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Comparison of transforaminal and posterior lumbar interbody fusion outcomes in patients receiving a novel allograft versus rhBMP-2: a radiographic and patient-reported outcomes analysis

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OBJECTIVE Recombinant human bone morphogenetic protein-2 (rhBMP-2) has been demonstrated to achieve the highest rates of arthrodesis in multilevel lumbar fusion but is also associated with possible perioperative morbidity. A novel allograft (OSTEOAMP) is a differentiated allograft that retains growth factors supporting bone healing. The authors sought to compare the clinical and radiographic outcomes of rhBMP-2 and the novel allograft in lumbar interbody arthrodesis to determine if the latter may be a safer and equally effective alternative to rhBMP-2 for single- and multilevel posterior or transforaminal lumbar interbody fusion (PLIF or TLIF).

METHODS Patients who underwent single- or multilevel TLIF or PLIF using either OSTEOAMP or rhBMP-2 at the authors' institution over a 2-year period were prospectively followed for 12 months. Healthcare utilization, safety measures, patient satisfaction, physical disability (measured on the Oswestry Disability Index [ODI]), back and leg pain (on the numeric rating scale [NRS]), quality of life (on the EQ-5D scale), and return to work (RTW) were prospectively recorded. For purposes of this study, this consecutive series was retrospectively analyzed and pseudarthrosis rates were assessed at 2 years of follow-up. All patients (100%) had both 12-month patient-reported outcome follow-up and 24-month clinical and radiographic follow-up.

RESULTS One thousand one hundred fifty-four patients (654 treated with OSTEOAMP, 500 with rhBMP-2) were prospectively enrolled in the institutional registry. After propensity score matching, there were no significant baseline differences between 330 novel allograft and 330 rhBMP-2 cases. Perioperative morbidity and 90-day hospital readmission (3.3% vs 2.4%, p = 0.485) did not significantly differ between the novel allograft and the rhBMP-2 cases. At the 2-year follow-up, symptomatic pseudarthrosis requiring revision surgery occurred in 8 patients (2.4%) with OSTEOAMP and 6 patients (1.8%) with rhBMP-2 (p = 0.589). The overall fusion rate at 2 years was similar between groups (p = 0.213). Both groups showed significant and equivalent improvement in patient-reported outcome measures (PROMs) from baseline to 12-month follow-up, with no significant difference in 1-year mean NRS leg pain score (2.5 vs 2.7), ODI (25 vs 26), quality-adjusted life years (0.73 vs 0.73), satisfaction (83% vs 80%), or RTW (6.6 vs 7 weeks).

CONCLUSIONS In the authors' institutional experience, OSTEOAMP is a clinically viable substitute for rhBMP-2 for single- and multilevel lumbar fusion. This novel allograft provides clinically effective arthrodesis and improvements in PROMs comparable to rhBMP-2 with a similar safety profile. Additional indications and outcome assessment in longitudinal studies are needed to further characterize this allogeneic graft.

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KEYWORDS lumbar fusion; TLIF; PLIF; bone morphogenetic protein; pseudarthrosis; structural allograft; degenerative

ABBREVIATIONS ASA = American Society of Anesthesiologists; DBM = demineralized bone matrix; EBL = estimated blood loss; LOS = length of stay; NRS = numeric rating scale; ODI = Oswestry Disability Index; OR = operating room; PLIF = posterior lumbar interbody fusion; PROM = patient-reported outcome measure; rhBMP-2 = recombinant human bone morphogenetic protein-2; RTW = return to work; SMD = standardized mean difference; TGF = transforming growth factor; TLIF = transforaminal lumbar interbody fusion.

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Lumbar interbody fusion is well validated for the treatment of degenerative spinal disorders. Two of the most commonly performed approaches include posterior lumbar interbody fusion (PLIF) and transforaminal lumbar interbody fusion (TLIF), with several studies demonstrating durable outcomes.[1–4] Pseudarthrosis, or a lack of bone fusion, is a known complication of these procedures that occurs in as many as 8%–11% of cases.[5–7]

Traditionally, autograft harvested from the patient's iliac crest at the time of surgery has been considered the gold standard for successful spinal fusion.[8] However, an adequate volume of local autograft bone is not always available and there is significant morbidity related to donor site harvesting.[9] Various surgical adjuncts have been developed to augment lumbar interbody fusion including noncellular allografts such as demineralized bone matrix (DBM), cellular allografts, and recombinant human bone morphogenetic protein-2 (rhBMP-2).[10–15] Data remain mixed regarding radiographic fusion rates and clinical outcomes with these various allogenic and synthetic bone graft materials.

Use of osteoinductive growth factors such as rhBMP-2 in spinal surgeries has significantly increased since their discovery in 1965.[16,17] rhBMP-2 is used in approximately 40%–50% of all TLIFs in the US because it does not cause any donor site pain and is as effective as iliac crest bone in achieving spinal fusion.[16,18] However, reported sequelae associated with the use of rhBMP-2 include radiculitis, vertebral osteolysis, and ectopic bone growth.[19–21] Additionally, some studies have indicated higher costs during the 90-day perioperative period when rhBMP-2 is used.[22]

In this era of healthcare reform that emphasizes value-based care, it is crucial that new products demonstrate their clinical efficacy.[23,24] This is especially true for spinal biologics, in which incomplete fusion can result in high costs and revision surgeries.[19] A novel allograft (OSTEOAMP, Bioventus) is a differentiated allograft that is a potentially lower-cost alternative to rhBMP-2 and other current bone graft substitutes. The unique processing of this novel allograft is intended to retain the endogenous growth factors that are present in bone and bone marrow.[25,26] An existing clinical study supports its use in promoting fusion in the lumbar spine.[26] However, there are no data on patient-reported outcomes, disability, quality of life, or work productivity after lumbar spinal fusion comparing this novel allograft and rhBMP-2. The goal of this study was to compare the clinical and radiographic outcomes between use of OSTEOAMP and rhBMP-2 in TLIF/PLIF procedures.

Methods

Study Population and Criteria

We performed a post hoc analysis of our prospective, single-center, patient-reported outcomes registry. IRB approval was obtained from the Atrium Health IRB. From 2012 to 2022, a weekly representative sampling of all lumbar fusions was performed to enroll patients into the prospective registry. Only patients who underwent first-time single- and multilevel TLIF or PLIF for degenerative lumbar spine conditions were included. During this 10-year period, all cases were submitted to the Quality Outcomes Database using this nationally standardized representative sampling methodology.[27]

For this post hoc analysis, we queried all and consecutive PLIF and TLIF cases utilizing either the novel allograft (OSTEOAMP) or rhBMP-2 (Infuse, Medtronic) over a 2-year period from 2018 to 2020. Two cohorts were identified: consecutive patients undergoing instrumented TLIF or PLIF procedures with the novel allograft in addition to local autograft, and consecutive patients undergoing instrumented TLIF or PLIF procedures with rhBMP-2 in addition to local autograft. Both open and minimally invasive cases were included. In all cases, interbody and posterolateral arthrodesis was performed. Iliac crest autograft harvesting was not performed in any cases. Additional DBM or biologics were not utilized in any cases. The volumes of OSTEOAMP and rhBMP-2 were standardized per level, in each case. All patients had a preoperative American Society of Anesthesiologists (ASA) class I, II, III, or IV. Propensity score–matched analysis was performed to control for selection bias. Propensity score matching allows the analysis of an observational, nonrandomized study to reduce the effects of confounding variables. The analysis looks for matched sets of subjects within each cohort with similar propensity scores. In this analysis, propensity scores were estimated using a logistic regression model. The baseline variables used in the fitted regression model were patient age, BMI, ASA class, number of operative levels, type of procedure (PLIF vs TLIF), comorbidities (including smoking, depression, anxiety, and osteoporosis), preoperative back pain, preoperative leg pain, preoperative Oswestry Disability Index (ODI), and preoperative EQ-5D score. Standard of care practice was used to detect symptomatic pseudarthrosis.

All patients were followed up at 6, 12, and 24 months postoperatively and underwent standing flexion-extension radiographs to detect any motion within the construct. Patients were also assessed clinically for recurrent back pain. Patients developing motion on dynamic radiographs and/or developing recurrent back pain by 2 years underwent CT. If CT confirmed a nonunion, patients were considered to have developed pseudarthrosis. If patients did not develop recurrent back pain while also maintaining no motion within their construct 2 years after index surgery, they were classified as successfully fused. Grade of fusion was not assessed.

Demographic, Clinical, and Patient-Reported Outcome Measure Data

Demographic data, comorbidities, and relevant clinical information were collected for all patients. Perioperative safety and healthcare utilization data, discharge disposition, hospital readmissions, and reoperation rates during the 90-day global period were prospectively collected. Patient-reported outcome measures (PROMs) were prospectively recorded in the dataset via patient-assessed questionnaires administered preoperatively and at 3-month and 1-year follow-up evaluations. These questionnaires included patient satisfaction, the numeric rating scale (NRS) for leg and back pain,[28] the ODI to assess disability,[29] the modified Japanese Orthopaedic Association scale score for patients with myelopathy, and the EQ-5D scale for quality

of life. The EQ-5D is a valid, reliable, and commonly used 5-question preference-based instrument that measures health-related quality of life in the form of a global index value (0 = death, 1 = perfect health).[30] Cumulative improvement on the EQ-5D over the 1-year follow-up period provided an estimate of quality-adjusted life years gained for each treatment group. Return to work (RTW) was also prospectively assessed for 1 year after surgery.

Radiographic Outcome and 2-Year Pseudarthrosis

To supplement the 12-month registry data on symptomatic pseudarthrosis and reoperation, we reviewed the clinical record for all cohort patients throughout a 2-year follow-up period. Standard of care practice was used to detect symptomatic pseudarthrosis. All patients underwent standing lumbar flexion-extension radiography to detect any segmental motion within the PLIF or TLIF construct. The stability of the construct was also assessed for screw haloing, hardware migration, or failure. Patients were assessed clinically for recurrent back pain. Patients developing motion on dynamic radiographs and/or developing recurrent back pain by 2 years underwent a lumbar CT scan. If the CT scan confirmed nonunion, patients were considered to have developed pseudarthrosis. Patients were classified as successfully fused if they did not develop recurrent back pain while also maintaining no motion within their construct 2 years after index surgery.

Statistical Analysis

All statistical analyses were performed using SPSS (version 29, IBM Corp.). Univariable parametric data are provided as means ± standard deviations and nonparametric data are given as percentages. Bivariate analyses were conducted using independent t-tests, paired t-tests, and chi-square tests. The statistical significance level was set at $p < 0.050$.

Results

Table 1 shows the full population demographics and clinical characteristics of the entire study population with bivariable comparison results between the novel allograft and rhBMP-2 cohorts. A total of 1154 patients (654 with the novel allograft, 500 with rhBMP-2) met the inclusion criteria. Few significant differences existed between groups. The rhBMP-2 cohort included more Caucasians (90.3% vs 84.2%, $p = 0.026$), were more frequently ASA class II (52.2% vs 37.6%, $p < 0.001$), and had a greater proportion of single-level fusions (54.4% vs 40.7%, $p < 0.001$). The novel allograft cohort was more frequently ASA class III (59.4% vs 43.2%, $p < 0.001$) and included a greater number of patients who underwent surgery on 4 or more levels (12.2% vs 5%, $p < 0.001$). Age, BMI, gender, education level, employment status, payer status, comorbidities, and preoperative PROMs (ODI, EQ-5D, back and leg pain) were similar between groups. A slightly greater percentage of OSTEOAMP (46.2%) versus rhBMP-2 (36.5%) cases used the PLIF rather than the TLIF technique ($p = 0.001$).

Table 2 displays the propensity score–matched population demographics with bivariable comparison results between the novel allograft and rhBMP-2 cohorts. Propensity score matching yielded 330 pairs of novel allograft and rhBMP-2 patients for comparison. All significant differences between both groups were controlled for and negated in the matched population, with the exception of the PLIF technique (25.5% vs 19.1%, $p = 0.049$; Table 2). The standardized mean difference (SMD) values in Table 1 indicate that most fields are well balanced between the two groups (SMD < 0.2). The only variables with an SMD > 0.2 were ASA class and number of operative levels, both of which were included in the propensity score matching criteria. After the propensity score match, all variables had an SMD < 0.2, indicating good balance between the two groups for all variables (Table 2).

Safety, Facility Utilization, and Pseudarthrosis

Table 3 shows the propensity score–matched safety and facility utilization by the patients in both cohorts. No significant differences were observed in the mean estimated blood loss (EBL) or levels of fusion between groups. However, mean surgery duration was slightly longer (160 vs 145 minutes, $p = 0.002$) in rhBMP-2 cases. Length of stay (LOS) was longer in the novel allograft group (3.3 vs 2.2 days, $p < 0.001$). Similar discharge disposition, 90-day readmission, and unplanned reoperation rates were observed between groups. Nineteen patients (2.9%) in the entire propensity score–matched cohort underwent an unplanned reoperation within 90 days for issues including epidural hematomas, wound debridement, Hemovac drain placements, and repositioning of screws, and did not significantly differ between the novel allograft and rhBMP-2 cohorts.

At 2 years, the overall fusion rate was 97.8%. Six patients (1.8%) in the rhBMP-2 group and 8 (2.4%) in the novel allograft group ($p = 0.589$) demonstrated increased back pain, motion on flexion-extension radiographs, and nonunion on a subsequent CT scan, requiring revision surgery for pseudarthrosis (Fig. 1). The median time to develop pseudarthrosis for the rhBMP-2 versus the novel allograft cohort was similar (15 vs 13 months, $p = 0.213$). A similar number of patients in both groups (4.8% [rhBMP-2] vs 5.5% [novel allograft]) were found to have a solid fusion after index surgery but had developed symptomatic adjacent-segment degeneration and stenosis, all of whom required reoperation for extension of their fusion.

Patient-Reported Outcomes, Satisfaction Rates, and RTW

Tables 1 and 2 show the 4 PROM scores at preoperative interviews. Figure 2 shows the mean PROM scores at preoperative, 3-month follow-up, and 12-month follow-up interviews for both cohorts. For all patients in both cohorts, there was a significant improvement from baseline to 3-month follow-up across all PROMs, which was maintained at 12 months (all significant at $p < 0.001$). For each of the PROMs assessed, improvement in these scores was similar for both cohorts at all time points. No significant difference was observed for 1-year patient satisfaction rates between both groups. The Kaplan-Meier survival curve in Fig. 3 demonstrates the RTW rate in patients undergoing fusion with the novel allograft or rhBMP-2. The

TABLE 1. Patient population baseline demographics and clinical history

Variable	rhBMP-2, n = 500	OSTEOAMP, n = 654	t* or χ^2 Value	p Value	SMD
Demographics					
Mean age ± SD, yrs	65 ± 10.5	64 ± 10.8	1.69*	0.091	0.101
Mean BMI ± SD	30.20 ± 5.6	30.51 ± 6.4	−0.87*	0.387	−0.051
Males, n (%)	215 (43.0)	306 (46.8)	1.64	0.200	0.076
Race, n (%)					
Caucasian	324 (90.3)	494 (84.2)	7.30	**0.026**	−0.164
Black	30 (8.4)	82 (14.0)			
Other	5 (1.4)	11 (1.9)			
Hispanic/Latino, n (%)	4 (1.2)	17 (3.1)	3.20	0.074	0.124
Education, n (%)					
≤ HS graduate/GED	224 (45.9)	269 (42.8)	2.09	0.351	−0.084
2–4 yrs of college	198 (40.6)	257 (40.9)			
Post-college	66 (13.5)	103 (16.4)			
Employed, n (%)	163 (32.7)	207 (31.8)	0.10	0.751	0.019
Payer, n (%)					
Private	157 (31.4)	219 (33.5)	1.03	0.597	−0.023
Medicare	314 (62.8)	392 (59.9)			
Other	29 (5.8)	43 (6.6)			
Comorbidities, n (%)					
Smoker	69 (14.4)	85 (13.8)	0.08	0.780	0.017
Diabetes	72 (14.4)	99 (15.1)	0.12	0.727	−0.021
Depression	95 (22.0)	128 (23.3)	0.23	0.634	−0.031
Anxiety	66 (15.3)	76 (13.8)	0.42	0.519	0.041
Osteoporosis	25 (5.8)	42 (7.6)	1.30	0.254	−0.073
Clinical history					
Back pain, n (%)	460 (95.4)	610 (97.3)	2.76	0.097	−0.101
Leg pain, n (%)	397 (81.9)	533 (85.6)	2.77	0.096	−0.101
ASA class, n (%)					
1	7 (1.9)	5 (1.1)	24.76	**<0.001**	−0.283
2	184 (52.2)	203 (37.6)			
3	146 (43.2)	311 (59.4)			
4	9 (2.7)	8 (1.9)			
Operative levels, n (%)					
1	272 (54.4)	266 (40.7)	30.44	**<0.001**	−0.315
2	143 (28.6)	217 (33.2)			
3	60 (12.0)	91 (13.9)			
4+	25 (5.0)	80 (12.2)			
PLIF	182 (36.5)	302 (46.2)	10.77	**0.001**	0.196
Preop PROMs					
Mean ODI ± SD	46.26 ± 15.1	48.00 ± 15.4	−1.92*	0.055	−0.114
Mean EQ-5D ± SD	0.6155 ± 0.2	0.6128 ± 0.2	0.32*	0.751	0.019
Mean NRS back pain score ± SD	6.87 ± 2.3	6.99 ± 2.2	−0.93*	0.354	−0.055
Mean NRS leg pain score ± SD	6.13 ± 2.8	6.26 ± 2.8	−0.82*	0.411	−0.049

GED = General Educational Development; HS = high school.
Only valid percentages are given; missing data were excluded from these calculations. Boldface type indicates statistical significance.

TABLE 2. Propensity score–matched patient population baseline demographics and clinical history

Variable	rhBMP-2, n = 330	OSTEOAMP, n = 330	t* or χ^2 Value	p Value	SMD
Demographics					
Mean age ± SD, yrs	64 ± 10.8	65 ± 10.6	−0.58*	0.561	−0.045
Mean BMI ± SD	30.21 ± 5.5	29.78 ± 6.0	0.94*	0.349	0.073
Males, n (%)	138 (41.8)	152 (46.1)	1.21	0.272	0.085
Race, n (%)					
Caucasian	244 (89.4)	256 (85.6)	2.67	0.263	−0.131
Black	27 (9.9)	37 (12.4)			
Other	2 (0.7)	6 (2.0)			
Hispanic/Latino, n (%)	4 (1.6)	8 (2.9)	0.99	0.319	0.087
Education, n (%)					
≤ HS graduate/GED	147 (45.1)	129 (40.6)	3.72	0.156	−0.138
2–4 yrs of college	136 (41.7)	130 (40.9)			
Post-college	43 (13.2)	59 (18.6)			
Employment, n (%)	116 (35.3)	107 (32.6)	0.51	0.475	0.056
Payer, n (%)					
Private	111 (33.6)	106 (32.1)	0.50	0.777	−0.011
Medicare	198 (60.0)	206 (62.4)			
Other	21 (6.4)	18 (5.5)			
Comorbidities, n (%)					
Smoker	45 (13.7)	40 (12.3)	0.26	0.613	0.040
Diabetes	46 (13.9)	44 (13.3)	0.05	0.821	0.018
Depression	57 (18.3)	63 (22.6)	1.69	0.193	−0.107
Anxiety	35 (11.2)	42 (15.1)	1.91	0.167	−0.114
Osteoporosis	19 (6.1)	21 (7.5)	0.48	0.487	−0.057
Clinical history					
Back pain, n (%)	315 (96.6)	307 (96.2)	0.07	0.791	0.021
Leg pain, n (%)	266 (82.1)	269 (85.4)	1.28	0.259	−0.089
ASA class, n (%)					
1	7 (2.1)	5 (1.5)	5.09	0.165	−0.021
2	169 (51.2)	162 (49.1)			
3	144 (43.6)	160 (48.5)			
4	10 (3.0)	3 (0.9)			
Operative levels, n (%)					
1	194 (58.8)	184 (55.8)	2.70	0.260	−0.009
2	96 (29.1)	114 (34.5)			
3	40 (12.1)	32 (9.7)			
PLIF	63 (19.1)	84 (25.5)	3.86	**0.049**	0.153
PROMs					
Mean ODI ± SD					
Preop	46.36 ± 15.2	46.02 ± 14.8	0.29*	0.772	0.023
1 yr	25.40 ± 20.7	26.56 ± 18.8	−0.75*	0.452	−0.059
Mean EQ-5D ± SD					
Preop	0.6049 ± 0.2	0.6030 ± 0.1	0.15*	0.878	0.012
1 yr	0.7317 ± 0.2	0.7279 ± 0.1	0.31*	0.759	0.029
Mean NRS back pain score ± SD					
Preop	6.99 ± 2.3	6.95 ± 2.2	0.25*	0.805	0.019
1 yr	3.70 ± 2.9	3.49 ± 2.7	0.96*	0.336	0.075

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TABLE 2. Propensity score–matched patient population baseline demographics and clinical history

Variable	rhBMP-2, n = 330	OSTEOAMP, n = 330	t* or χ^2 Value	p Value	SMD
PROMs (*continued*)					
Mean NRS leg pain score ± SD					
Preop	6.14 ± 2.8	6.23 ± 2.7	−0.42*	0.676	−0.033
1 yr	2.57 ± 2.9	2.52 ± 2.9	0.23*	0.822	0.018
Satisfaction w/ surgical outcomes, n (%)					
3 mos	262 (88.5)	272 (89.5)	0.41	0.707	0.031
1 yr	271 (83.1)	257 (80.1)	1.01	0.314	−0.079

Only valid percentages are given; missing data were excluded from these calculations. Boldface type indicates statistical significance.

median time to RTW was similar between cohorts (6.6 vs 7 weeks).

Discussion

Pseudarthrosis following lumbar interbody fusion can lead to recurrent back pain, poor functional outcomes, and the need for revision surgery. Therefore, achieving successful fusion is important to minimize patient morbidity and healthcare costs.[19] Various bone graft materials are currently available to augment arthrodesis including patient-derived autograft, cadaver-derived allografts, and synthetic bone grafts.[15,31] An autograft has long been considered the gold standard, but is limited by donor site morbidity, increased operative time, limited availability, and poor bone quality.[9,32]

Recombinant human BMP-2 was approved by the US FDA for use in anterior lumbar interbody fusion surgery in 2002, and its off-label use in other fusion procedures soon followed.[18] Several high-quality studies have compared the efficacy of rhBMP-2 to an autograft, with multiple reports indicating similar or improved fusion rates associated with its use.[5,16,18,33] However, several adverse effects of rhBMP-2 use have since been reported including inflammatory complications such as seromas or swelling, radiculitis, vertebral osteolysis, and ectopic bone growth.[21,34] Thus, alternative bone graft substitutes that increase fusion while limiting patient morbidity are still needed.

OSTEOAMP is a differentiated novel allograft with unique processing designed to retain a wide array of growth factors that support each stage of the bone healing cascade. The unique processing of this allogeneic implant maintains the bioavailability of growth factors found within bone marrow cells.[25] Proteomic assays of multiple lots of OSTEOAMP confirmed that physiologically relevant osteogenic growth factors from the transforming growth factor (TGF)–β/rhBMP-2 superfamily (including TGF-β1, -2, and -3, and rhBMP-2, -4, -5, -6, -7 and -9), as well as other cell-recruitment/differentiation and angiogenic factors (i.e., vascular endothelial growth factor, epidermal growth factor, insulin-like growth factor-1, and angiogenin/angiopoietins), are consistently present in the product.[25] Previous studies have shown high fusion rates with the use of OSTEOAMP in both lumbar and cervical fusion,[26,35] and an assessment of health economics demonstrated a per-patient cost reduction of 80.5% for OSTEOAMP relative to rhBMP-2.[26] To date, however, comparisons of this novel allograft to rhBMP-2, as well as the resultant effects on patient clinical outcomes, remain relatively sparse. In the current study, we performed a post hoc analysis utilizing a prospectively maintained data registry and used propensity score matching to compare 330 pairs of TLIF/

TABLE 3. Propensity score–matched 90-day safety and utilization

Variable	rhBMP-2, n = 330	OSTEOAMP, n = 330	t* or χ^2 Value	p Value
Mean EBL ± SD, ml	196.94 ± 188.6	212.58 ± 186.1	−0.99*	0.323
Mean duration of surgery ± SD, mins	160.10 ± 70.6	144.54 ± 45.8	3.17*	**0.002**
Mean LOS ± SD, days	2.23 ± 1.8	3.33 ± 1.8	−7.45*	**<0.001**
Discharge to facility, n (%)	17 (5.4)	15 (5.4)	0.001	0.977
Hospital readmission w/in 90 days, n (%)	9 (2.7)	17 (5.2)	2.56	0.109
Unplanned return to OR w/in 90 days, n (%)	8 (2.4)	11 (3.3)	0.49	0.485
Pseudarthrosis revision w/in 2 yrs, n (%)	6 (1.8)	8 (2.4)	0.29	0.589
Median time to pseudarthrosis revision ± SE, mos	15.00 ± 0.82	13.00 ± 3.65	1.55	0.213
Median time to RTW ± SE, wks	6.86 ± 0.6	7.00 ± 0.9	0.17	0.897

Boldface type indicates statistical significance.

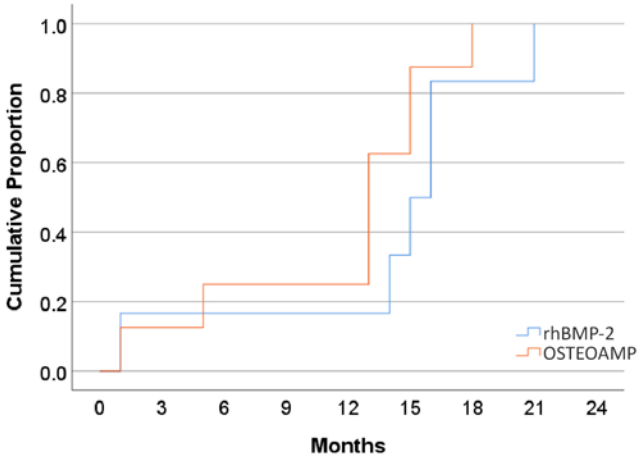

FIG. 1. Graph of propensity score–matched 2-year pseudarthrosis rates. The Kaplan-Meier survival curve shows similar pseudarthrosis rates at 24 months between the OSTEOAMP and rhBMP-2 cohorts. Figure is available in color online only.

PLIF patients whose fusion was augmented using either OSTEOAMP or rhBMP-2. Our results showed similar fusion rates at 2 years for patients with OSTEOAMP (97.6%) and rhBMP-2 (98.2%). We found no significant differences in 90-day readmissions or unplanned return to the operating room (OR), and no differences in time to RTW. Additionally, there were no differences across all PROMs between the groups up to 1 year.

Lumbar fusion rates with the use of various bone grafts have been well studied in the literature. A systematic review by Tuchman et al. evaluated fusion rates with the use of iliac crest bone graft and local autograft.[36] They found only 2 randomized controlled trials reporting fusion rates, both of which did not exceed 85%.[37,38] Previous studies have reported fusion rates with autograft use during interbody fusion. A retrospective study by Wang et al. reported a fusion rate of 83% in 40 patients who underwent PLIF with an autograft.[39] Another retrospective study by Khan et al. reported a fusion rate of 92.3% in 104 patients undergoing TLIF treated with an autograft.[16] A study of minimally invasive TLIF using an autograft similarly reported a fusion rate of 92%.[6] Buser et al. performed a systematic review to evaluate fusion rates with the use of autologous stem cells from bone marrow aspirate. In this review, the highest reported fusion rate for cases using bone marrow aspirate was 92%.[40]

The current literature exploring the effect of rhBMP-2 on interbody fusion rates is heterogeneous. The study by Khan et al. reported no differences in fusion rates for TLIF patients with and without rhBMP-2 use (92.7% vs 92.3%).[16] Other studies of minimally invasive TLIF with rhBMP-2 use have reported fusion rates of 92%–93%.[7,19] However, Crandall et al. reported a fusion rate of 99% at 5 years in 509 patients following TLIF with rhBMP-2.[20] Together, these studies demonstrate that rhBMP-2 use in TLIF is at least as efficacious at achieving fusion as an autograft. The overall fusion rate in our study was 98% (i.e., pseudarthrosis in approximately 2%). These findings suggest that both rhBMP-2 and the novel allograft can improve fusion rates compared with many of these reported historical norms. Furthermore, our results demonstrate significant improvements in PROMs up to 1 year with the use of both substrates. However, OSTEOAMP may provide the additive benefit of decreasing the potential proinflammatory complications related to rhBMP-2 use, such as reducing peripheral neuritis and ectopic bone formation[21] as well as incurring lower costs. In their study of 95 patients, Roh et al. conducted a formal cost analysis comparing this novel allograft to rhBMP-2.[26] They reported the novel allograft arm to be 80.5% less expensive per patient (73.7% per level) than the rhBMP-2 arm, with the supply cost associated with rhBMP-2 being US $2523.52 per level, while the cost of the novel allograft along with a Jamshidi needle used for bone marrow aspirate collection was $663.61. They also reported that the average volume of rhBMP-2 used inside the interbody device was 2.05 cc (3.07 mg) per level, while the OSTEOAMP arm utilized an average of 2.5 cc per level inside the spinal spacer.

Limitations of the Study

This study has inherent limitations. It is a nonrandomized observational study of a prospectively collected database. Therefore, selection bias cannot be fully excluded. Primarily, graft selection and surgical approach (PLIF vs TLIF) were at the discretion of the treating surgeon. We attempted to minimize this bias and others through propensity score matching with a high number of patients that created well-matched subject pairs. Additionally, the protocol for evaluation of fusion used in this study may not have captured all cases of pseudarthrosis. We specifically assessed for symptomatic pseudarthrosis. If a patient lacked back pain or motion on flexion-extension radiographs, they would not have undergone a CT scan and the asymptomatic lack of bridging bone could have been missed. However, all patients with motion or recurrent back pain at or beyond 6 months required a CT scan to be screened for the development of pseudarthrosis. We also feel that if there were a few patients who may have had a lack of solid bone fusion but who were pain free with no motion, from a health economic value and resource utilization perspective, they were achieving the same outcome as a full CT-defined bone-bridged patient. Third, our propensity score–matched dataset contained more PLIF cases in the OSTEOAMP versus rhBMP-2 cohort (25.5% vs 19.1%, $p = 0.049$). However, the 2-year pseudarthrosis rates between PLIF and TLIF procedures did not vary significantly (2.7 vs 1.9%, $p = 0.567$), which shows that more PLIF cases in the OSTEOAMP cohort did not skew the efficacy of the novel biological allograft. Finally, while this study reports rates of symptomatic pseudarthrosis at 2 years postoperatively, longer follow-up to 5 and 10 years would improve our understanding of the long-term clinical impact of OSTEOAMP use. Further prospective studies with extended follow-up are warranted.

Conclusions

Determining which bone graft substitutes minimize pseudarthrosis following lumbar interbody fusion is vi-

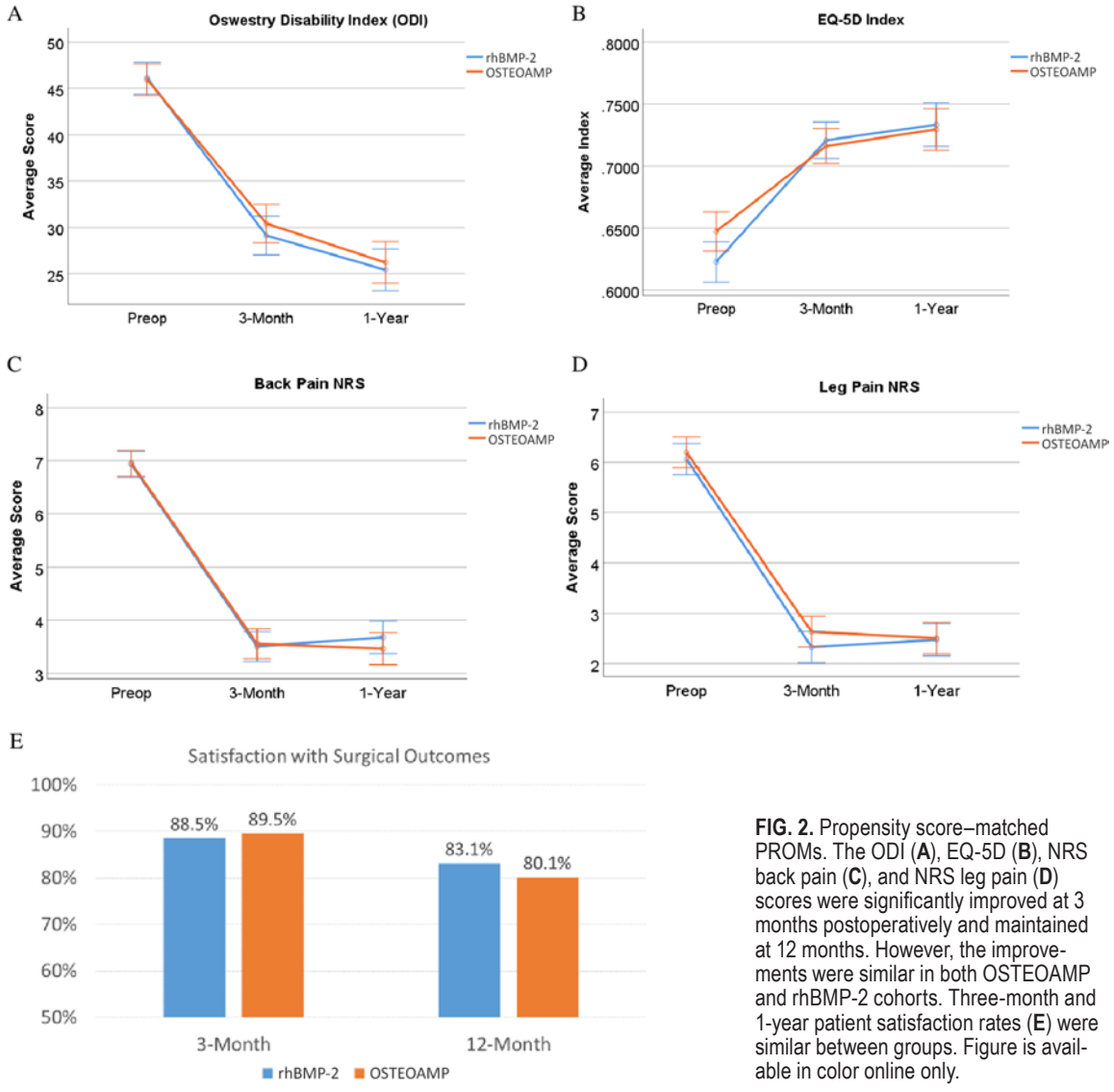

FIG. 2. Propensity score–matched PROMs. The ODI (**A**), EQ-5D (**B**), NRS back pain (**C**), and NRS leg pain (**D**) scores were significantly improved at 3 months postoperatively and maintained at 12 months. However, the improvements were similar in both OSTEOAMP and rhBMP-2 cohorts. Three-month and 1-year patient satisfaction rates (**E**) were similar between groups. Figure is available in color online only.

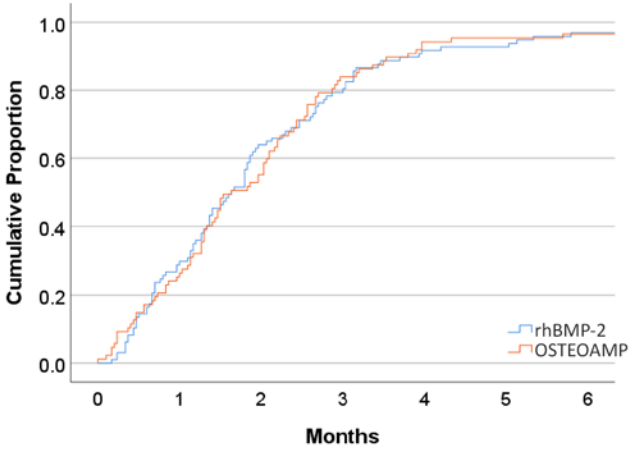

FIG. 3. Kaplan-Meier survival curve shows similar RTW rates in both the OSTEOAMP and rhBMP-2 cohorts. Figure is available in color online only.

tal to increase the value of a surgical intervention. This study demonstrates that the use of a novel allograft (OSTEOAMP) results in similar fusion rates compared to rhBMP-2 in TLIF/PLIF, which are both higher than literature values for other commercially available bone graft options. There were no major differences in perioperative or long-term clinical outcomes between the novel allograft and rhBMP-2. These data suggest that the novel allograft is a viable alternative to rhBMP-2 for use in lumbar interbody fusion.

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Author Contributions

Conception and design: McGirt, Hani, Kim, Bohl. Acquisition of data: Hani, Holland. Analysis and interpretation of data: Farber, Kim, Holland. Drafting the article: Hani, Farber, Kim, Holland. Critically revising the article: McGirt, Hani, Farber, Kim, Bohl, Holland. Reviewed submitted version of manuscript: McGirt, Hani, Farber, Kim, Bohl, Holland. Approved the final version of the manuscript on behalf of all authors: McGirt. Statistical analysis: Pfortmiller. Study supervision: McGirt, Kim.

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