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High Lumbar Spinal Fusion Rates Using Cellular Bone Allograft Irrespective of Surgical Approach

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ABSTRACT

Background: Mounting evidence demonstrates a promising safety and efficacy profile for spinal fusion procedures using cellular bone allograft (CBA). However, limited data exists on fusion outcomes stratified by surgical approach. The current study investigates the effectiveness of CBA in lumbar spinal fusion by surgical approach (ie, anterior, lateral, and posterior approaches).

Methods: Patients undergoing lumbar spinal fusion with CBA (Trinity Elite) were enrolled into a prospective, multicenter, open-label clinical study (NCT 02969616). Fusion status was assessed by an independent review of dynamic radiographs and computed tomography images. Clinical outcome measures included quality of life (QoL; EQ5D), disability (Oswestry Disability Index [ODI]), and pain (visual analog scale [VAS]) for back pain and leg pain). Patient data extending to 24 months were analyzed in a post-hoc analysis.

Results: A total of 252 patients underwent interbody fusion (159 women; 93 men). Patients had a mean age of 58.3 years (SD 12.5), height of 168.3 cm (SD 10.2), and weight of 87.3 kg (SD 20.0) with a body mass index of 30.8 kg/m^2 (SD 6.5). At 12 months, the overall fusion success rate for bridging bone was 98.5%; fusion success was 98.1%, 100.0%, and 97.9% for anterior, lateral, and posterior approaches, respectively. At 24 months, the overall fusion success rate for bridging bone was 98.9%; fusion success was 97.9%, 100.0%, and 98.8% for anterior, lateral, and posterior approaches, respectively. The surgical approach did not significantly impact fusion success. A significant ($P < 0.0001$) improvement in QoL, pain, and disability scores was also observed. Significant differences in the ODI, VAS, and EQ5D were observed between the treatment groups ($P < 0.05$).

Conclusions: CBA represents an attractive alternative to autograft alone, reporting a high rate of successful fusion and clinical outcomes across various surgical approaches.

Clinical Relevance: The use of CBA for spinal fusion procedures, regardless of surgical approach, provides high rates of fusion with a favorable safety profile and improved patient outcomes.

Level of Evidence: 4.

Trial Registration: NCT 02969616.

Lumbar Spine

Keywords: lumbar fusion, arthrodesis, cellular allograft, Trinity Elite, cellular bone allograft

INTRODUCTION

Lumbar spinal fusion has seen an annual increase in the volume of procedures reported, most notably within the aging population. Increases are greatest among individuals older than 65 years, with a 138% increase in procedure volume from 2004 to 2015. Lumbar spinal surgeries most commonly are performed for back pain, spondylolisthesis, scoliosis, disc degeneration, herniation, and stenosis.[1] As these surgical procedures continue to expand, efforts are underway to research and educate surgeons on avenues to improve lumbar fusion success and minimize patient perioperative complications. Successful arthrodesis in lumbar spinal surgery depends on a myriad of factors, most notably the surgical approach and the bone graft material.

Lumbar interbody fusion is a method used to provide more biomechanical stability to the spine structure, thereby theoretically increasing the odds of successful fusion. Interbody fusion can be achieved using anterior, lateral, or posterior surgical approaches. Individual patient pathological factors, anticipated perioperative complications, and the surgeon's preferences guide the selection of the approach used. Each approach has its own advantages and disadvantages. While many studies on spinal fusion have been conducted and findings reported, the array of study designs, bone grafting materials used, and types of analytical methodologies

make it difficult to identify which approach yields the highest fusion rate and optimal patient outcomes. Lumbar fusion rates can vary widely according to the surgical technique. While these procedures are commonly performed, clear evidence does not exist regarding which surgical approach is best, and long-term patient outcomes demonstrating superiority are limited.

Selection of the bone grafting material is a modifiable factor that may impact surgical outcomes. There are three main types of graft materials: autograft (patient's own body), allograft (human cadavers and/or living donors), and synthetic bone graft or substitutes.[2] Autologous bone grafts (autograft) have long been considered the gold standard in bone grafting material due to their innate ability to provide critical elements for bone formation. However, although commonly used, autograft procedures such as those requiring iliac crest bone are associated with significant donor site morbidity and may be limited by the quantity and quality of available bone. Furthermore, patients are subjected to increased operative time, blood loss, postoperative pain and risk of infection, pseudoaneurysm of the pelvic vasculature, and neurological injury. Up to 38% of such procedures lead to donor site morbidities, highlighting the impact of these complications.[3–5] As an alternative to autograft, cellular bone allografts (CBAs) represent a more recent addition to allograft technologies. CBAs have received much interest as a grafting material with mounting evidence showing similar benefits as a bone graft source to autologous bone, while minimizing its limitations.[3–12] CBAs are carefully processed from deceased donors shortly after death to maintain viable, endogenous osteogenic cells and then are cryopreserved for long-term storage. These grafts typically also contain an osteoconductive cancellous bone matrix as well as an osteoinductive demineralized cortical bone component.[13–15] Thus, the composition of CBAs allows these grafts to contribute all three of the critical elements necessary for successful bone formation.

Despite growing evidence on the use of CBA in lumbar and cervical spinal fusion surgery, there is limited published literature regarding the efficacy of CBA in varying surgical approaches.[16–19] The current report further investigated lumbar spinal fusion rates with CBAs by surgical approach (ie, anterior, lateral, and posterior) and associated clinical outcomes with data collected from a 24-month, prospective, postmarket, multicenter clinical study (NCT 02969616).

MATERIALS AND METHODS

Patients

The study was conducted in accordance with Good Clinical Practice Guidelines and approved by associated ethical review boards in accordance with the Declaration of Helsinki. The study was registered on clinicaltrials.gov (NCT 02969616). As previously described in a 12-month analysis of the trial data,[20] patients were eligible for enrollment if they were adults older than 18 years, had failed at least 6 months of conservative treatment, and were planning to undergo posterolateral fusion (1–4 levels) or interbody fusion (1–2 levels) and met all predefined inclusion/exclusion criteria. Exclusion criteria included prior lumbar spine fusion surgery at a level currently scheduled for surgery, currently or previously (prior 5 years) undergoing treatment for malignancy, having an active local or systemic infection, or undergoing adjunctive treatment for local or systemic infection. Patients were enrolled following informed consent. All inclusion and exclusion criteria are described in Supplemental Table 1.

Study Design

Data were collected from a prospective, postmarket, multicenter clinical study.[20] Patients were enrolled from nine clinical sites throughout the United States and screened for inclusion/exclusion criteria. The surgical approach and technique were determined by the treating surgeon. Patients received CBA using Trinity Elite allograft (MTF Biologics, Edison NJ), which is a cryopreserved, viable CBA containing cancellous bone and demineralized cortical bone. CBA was used as the primary (>50% by volume) bone graft, with augmentation of up to 50% of locally harvested autograft and/or cancellous allograft chips. No additional bone grafts were used.

Assessments

Radiographic fusion was assessed by an independent review (TELOS Partners, Warsaw, IN, and MMI, Houston, TX). Fusion was defined as (1) the presence of bridging bone across the adjacent endplates on thin-cut computed tomography (CT) images, (2) lack of angular and translational motion (<3° and <3 mm, respectively) on Quantitative Motion Analysis (QMA), and (3) a composite of bridging bone and QMA. Patients undergoing 2-level procedures had to demonstrate fusion at both levels to be considered a fusion success. Dynamic radiographs (flexion/extension) for QMA were obtained at 3, 6, 12, and 24 months postoperatively, while CT images

were obtained at 12 and 24 months. Clinical outcomes included quality of life (QoL; EQ5D), Oswestry Disability Index (ODI), and visual analog scales (VAS) for back and leg pain. Clinical outcomes were assessed at baseline, 6 weeks, and 3, 6, 12, and 24 months postoperatively. Surgical techniques included interbody procedures from anterior, posterior, and lateral approaches. Lateral interbody approaches included oblique lumbar interbody fusion, extreme lumbar interbody fusion, lateral lumbar interbody fusion, and direct lateral lumbar fusion. Posterior interbody approaches included transforaminal lumbar interbody fusion and posterior lumbar fusion. Primary endpoints included between-group comparisons (anterior vs posterior vs lateral) for fusion success and patient-reported outcomes. Secondary endpoints included within-group comparisons among patient-reported outcomes.

Statistical Analysis

Data were analyzed using SAS version 9.4. Counts and percentages are reported for categorical baseline variables. Mean, standard deviation (SD), and range are reported for continuous variables. Pre- and postoperative patient-reported outcomes were compared with a paired samples *t* test. Alpha was set at 0.05, and a *P* value < 0.05 was considered significant. A Fisher's exact test was used for the overall comparison. If significance was observed, a Bonferroni corrected posthoc analysis was used to determine specific differences. Between-group comparisons were calculated using the Kruskal Wallis test—a nonparametric alternative to the 1-way analysis of variance. All available data were evaluated at each timepoint extending out to 24 months.

RESULTS

Patients

A total of 274 patients were enrolled into the study. Of the 274 patients enrolled, 252 patients (159 women [63.1%] and 93 men [36.9%]) underwent an interbody fusion procedure. Twenty-two patients underwent a posterolateral fusion procedure and were not included in this analysis. The majority of patients were of Caucasian or white race (86.5%) and not of Hispanic or Latino ethnicity (96.4%). Patients had a mean age of 58.3 (SD 12.5) years, height of 168.33 (SD 10.2) cm, and weight of 87.3 (SD 20.0) kg with a body mass index of 30.8 (SD 6.5) kg/m^2. Overall, 18.7% of patients reported being nicotine users and 6.4% reported having osteoporosis (Table 1). Patient enrollment is presented in Figure 1. All available data were evaluated at each timepoint extending out to 24 months.

Surgical Procedure

Of the 252 patients who underwent an interbody procedure, there were 63 patients each in the anterior and lateral groups and 126 patients in the posterior group. The surgical approach and number of levels treated are presented in Table 2.

Efficacy Outcomes

Fusion Success

At 12 months, overall fusion success based on the presence of bridging bone was 98.5%; fusion success for anterior, lateral, and posterior groups was 98.1%, 100.0%, and 97.9%, respectively. Overall fusion success based on the QMA assessment was 92.2%; fusion success for anterior, lateral, and posterior groups was 85.0%, 94.6%, and 94.7%, respectively. Overall fusion success based on bridging bone plus QMA assessment was 91.2%; fusion success for anterior, lateral, and posterior groups was 83.0%, 94.6%, and 93.8%, respectively. No statistically significant difference was observed between treatment groups at 12 months. Three patients failed the bridging bone assessment at 12 months ($n = 1$ anterior group; $n = 2$ posterior group; Table 3).

At 24 months, overall fusion success based on the bridging bone assessment was 98.9%; fusion success for anterior, lateral, and posterior groups was 97.9%, 100.0%, and 98.8%, respectively. Overall fusion success based on the QMA assessment was 92.4%; fusion success for anterior, lateral, and posterior groups was 87.5%, 94.1%, and 94.1%, respectively. Overall fusion success based on the presence of bridging bone and QMA was 91.8%; fusion success for anterior, lateral, and posterior groups was 85.4%, 96.1%, and 92.9%, respectively. No statistically significant difference was observed between treatment groups at 24 months (Figure 2; Table 4). Radiographic images showing fusion success and failure are presented in Figure 3. One of the bridging bone failures in the posterior group at 12 months demonstrated successful bridging bone at 24 months, while the other 2 failures at 12 months remained failures at 24 months.

There were 3/51 (5.9%) patients in the posterior group who were supplemented with local bone and 67/85 (78.8%) in the lateral group. None of the patients in the anterior group were supplemented with autograft. The fusion rates for patients in the posterior group and

Table 1. Patient demographics.

Variable	Anterior *n* = 63 (25%)	Lateral *n* = 63 (25%)	Posterior *n* = 126 (50%)	Overall *n* = 252 (100%)
Sex, *n* (%)				
Women	36 (57.1)	46 (73.0)	77 (61.1)	159 (63.1)
Men	27 (42.9)	17 (27.0)	49 (38.9)	93 (36.9)
Ethnicity, *n* (%)				
Hispanic or Latino	4 (6.4)	1 (1.6)	3 (2.38)	8 (3.2)
Not Hispanic or Latino	59 (93.7)	62 (98.4)	122 (96.8)	243 (96.4)
Unknown	0 (0.0)	0 (0.0)	1 (0.8)	1 (0.4)
Race, *n* (%)				
Black or African American	7 (11.1)	10 (15.9)	9 (7.1)	26 (10.3)
Other	1 (1.6)	2 (3.2)	5 (4.0)	8 (3.2)
Caucasian or white	55 (87.3)	51 (81.0)	112 (88.9)	218 (86.5)
Work Status, *n* (%)				
Full time	30 (47.6)	17 (27.0)	49 (38.9)	96 (38.1)
Part time	3 (4.8)	3 (4.8)	14 (11.1)	20 (7.9)
Not working	30 (47.6)	43 (68.3)	63 (50.0)	136 (54.0)
Age, y				
Mean (SD)	55.0 (13.9)	63.5 (9.7)	57.4 (12.2)	58.3 (12.5)
Min–max	19–76	41–82	24–82	19–82
Height, cm				
Mean (SD)	170.9 (9.5)	164.2 (11.1)	169.1 (9.5)	168.3 (10.2)
Min–max	152.4–200.7	132.1–195.6	149.9–190.5	132.1–200.7
Weight, kg				
Mean (SD)	87.52 (20.7)	87.31 (19.5)	87.19 (20.1)	87.30 (20.0)
Min–max	45.4–163.3	49.0–122.9	41.7–131.5	41.7–163.3
BMI, kg/m^2				
Mean (SD)	29.9 (6.2)	32.4 (6.8)	30.4 (6.5)	30.8 (6.5)
Min–max	18.5–51.4	18.0–44.9	18.0–46.5	18.0–51.4
Nicotine Use, *n* (%)				
Smoker	10 (15.9)	17 (27.0)	20 (15.9)	47 (18.7)
Nonsmoker	53 (84.1)	46 (73.0)	106 (84.1)	205 (81.4)
Osteoporosis, *n* (%)				
Osteoporosis	2 (3.2)	8 (12.7)	6 (4.8)	16 (6.4)
No osteoporosis	61 (96.8)	55 (87.3)	120 (95.2)	236 (93.7)

Abbreviation: BMI, body mass index.

anterior group supplemented with local bone were 100% and 95.5%, respectively (Table 4).

Quality of Life (EQ5D)

Mean preoperative EQ5D index scores for the anterior group ($n = 63$) were 0.62 ± 0.15 and improved to 0.80 ± 0.18 ($P < 0.0001$) at 24 months. Mean preoperative EQ5D index scores for the lateral group ($n = 63$) were 0.56 ± 0.16 and improved to 0.72 ± 0.17 ($P < 0.0001$) at 24 months. Mean preoperative EQ5D scores for the posterior group ($n = 126$) were 0.62 ± 0.17 and improved to 0.83 ± 0.16 ($P < 0.0001$) at 24 months (Figure 4).

Patients in each treatment group showed significant improvements in EQ5D scores at all timepoints through 24 months. At 24 months, the posterior group (0.83 ± 0.16) had significantly greater improvement in the EQ5-D compared with the anterior (0.80 ± 0.18; $P = 0.04$) and lateral (0.72 ± 0.17; $P < 0.001$) groups (Figure 4).

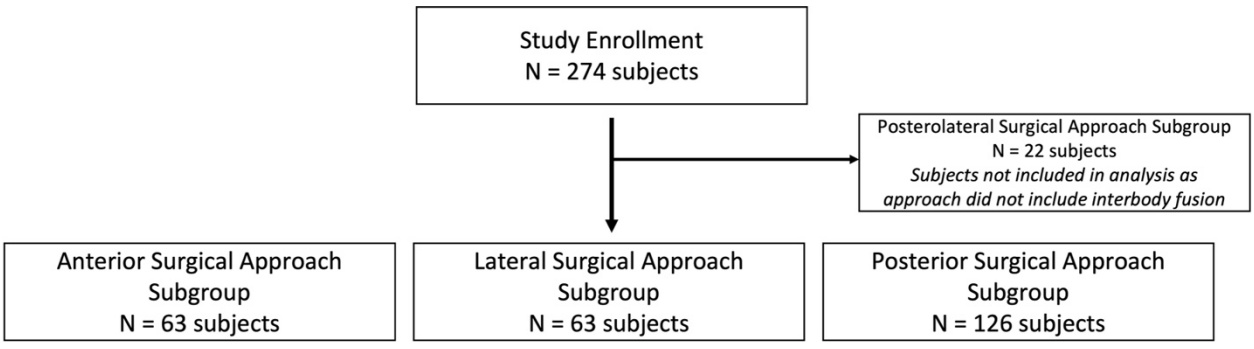

Figure 1. Study enrollment. A total of 274 patients were enrolled into the study. Surgical analyses included patients who underwent interbody fusion (ie, anterior, lateral, and posterior surgical approaches). Available data from all timepoints extending through 24 months are reported.

Table 2. Surgical approach and number of levels treated.

No. of Levels Treated	Overall *n* = 252 (100%) *n* (%)	Anterior *n* = 63 (25%) *n* (%)	Lateral *n* = 63 (25%) *n* (%)	Posterior *n* = 126 (50%) *n* (%)
1 Level	189 (75.0)	39 (61.9)	46 (73.0)	104 (82.5)
2 Levels	61 (24.2)	22 (34.9)	17 (27.0)	22 (17.5)
3 Levels	2 (0.8)	2 (3.2)	0 (0.0)	0 (0.0)

Oswestry Disability Index

Mean preoperative disability as assessed by the ODI in the anterior group ($n = 63$) was 65.51 ± 14.68 and improved to 43.53 ± 21.67 ($P < 0.0001$) at 24 months. Mean preoperative disability in the lateral group ($n = 63$) was 69.10 ± 17.60 and improved to 50.87 ± 18.29 ($P < 0.0001$) at 24 months. Mean preoperative disability in the posterior group ($n = 126$) was 64.21 ± 16.89 and improved to 37.89 ± 17.81 ($P < 0.0001$) at 24 months (Figure 5).

Patients in each treatment group showed significant improvements in ODI scores at all timepoints through 24 months. There was a significantly greater improvement in ODI for the posterior group compared with the lateral group at 6 ($P = 0.015$), 12 ($P = 0.008$), and 24 months ($P = 0.002$; Figure 5).

Visual Analog Scale

The mean preoperative VAS back score ($n = 63$) in the anterior group was 61.03 ± 24.87 and improved to 15.90 ± 22.72 ($P < 0.0001$) at 24 months. The mean preoperative VAS back score ($n = 63$) in the lateral group was 59.82 ± 28.38 and improved to 6.46 ± 12.50 ($P < 0.0001$) at 24 months. The mean preoperative VAS back score ($n = 126$) in the posterior group was 56.23 ± 29.92 and improved to 12.17 ± 21.36 ($P < 0.0001$) at 24 months (Figure 6).

Mean preoperative VAS leg scores ($n = 63$) in the anterior group were 35.21 ± 25.26 and improved to 7.97 ± 15.73 ($P < 0.0001$) at 24 months. Mean preoperative VAS leg scores ($n = 63$) in the lateral group were 42.94 ± 28.51 and improved to 3.86 ± 7.81 ($P < 0.0001$) at 24 months. Mean preoperative VAS leg scores ($n = 126$) in the posterior group were 38.50 ± 24.93 and improved to 5.72 ± 12.92 ($P < 0.0001$) at 24 months (Figure 6).

Patients in all 3 treatment groups showed significant improvements in VAS scores for back ($P < 0.001$) and leg ($P < 0.001$) at all timepoints through 24 months. A comparison between treatment groups for VAS back showed that the lateral group had significantly greater pain reduction compared with the anterior group at the 6-week postoperative timepoint ($P = 0.0058$). No significant differences were observed between the treatment groups for VAS leg ($P > 0.05$; Figure 6).

Table 3. Fusion status success.

Surgical Approach	Successful Fusion: Bridging Bone *n* (%)	QMA *n* (%)	Bridging Bone + QMA[a] *n* (%)
12 Mo ($n = 205$)			
Overall fusion success	202 (98.5)	189 (92.2)	187 (91.2)
By approach			
Anterior ($n = 53$)	52 (98.1)	45 (84.9)	44 (83.0)
Lateral ($n = 56$)	56 (100.0)	53 (94.6)	53 (94.6)
Posterior ($n = 96$)	94 (97.9)	91 (94.7)	90 (93.8)
24 Mo (n = 184)			
Overall fusion success	182 (98.9)	170 (92.4)	169 (91.8)
By approach			
Anterior ($n = 48$)	47 (97.9)	42 (87.5)	41 (85.4)
Lateral ($n = 51$)	51 (100.0)	48 (94.1)	49 (96.1)
Posterior ($n = 85$)	84 (98.8)	80 (94.1)	79 (92.9)

Abbreviation: QMA, quantitative motion analysis.

Note: Numbers reported for bridging bone, QMA, and bridging bone plus QMA are only for patients with successful fusion.

[a]No statistically significant difference was observed between surgical approaches at 12 and 24 months.

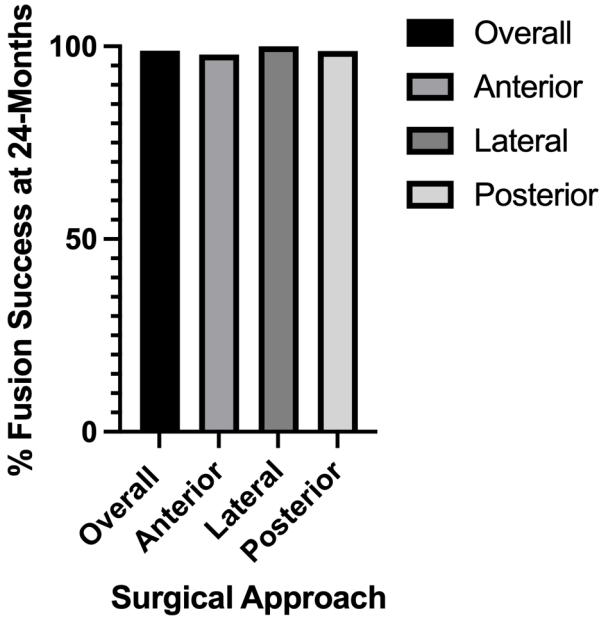

Figure 2. Successful fusion status by a surgical approach using bridging bone. Overall, a 98.9% successful fusion rate was observed at 24 months. Stratified by surgical approach, a 97.9% successful fusion rate was observed in patients who underwent anterior surgery; 100.0% in patients who underwent lateral surgery; and 98.8% in patients who underwent posterior surgery. Between-group comparisons showed no significant difference of approach on fusion success ($P > 0.05$).

Table 4. Surgical fusion type.

CBA + Local Bone	Successful Fusion, *n/N* (%)
Lateral—interbody	64/67 (95.5)
Posterior—interbody	3/3 (100.0)

Abbreviation: CBA, cellular bone allograft.

Safety Outcomes

There were 665 adverse events (AEs) reported through the 24-month follow-up period including 2 serious AEs (0.3%) and 12 nonserious AEs (1.8%) that were considered related to the surgical procedure and/or bone graft as determined by the treating surgeon. The serious AE classified as definitely related to the surgical procedure and/or the bone graft was worsening radiculopathy with the onset at the 6-week visit in a patient in the posterior group. The serious AE classified as probably related to the surgical procedure and/or the bone graft occurred at 24 months wherein a patient in the anterior group underwent a second surgery that revealed extrusion of the graft from the disc space. This patient then underwent a laminectomy and fusion at L4/5 and L5/S1, which resulted in successful fusion.

The most common AE reported was pain (53 events, 8%) and back pain (37 events, 5.6%). No other category of AE exceeded 2%. Twelve nonserious AEs were considered probably or possibly related to the procedure and/or bone graft. When stratified by treatment groups, 7 AEs were observed in the anterior group and 5 AEs in the lateral group. Descriptions of the AEs are provided in Table 5.

DISCUSSION

Lumbar spinal surgery is an area of medicine that has expanded considerably in recent years. This field has a variety of modifiable surgical parameters that can impact surgical success and patient outcomes, including the surgical approach and bone graft material used. Research efforts have focused on elucidating optimized surgical strategies but have been complicated by varying protocols. Consequently, this study focused on radiographic and clinical outcomes in patients who were treated with CBA[20] and further stratified by anterior, lateral, and posterior interbody approaches.

Overall, a high rate of fusion success was observed at 12 and 24 months among patients. Fusion rates were high across all assessments, which included bridging bone, QMA, and bridging bone plus QMA. When evaluating bridging bone, fusion success rates were high

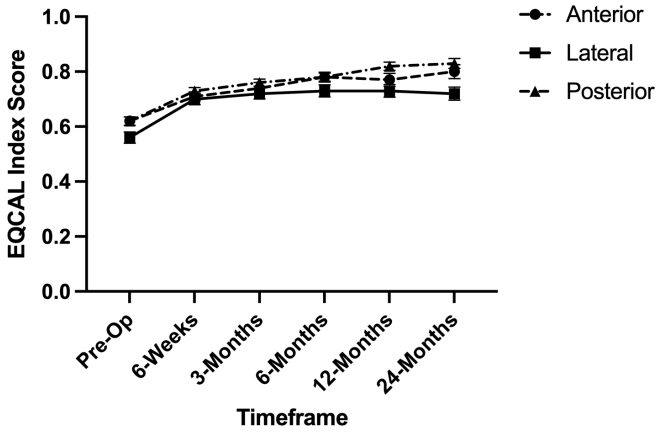

Figure 4. Improvement in quality of life EQ5D EQCAL Index Score by surgical approach. A significant improvement in EQ5D was noted in patients who underwent anterior, lateral, and posterior surgery at all timepoints ($P < 0.0001$). At 12 months, a significant difference between anterior and posterior approaches ($P = 0.04$) and lateral and posterior approaches ($P = 0.0009$) was observed. At 24 months, a significant difference between anterior and lateral approaches ($P = 0.01$) and posterior and lateral approaches ($P = 0.0001$) was observed.

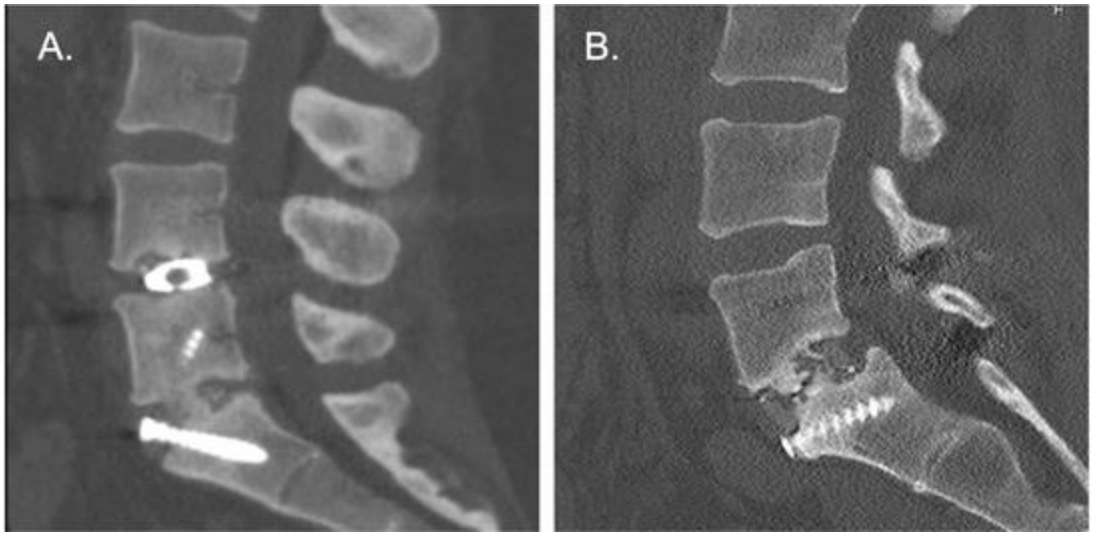

Figure 3. Radiographic images showing fusion status at 24 months. (A) Fusion success. (B) Fusion failure.

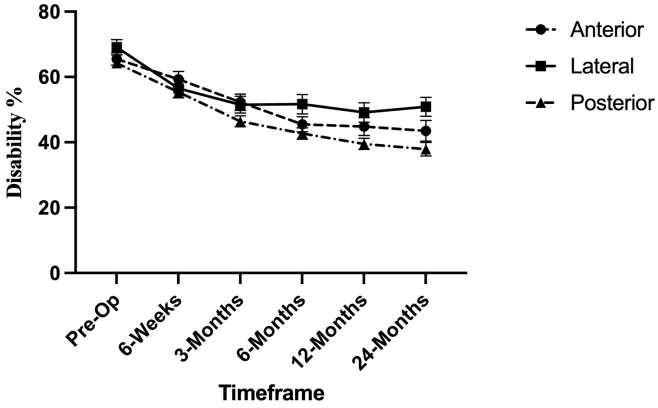

Figure 5. Improvement in Oswestry Disability Index (ODI) by surgical approach. A significant improvement in ODI was noted in patients who underwent anterior, lateral, and posterior surgery at all timepoints, $P < 0.0001$. At 6, 12, and 24 months, a significant difference between lateral and posterior approaches ($P < 0.05$) was observed.

across all approaches and ranged from 97% to 100% success (ie, an observed failure rate of 0%–3%). At 24 months, 97.9% of anterior, 100.0% of lateral, and 98.8% of posterior approaches resulted in successful fusion. Other studies have shown a failure rate of lumbar fusion as high as 37%.[21,22] A 2022 systematic review and meta-analysis of fusion rate enhancements and bone graft options for spinal surgery presented detailed fusion rates among various grafting groups. Local bone presented significantly higher proportions of fusion rates (95.3%, 95% CI 89.7%–98.7%) compared with the autologous iliac crest (88.6%, 95% CI 84.8%–91.9%), allograft (87.8%, 95% CI 80.8%–93.4%), and alloplastic (hydroxyapatite, rhBMP-2, rhBMP-7, or the association between them; 85.8%, 95% CI 75.7%–93.5%) study groups.[3] Accordingly, our results showcase a highly positive fusion success profile within the context of other bone graft materials in support of CBA, regardless of the surgical approach used. Our observed high rates of fusion success are in keeping with rates reported using the gold standard autologous bone grafts and in other bone graft studies.[3,16,23]

Patient outcomes including QoL, pain, and disability were also assessed out to 24 months and reviewed by surgical approach. Statistically significant improvements in all clinical outcomes were observed at 24 months. The QoL EQ-5D index score is anchored at 1 (full health) and 0 (dead). All surgical groups showed a moderate impairment in EQ-5D QoL (preoperative index score range of 0.57–0.63), which improved from 0.15 to 0.2. All 3 surgical groups demonstrated a significant improvement in ODI. Between surgical approach groups, significant differences in anterior and posterior groups compared with the lateral group were seen. Previous reports have shown improvement in ODI scores across surgical approaches with the greatest improvement observed in posterior approaches compared with others.[24] All surgical groups showed a VAS pain score for both back and leg that was considered "moderate" and improved to "mild" pain. These improvements fall within a clinically meaningful range noted for ODI and VAS established by Copay et al.[25] Clinical improvements in QoL, ODI, and pain outcomes are of impact to this patient population and may be a factor in the initial election of the surgical procedure. Furthermore, these data present improvement observed at 24 months postoperation and demonstrate sustained benefit of spinal surgery success using CBA regardless of surgical approach.

Of note, there was a lower fusion success rate observed in the anterior surgical approach when incorporating QMA in the fusion assessment. This is in contrast to a recent (2022) systematic review and meta-analysis that reported anterior surgical approaches

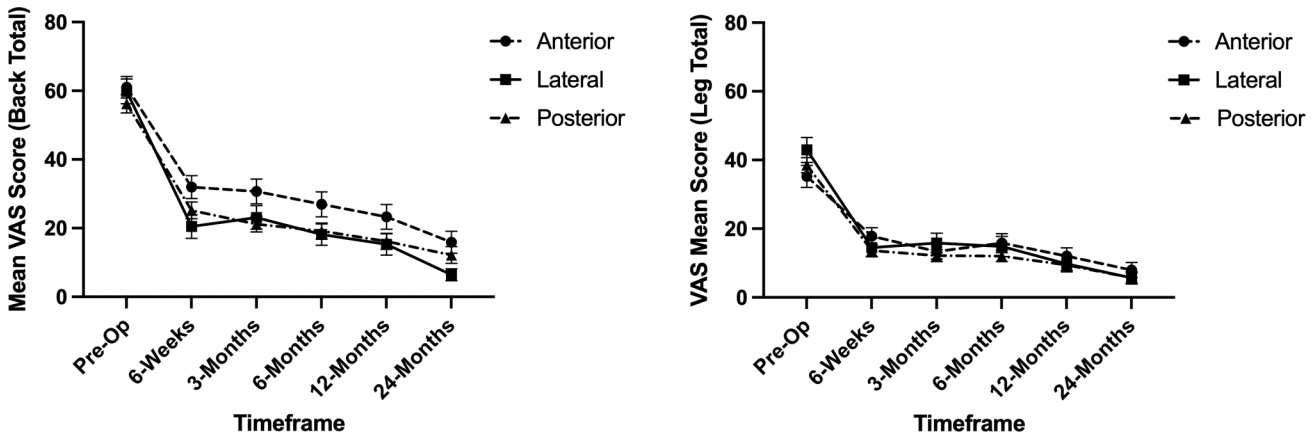

Figure 6. Improvement in visual analog scale (VAS) by surgical approach. A significant improvement in VAS scores was noted in patients who underwent anterior, lateral, and posterior surgery at all timepoints, $P < 0.0001$. A significant difference was observed in VAS back scores between anterior and lateral surgical approaches at the 6 weeks timepoint ($P < 0.01$).

Table 5. Adverse events by surgical approach.

Adverse Events Term	Serious	Relatedness	Severity	Surgical Approach
Radiculopathy L5–S1 distribution	Yes	Definitely related	Severe	Posterior
Surgery; lami fusion L4/5 and L5/S1	Yes	Probably related	Severe	Anterior
Back pain with sciatica	No	Probably related	Severe	Anterior
Swelling	No	Possibly related	Moderate	Anterior
Increased numbness	No	Possibly related	Moderate	Anterior
Worsening foraminal stenosis	No	Possibly related	Moderate	Anterior
Postoperative neuritis	No	Possibly related	Moderate	Anterior
Tingling	No	Possibly related	Mild	Anterior
Numbness	No	Probably related	Mild	Anterior
Pain	No	Possibly related	Moderate	Lateral
Increased spondylosis	No	Possibly related	Mild	Lateral
Increased spondylolisthes	No	Possibly related	Mild	Lateral
Increased back pain	No	Possibly related	Moderate	Lateral
Pain	No	Possibly related	Moderate	Lateral

Note: Adverse events may present from the same patient.
[a]There were a total of 14 adverse events: 8 (57.1%) in the anterior group, 5 (35.7%) in the lateral group, and 1 (7.1%) in the posterior group.

yielded the highest fusion rates.[24] In our study, the number of lumbar spinal surgeries that utilized the anterior approach was slightly lower compared with surgeries that used posterior and lateral approaches. Fusion rates (evaluated by QMA or Bridging bone plus QMA assessment) for the anterior group ranged from 83.0% to 87.5%, whereas fusion rates for the lateral and posterior approaches were 92.9% to 96.1%. This reduction may be attributed to the limited number of sites/surgeons that performed this type of surgery and the QMA that impacted the overall fusion rate score. Three of the 6 patients in the anterior group who failed the QMA assessment at 24 months underwent stand-alone anterior lumbar interbody fusion, which did include posterior supplemental fixation. While numerically reduced, there was no significant difference when stratified by surgical approach. These findings highlight that high rates of fusion success are observed using CBA regardless of the assessment or surgical approach used by the treating surgeon.

The systematic review conducted by Teng et al showed that AE complication rates were similar among surgical approaches for lumbar spinal surgeries.[26] The current study shows a small number of AEs that were considered by the treating surgeon to be possibly, probably, or definitely related to the surgical procedure and/or the bone graft in the present study. Of the 14 AEs, patients who were in the anterior and lateral surgical groups showed the highest frequency of AE reporting. The overall low number of AEs observed highlights the favorable safety profile for CBA and patient success outcomes.

Limitations

The study does present with a couple of limitations. The goal of this study was to assess the performance of CBA in various surgical approaches; however, a study arm with autograft only would have provided an opportunity to compare fusion success and patient-reported outcomes in CBA plus autograft vs stand-alone autograft. While no stand-alone arm was included, we pose that the outcomes of this study, which found similar fusion rates and improvement in pain and disability regardless of the surgical approach, are important contributions to the clinical literature. A second limitation is the volume of CBA, and autograft used was not prescribed but was at the discretion of the treating surgeon. Although the bone graft had to be at least 50% CBA, the majority of patients (155/252; 61.5%) received only CBA. Of note, osteoporosis and nicotine use are risk factors for poor outcomes following surgical procedures. A limited number of patients presented with these risk factors.

CONCLUSIONS

These data provide evidence of high rates of fusion success using CBA and promote further exploration into this alternate graft modality as a beneficial source for bone graft in lumbar spinal surgery. CBAs provide a unique alternative to autograft given that they are processed to preserve the inherent osteoconductive, osteoinductive, and osteogenic components found within the donor bone matrix. These study findings provide additional support for the viability and efficacy of CBA in spinal fusion across various surgical approaches.

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Ethics Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board at each respective clinical site for studies involving humans. Informed consent was obtained from all patients involved in the study.

Data Availability Statement: Data supporting the findings of this study are available upon reasonable request.

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