; SF-12, 12-Item Short Form Survey; SD, standard deviation.

Table 4 Complications to 24-month follow-up (n=81)

Complications	Counts, n (%)	Management [n]
Persisting back pain	2 (2.5)	Conservative [1], sacroiliac joint injection and referral to pain specialist [1]
Persisting radicular pain	5 (6.2)	Conservative [3], facet joint injections [2]
Adjacent segment disease	3 (3.7)	Conservative [1], facet joint injections [2]
Asymptomatic radiologic subsidence	6 (7.4)	NA
Clinical subsidence	1 (1.2)	Intraoperative endplate fractures of L4 and L5
Reoperation	5 (6.2)	Removal of retropulsed L5/S1 cage [1], removal and reinsertion of retropulsed L4/5 cage [1], revision of L5/S1 PLF for symptomatic non-union with loose L5 and S1 pedicle screws [1], revision of L4/5 PLIF for L4 and L5 vertebral endplate fractures [1], revision of L4/5 PLIF for symptomatic left L4/5 lateral recess stenosis [1]

NA, not available; PLF, posterior lumbar fusion; PLIF, posterior lumbar interbody fusion.

This cohort experienced a total clinical complication rate of 27.2%. Complication counts and subsequent management are summarised in *Table 4*. There was one case of clinical subsidence (*Figure 2*) and two cases of cage retropulsion (*Figure 3*). The mean subsidence rate for all patients who experienced radiographic or clinical subsidence was 8.6%. The case of cage retropulsion in an elderly man occurred 3 weeks postoperatively at level L5/S1 secondary to a fall forward at home. An elderly woman suffered a case of cage retropulsion at L4/5 occurring secondary to loose screw fixation at 9 months.

The Bridwell grade fusion status is reported in *Table 5*. Total fusion at 24-month was achieved in 86.3% (interbody) and 93.2% (posterolateral) of patients. Case example of cage placement seen on CT shown in *Figure 4* and fusion in *Figure 5*. During follow-up, six patients (two at 6-month, three at 12-month, and one at 24-month) experienced asymptomatic radiological subsidence found on CT when assessing fusion status.

The use of rhBMP-2 in PLIF showed a trend to earlier but not significantly different fusion rates on average at each timepoint when compared to allograft. At 6-, 12-, and 24-month the mean interbody fusion scores for rhBMP-2 compared to DBA was 2.6 *vs.* 2.7 (difference =0.1; 95% CI: −0.3 to 0.5; P=0.60), 1.9 *vs.* 1.9 (difference =0; 95% CI: −0.4 to 0.4; P=0.90), and 1.8 *vs.* 1.7 (difference =0.1; 95% CI: −0.3 to 0.4; P=0.70) respectively. At 6-, 12-, and 24-month the mean posterolateral fusion scores for rhBMP-2 compared to DBA was 2.6 *vs.* 2.2 (difference =0.4, 95% CI: −0.08 to −0.8; P=0.10), 1.8 *vs.* 1.5 (difference =0.3; 95% CI: −0.1 to −0.6; P=0.20), and 1.7 *vs.* 1.5 (difference =0.3; 95% CI: −0.05 to −0.6; P=0.10) respectively.

Discussion

There is considerable debate over expandable cage technology; best design, clinical benefit, cage geometry (straight or banana), and even cost (10-14,16). Conflicting and limited evidence is important to address because utilisation of a particular technology will be driven by evidence supported by best patient outcomes, easiest and safest implantation, and cost.

Outcomes

MCID allows standardised comparison between heterogenous literature (17-19). Our study showed significant mean improvements reaching the MCID over 12 months in SF-12 physical of 19.7, and reductions of 5.7 for VAS leg, 5.2 for VAS back, and 19.2 for ODI.

We compared the outcomes in our hybrid P-TLIF procedure with a single straight expandable cage to reports in conventional PLIF procedures. Folman *et al.* [2003] using expandable cages in PLIF reported significant improvements in VAS pain (60%) and ODI (58%) at 12 months postoperatively (23). Mulvaney *et al.* [2020] reported improvements in pain (62%) and ODI (50%) using expandable cages in PLIF (35 patients) and in TLIF (15 patients) (20). The authors did not differentiate between PLIF and TILF in their results. We saw comparable statistically significant improvements in VAS pain and ODI of 70% and 62%, respectively at 24-month.

We report significant improvement in all PROMs (P<0.05) comparable with Barrett-Tuck *et al.* [2017] study reporting the use of a PLIF with the VariLift standalone

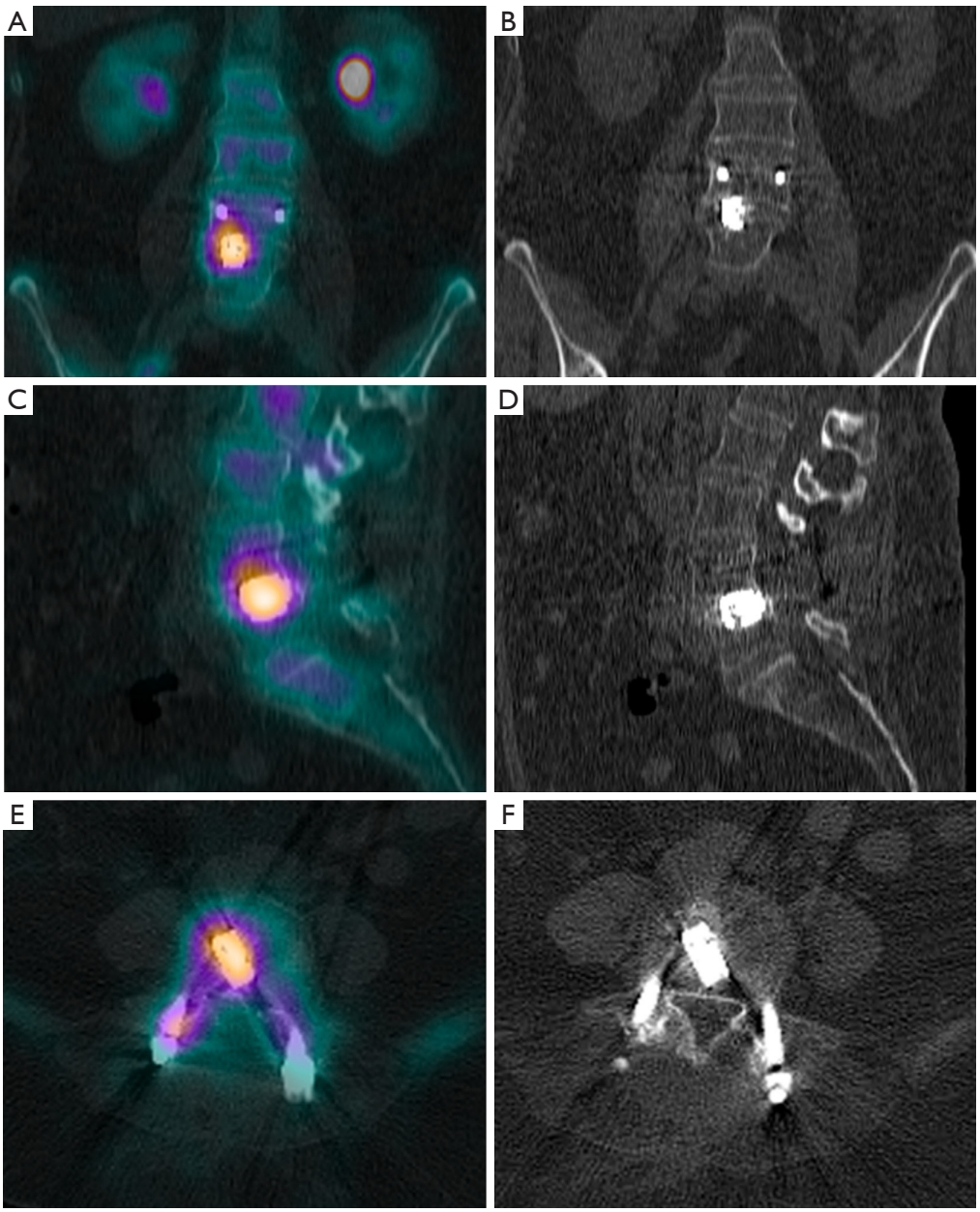

Figure 2 A 74-year-old female suffered L4/5 clinical subsidence secondary to intraoperative endplate (superior and inferior) fractures from overexpansion of cage: (A) coronal SPECT-CT scan; (B) coronal CT scan; (C) sagittal SPECT-CT scan; (D) sagittal CT scan; (E) axial SPECT-CT scan; and (F) axial CT scan. SPECT-CT, single photon emission computed tomography-computed tomography; CT, computed tomography.

expandable interbody cage without supplemental pedicle screw-rod fixation (24). There was a significant improvement in pain scores at 12-month (P<0.001). Likewise, using the same interbody device without posterior fixation, Neely *et al.* [2016] assessed 470 patients over an average of 4 years reporting back pain improved from 8.5 to 0.8 similar to our mean VAS back improvement of 7.9 to 2.1 at 2 years postoperative (25).

The outcomes of our study compare favourably to previous reports on PLIF with the use of expandable cages.

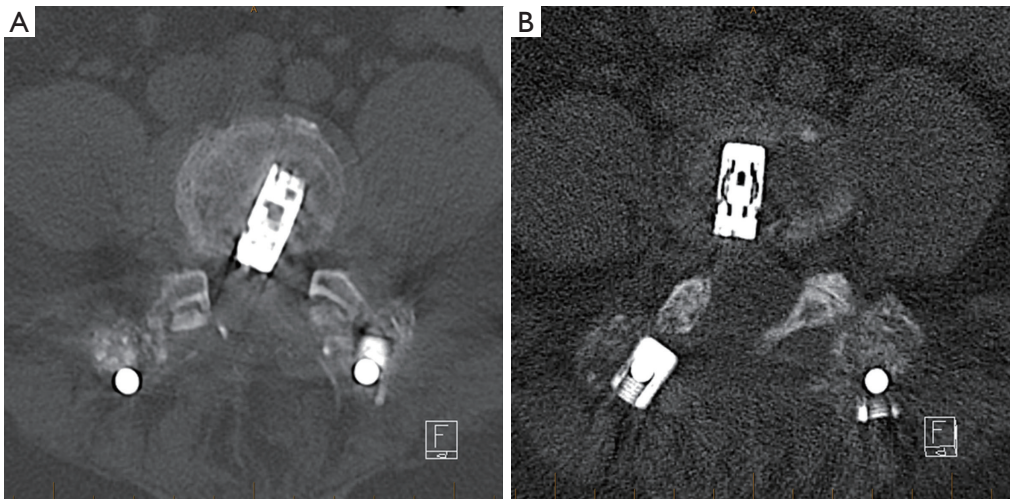

Figure 3 A 72-year-old male suffered an early fall forwards causing L4/5 cage retropulsion: (A) axial CT 2 weeks post-operative; (B) axial CT showing cage removal then repositioning. CT, computed tomography.

Table 5 Total (interbody and posterolateral) Bridwell CT fusion scores

Fusion scale	6-month		12-month		24-month	
	Interbody fusion	Posterolateral fusion	Interbody fusion	Posterolateral fusion	Interbody fusion	Posterolateral fusion
Number	61	61	69	69	73	73
Bridwell scores	2.7±0.7	2.3±0.8	1.9±0.7	1.6±0.7	1.8±0.7	1.5±0.6
Bridwell grade						
I	4 (6.6)	10 (16.4)	22 (31.9)	35 (50.7)	25 (34.2)	39 (53.4)
II	17 (27.9)	24 (39.3)	31 (44.9)	26 (37.7)	38 (52.1)	29 (39.7)
III	36 (59.0)	23 (37.7)	16 (23.2)	8 (11.6)	10 (13.7)	5 (6.8)
IV	4 (6.6)	4 (6.6)	0	0	0	0
Fused (Bridwell I or II)	21 (34.4)	34 (55.7)	53 (76.8)	61 (88.4)	63 (86.3)	68 (93.2)

Data are presented as n, mean ± SD, or n (%). CT, computed tomography; SD, standard deviation.

It is difficult to compare our hybrid P-TLIF procedure to open or minimally invasive surgery PLIF or TLIF procedures given the literature is heterogenous.

Expandable and static cages have been investigated in LLIF (12,15,26) and TLIF (11,14,27,28) with notable improvements in radiological and clinical outcomes. We report similar improvements in PROMs. The straight interbody cage utilised in this study has been shown to have acceptable clinical and radiological outcomes in TLIF (29,30). Our cohort experienced an average improvement in PROMs from baseline to final follow-up which suggests a clinical benefit in the use of expandable cages.

We report high CT fusion rates of 86.3% interbody and 93.2% posterolateral at 24-month follow-up. These were consistent with other studies reporting the use of expandable cages in PLIF with fusion rates ranging from 92% to 98.9% (20,23-25). It is important to distinguish between studies based on how and when fusion was assessed; CT *vs.* X-ray and if established fusion criteria such as the Bridwell classification were used.

A systematic review by Macki *et al.* [2021] analysed the use of expandable cages in anterior, lateral, and TLIF but

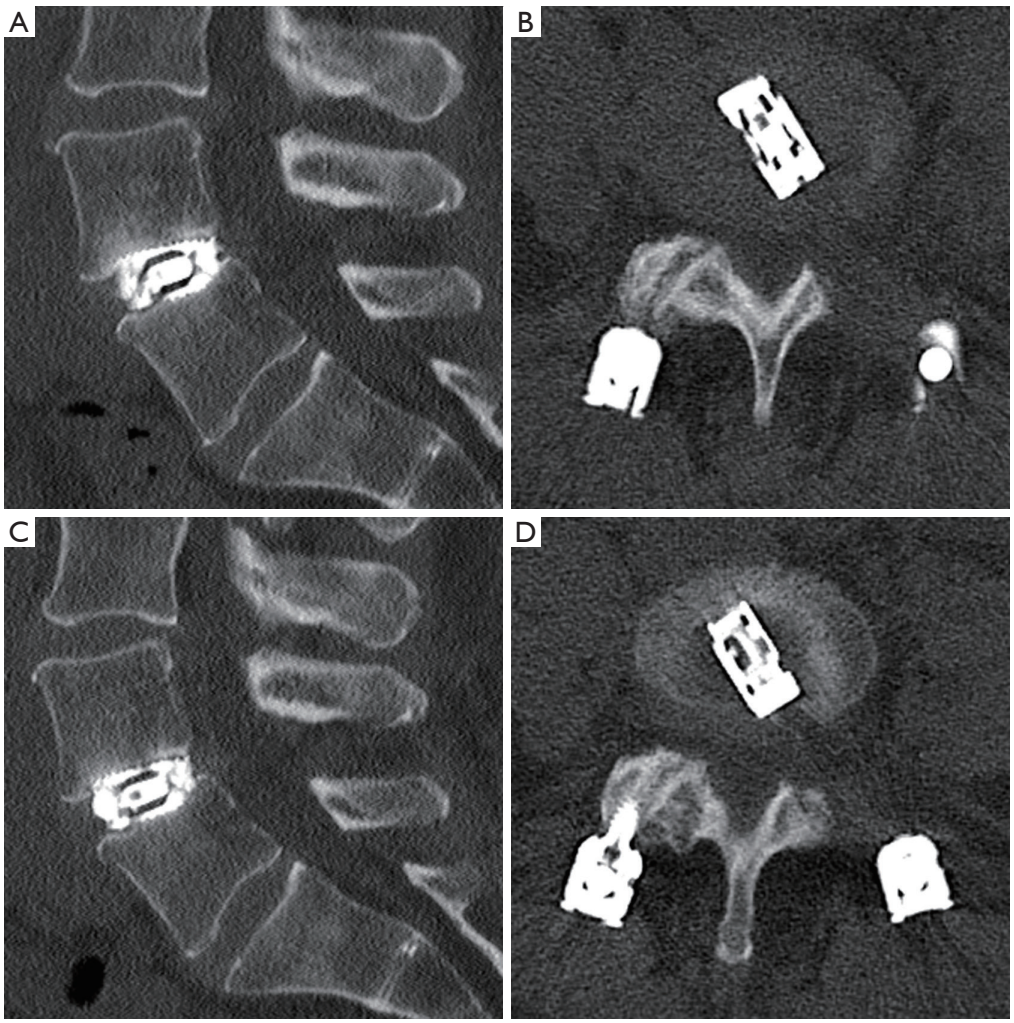

Figure 4 Postoperative CT scan showing cage positioning at level L4/5: (A) sagittal 6-month; (B) axial 6-month; (C) sagittal 12-month; (D) axial 12-month. CT, computed tomography.

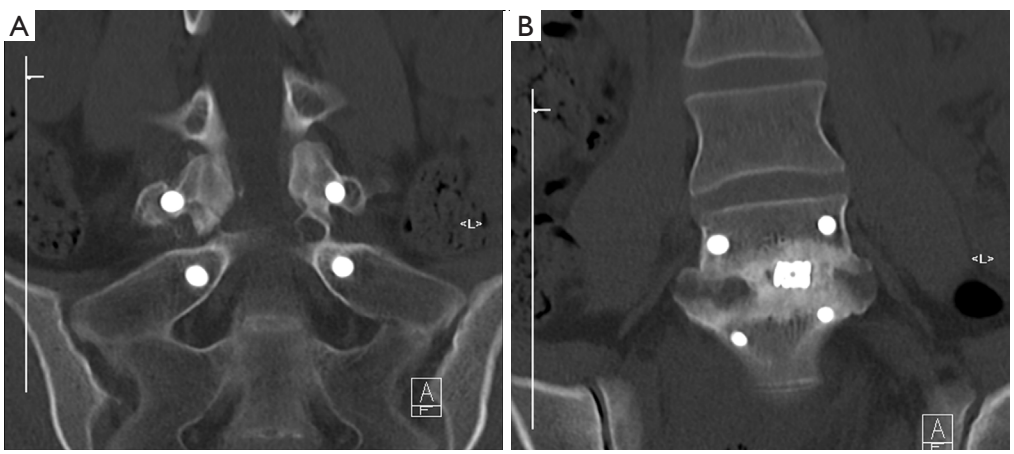

Figure 5 Postoperative 6-month CT scan confirming: (A) posterolateral bone fusion; (B) interbody fusion. CT, computed tomography.

did not include PLIF (12). They highlight that expandable cages in TLIF do offer benefits to restoration of lordosis and disk height but may not offer increased benefit on clinical outcomes when compared to static cages. Other systematic reviews and meta-analyses conclude that there is limited evidence assessing expandable cage use, especially assessing expandable cage use in PLIF. Some reviews acknowledge that their analyses may be impacted by heterogenous data and no standardised technique. They conclude that the benefits in radiological outcomes may not translate to the same benefits in clinical outcomes, but further evidence is needed (11,13,14,16).

Several clinical studies (29,31,32) and meta-analyses (33) have highlighted the importance of radiographic parameters and their correlation to PROMs. We hypothesise our cohort's improvement in PROMs was related to progressive fusion on CT over this mid-term follow-up. Future studies should investigate this relationship to better understand the benefits of an expandable cage design.

Complications

The overall complication rates reported for PLIF and TLIF in the literature average at 36% which includes reoperation, neurological injury, hardware subsidence or migration, dural tears, superficial and deep infections, postoperative radiculopathies, and pseudoarthrosis (34).

Our cohort experienced a total complication rate of 27.2%. Persisting pain or symptomatic atrial septal defect was managed either conservatively, with steroid injections, or referral to an appropriate specialist. Five patients suffered further injury/symptoms requiring reoperation. Two expandable cages migrated posteriorly from traumatic falls early postoperatively which has been previously reported (35).

Six (7.4%) patients showed asymptomatic delayed cage subsidence and one patient suffered symptomatic intraoperative end-plate injury on CT follow-up. A recent systematic review of subsidence with interbody cages found subsidence rates ranging from 7.4% to 31.8% in PLIF and 0% to 51.2% in TLIF (36). Lee *et al.* [2017] concluded that the 2-year cage subsidence rates for PLIF were lower at 10% compared to TLIF at 38% (37). Stickley *et al.* [2021] in a retrospective analysis of 252 patients undergoing TLIF found a significantly higher risk of intraoperative subsidence with an expandable cage (29%) *vs.* a static cage (11.8%) but no difference in the rate of postoperative subsidence (19% *vs.* 16.4%) between the cage types (38). Tassemeier *et al.* [2018] (39) reported 61 patients who received an expandable titanium TLIF cage a lower subsidence rate with a banana-shaped cage (6.6%) compared to 14.8% with a straight cage. We found with a straight expandable titanium cage a lower (8.6%) total (intraoperative and postoperative) rate of subsidence. However, the existing literature is very heterogeneous with static *vs.* expandable cages, intraoperative *vs.* postoperative subsidence, asymptomatic *vs.* symptomatic subsidence, and the relatively small sample sizes of studies reported. Hence, larger, and more defined studies are needed to make definitive conclusions on the subsidence rates with expandable PLIF or TLIF cages *vs.* static PLIF or TLIF cages.

Surgical technique

We believe our hybrid P-TLIF technique used in this series offers numerous benefits compared to a conventional PLIF or TLIF approach. The hybrid P-TLIF allowed placement of a single straight long expandable cage obliquely across the disc space. This cage can be repositioned intraoperatively to reduce the risk of anterior extrusion and posterior retropulsion. Additionally, the cage can be backfilled with available bone graft after final positioning, thereby optimising graft/endplate contact. Bilateral facetectomies permit optimal neural decompression bilaterally and pedicle-screw compression to improve target segmental lordosis (40).

The expandable design allowed for easier and safer introduction and repositioning of the cage with a contracted insertion height compared to equivalent-sized static cages. Furthermore, tactile feedback on cage expansion reduces risk of cage subsidence based on a surgeon's learning curve (25). The solitary early symptomatic endplate fracture in our series was due to cage over expansion early in the surgeon's learning curve. We must emphasise judicious cage expansion for a snug fit to minimise risk of intraoperative endplate injury and delayed subsidence (41).

In rare but serious cases of postoperative cage retropulsion, conventional PLIF cages will retropulse directly into either the cauda equina or the descending nerve root (42). Whereas the obliquely placed straight cage in our hybrid P-TLIF series can retropulse into Kambin's triangle, between the two nerve roots potentially having a lower rate of neurological complications. Our series had two cases of cage retropulsion, and neither resulted in nerve root injury

persisting post-revision surgery.

Single banana-shaped cages have been a popular option for TLIF fusions ideally being placed under fluoroscopy into the ventral third of the target disc space to optimize segmental lordosis (33). However, banana cages risk injury to the descending nerve root on insertion, can often fail to rotate anteriorly to lie either in a straight or oblique orientation in the disc space and risk anterior longitudinal ligament rupture with retroperitoneal positioning (43). The benefits of a straight long cage in comparison are direct visualisation on insertion reducing fluoroscopy and the need for wearing lead protection, consistent cage positioning across the midline to the contralateral anterolateral corner of the disc space, easier cage removal and repositioning, and less risk of anterolateral ligament (ALL) rupture or anterior cage extrusion. Straight cages do have the option of using navigation and minimally invasive tubular retractors during insertion (44). Theoretically, expandable single straight cages positioned obliquely across the weakest central part of the vertebral endplate risk higher subsidence than banana-shaped expandable cages (45). However, recent systematic reviews and meta-analyses found straight cages had similar (33) or lower (9) subsidence rates compared to banana-shaped cages explained in part by the absence of optimal anterior placement of the curved cages. Compared to the reports included in these systematic reviews we report lower subsidence rates of 8.6% using our expandable straight cages.

Our study consecutively used rhBMP-2 then DBA both mixed with available local laminectomy/osteotomy bone graft. This comparison found no significant difference in fusion rates when using rhBMP-2 compared to DBA. Our cohort reported no radiculitis as previously associated with rhBMP-2 (22). We note the importance of using rhBMP-2 within the dosing guidelines.

Strengths and limitations

This study is a mid-term retrospective review of prospectively collected data at a single institution with 81 patients suffering from degenerative pathology from one senior spine surgeon performing a consistent surgical technique using the same expandable interbody cage. Average follow-up was 20 months with pain, disability and function reported; and CT assessment of fusion and subsidence rates by an independent radiologist. The authors acknowledge the heterogeneity of the patient cohort and that the two graft substitutes used were not randomised given rhBMP-2 was withdrawn from the market in Australia March 2020 then DBA was used thereafter.

Conclusions

A hybrid P-TLIF with a single straight titanium expandable cage permitted safe cage insertion, guided repositioning, and controlled expansion. Patients demonstrated significant improvements in pain, disability and function with low subsidence and high CT fusion rates over 24-month follow-up. The use of DBA in our cohort with an expandable straight cage showed no significant difference in fusion rates across 24-month when compared to rhBMP-2.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-24-82/rc

Data Sharing Statement: Available at https://jss.amegroups.com/article/view/10.21037/jss-24-82/dss

Peer Review File: Available at https://jss.amegroups.com/article/view/10.21037/jss-24-82/prf

Funding: None.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-24-82/coif). G.M.M. serves as an unpaid editorial board member of *Journal of Spine Surgery*. G.M.M. has disclosures of Globus Medical (consultancy), Device Technologies (travel), Life Healthcare (consultancy, travel), Australian Biotechnology (consultancy), National Surgical (travel), and SeaSpine (travel). The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are

appropriately investigated and resolved. Institutional approval was granted by Epworth HealthCare (No. EH2022-599). This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and the Australian, National Statement on Ethical Conduct in Human Research [2023]. This was a review of cases collected under a standard privacy disclosure to patients that their information will be used for ongoing evaluation of outcomes and their identity will be protected in any publication arising from this. Patients were verbally briefed on the research being conducted during their final follow-up, and these patient's verbal consent for their de-identifiable data to be used was granted.

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Cite this article as: Faulks C, Cabbabe K, Biddau DT, Munday NR, Malham GM. A single straight expandable cage via a hybrid posterior-transforaminal approach with rhBMP-2 or allograft provides high fusion rates with low risk of subsidence. J Spine Surg 2025;11(1):1-14. doi: 10.21037/jss-24-82