Research Article
Volume 12:05, 2023

Journal of Spine

ISSN: 2165-7939 Open Access

Radiographic Evaluation of MI-TLIF Procedures Utilizing Novel Allograft Growth Factor

Samuel Joseph[1]* and Lauren Edge[1,2]

[1]*Department of Orthopaedics, Joseph Spine Institute, Tampa, Florida, USA*
[2]*HCA Healthcare / USF Morsani College of Medicine GME: HCA Florida Largo Hospital, Department of Orthopedic Surgery, Largo, Florida*

Abstract

Introduction: Minimally-invasive transforaminal lumbar interbody fusion offers a conservative surgical option designed to reduce complications. A novel allograft growth factor including multiple factors associated with bone remodeling is utilized and independently assessed for efficacy in supporting fusion.

Case presentation: To evaluate post-surgical follow-up radiology for fusion status of MI-TLIF levels implementing novel allograft growth factor to support bony remodeling

Methods: A fellowship trained orthopedic surgeon collected 102 consecutive studies and was granted a waiver by an Institutional Review Board for retrospective assessment of post-surgical radiology to follow state of fusion.

Results: At three months, 72 of 104 (69.2%) levels assessed were deemed to be fused, at six months 87 of 116 (75.0%) levels assessed were deemed to be fused, at twelve months 107 of 113 (94.7%) levels assessed were deemed to be fused, at eighteen months 107 of 109 (98.2%) levels assessed were deemed to be fused and ultimately at twenty-one months all 108 of 108 (100%) levels reviewed were deemed to be fused.

Conclusion: Novel allograft growth factor demonstrates efficacy with regards to supporting bony fusion with regards to MI-TLIF procedures observed.

Keywords: Minimally invasive • Transforaminal lumbar interbody fusion • Biologic • Allograft growth factor • Fusion • TLIF

Introduction

Beneficial to post-surgical healing, the Minimally Invasive Transforaminal Lumbar Interbody Fusion (MI-TLIF) procedure generally requires smaller instrumentation; however, the reduction in operative aperture can present unique challenges including reducing or limiting access to the disc space. Cages deployed to facilitate MI-TLIF have seen a progression of technology including the advent of expandable variations in the last decade, generally with the goal to better serve the microscopic environment common to the minimally invasive methodology. In recent years, biologics used to support remodeling associated with fusion of bone have grown beyond the single rhBMP approach. [1,2]. Additional growth factors important to these osteogenic cascades such as Transforming Growth Factor Beta (TGF-β), Fibroblast Growth Factor (FGF), Platelet-Derived Growth Factor (PDGF) and Vascular Endothelial Growth Factor (VEGF) have also proven beneficial to the paradigm [1-5].

Derived primarily from facetectomy and osteophyte removal, autograft collected in service of MI-TLIF procedures has shown to incorporate benefit from both the cortical bone lending structural support to the intervention as well as the cancellous bone shown to contain bone cells crucial to bony remodeling [4]. When used alone, local autograft has reported variable success [6-8]. These local components are often bolstered by iliac crest autograft which has remained the gold standard despite the challenges and morbidity associated with collection [9]. Many extenders such as Demineralized Bone Matrix (DBM) and various ceramic compounds have demonstrated benefit and have been increasingly employed to offset the risks associated with iliac crest collection methods [10].

Recombinant biologics including rhBMP-2 have long been used to assist surgeons in achieving interbody fusion of the lumbar spine [11-14]. On occasion the use of singular recombinant bone morphogenetic protein has also demonstrated complications including pseudoarthrosis [15-17]. Additionally, potential post-operative inflammatory changes hypothesized to be the result of supra-elevated concentrations of BMP-2 at the surgical site have also been reported [13-17].

A novel approach has been developed to harvest the growth factor content contained in the endosteal portion of allograft bone which provides a broad spectrum of proteins present in the native tissue. This endosteal allograft material contains many growth factors that have previously been cited in the literature to provide benefit to several aspects of bony remodeling. These include BMP-2, BMP-4, BMP-6, BMP-7, BMP-9, TGF-β, FGF-2, PDGF and VEGF among many others [2-5]. To date, single growth factor biologics including rhBMP-2, when paired with appropriate scaffold have demonstrated efficacy on par with the gold standard iliac crest autograft [1,2]. However, some have suggested the complications associated with its use is a product of a supraphysiological dose of a single growth factor. Instead, hydrating the scaffold with this novel allograft growth factor supports the use of a comprehensive collection of proteins to be used in promoting bony fusion, which better replicates the natural environment [12-14].

Materials and Methods

A single, fellowship trained orthopedic surgeon aggregated 102 consecutive patients requiring at least one-level, minimally invasive transforaminal lumbar interbody fusion over a window to include procedures from November 2018 thru August 2022. The 102 patients reviewed included

***Address for Correspondence:** Samuel Joseph, Department of Orthopaedics, Joseph Spine Institute, Tampa, Florida, USA, E-mail: sjosephmd.jsi@gmail.com*

Received: 14 September, 2023, Manuscript No. jsp-23-113828; **Editor Assigned:** 16 September, 2023, PreQC No. P-113828; **Reviewed:** 30 September, 2023, QC No. Q-113828; **Revised:** 07 October, 2023, Manuscript No. R-113828; **Published:** 16 October, 2023, DOI: 10.37421/2165-7939.2023.12.606

102 procedures. Available radiology was binned in reporting windows of 3, 6, 12, 18, and 24 months with each category including a margin of error of ± 1.5 months [15-17]. A waiver was granted by an Institutional Review Board (WIRB) for retrospective evaluation of radiology collected in order to follow and determine the state of fusion on any levels requiring surgical intervention in which ProteiOS® (Biologica Technologies, Carlsbad, CA) allograft growth factor was utilized [18,19]. Radiology assessment was independent radiologist reviewed and classified by state of fusion according to Brantigan, Steffee and Fraser criteria reproduced in (Table 1a).

Pathologies requiring the MI-TLIF procedure included pain, stenosis, radiculopathy, instability, kyphosis, spondylolisthesis and/or scoliosis. The cohort included two prior pseudoarthroses, two post-traumatic Herniated Nucleus Propulsi (HNP) and one individual diagnosed with sagittal imbalance (flat back syndrome). Pain presented the largest single diagnosis at time of procedure impacting 88 of the 102 patients involved (86.3%), followed by stenosis (64/102, 62.7%), radiculopathy (58/102, 56.9%) and instability (51/102, 51.0%), each impacting more than half of the cohort. Additionally, kyphosis (40/102, 39.2%), spondylolisthesis (31/102, 30.4%) and scoliosis (7/102, 6.9%) are represented as well as HNP (3/102, 2.9%), prior pseudoarthrosis (2/102, 2.0%), and sagittal imbalance (1/102, 1.0%) noted on (Table 2a).

Only 1 of 102 (1.0%) procedures included adjacent-level intervention to three levels and thus accounted for only 3 of 124 (2.4%) the levels reviewed. Another 20 of 102 procedures (19.6%) included adjacent-level intervention to two levels and thus accounted for 40 of 124 (32.2%) levels reviewed. The bulk of TLIF procedures reviewed were single level, 81 of 102 (79.4%), accounting for 81 of 124 (65.3%) levels reviewed.

Of the interventions reviewed by level, 1 of 124 (0.8%) occurred at L1-L2, 1 of 124 (0.8%) occurred at L2-L3, 7 of 124 (5.6%) occurred at L3-L4, 62 of 124 (50.0%) occurred at L4-L5 and 53 of 124 (42.7%) at L5-S1 noted on (Table 2b) (Figures 1-6).

In each of the procedures considered, the physician elected to utilize collagen-mineral matrices, demineralized bone fibers, or Demineralized Bone Matrix (DBM) where the scaffold was first rehydrated using the novel allograft growth factor as noted on (Table 2c).

Of the 102 patients included in this review providing 102 procedures or 124 levels, 56 were female (55.4%) and 46 were male (45.6%) with a median age of 61.8 years [21.5-88.9] with the youngest reported to be 21.5 years and the oldest reported to be 88.9 years. Of the 102 procedures considered 4 of 102 (3.9%) were aged 20 – 34.9 years, 16 of 102 (15.7%) were aged 35 – 49.9 years, 37 of 102 (36.3%) were aged 50 – 64.9 years, 38 of 102 (37.3%) were aged 65-79.9 years and 7 of 102 (6.9%) were aged 80 – 94.9 years at time of surgical intervention presented on (Table 2d).

Comorbidities within the cohort were reviewed and 35 of 102 (33.7%) patients did not report a comorbidity, 31 of 102 (30.4%) reported High Blood Pressure (HBP), with 12 of 102 (11.8%) reporting hypertension, 11 of 102 (10.8%) reported a thyroid condition, 10 of 102 (9.8%) reported heart disease, 9 of 102 (8.8%) reported osteoporosis, 7 of 102 (6.9%) reported rheumatoid arthritis, 5 of 102 (4.9%) reported lung disease, 4 of 102 (3.9%) reported diabetes, 3 of 102 (2.9%) reported osteoarthritis, 2 of 102 (2.0%) reported kidney disease, 2 of 102 (2.0%) reported stroke, 2 of 102 (2.0%) reported asthma, 2 of 102 (2.0%) reported a history of cancer, 1 of 102 (1.0%) reported multiple myeloma, 1 of 102 (1.0%) reported Lyme disease, 1 of 102 (1.0%) reported Meneire's disease, and 1 of 102 (1.0%) reported a history of myocardial infarction per (Table 2e).

Additional observation was accrued for a limited portion of the cohort with 25 of the 102 patients reviewed by the authors for extended profile data specifically regarding AHA status, smoking status, BMI, length of surgery, OR time, return visit (ER/OR) and infection. For the 25 of the 102 patients currently represented in this extended profile component, 15 of 25 (60.0%) reported status ASA III and the remaining 10 of 25 (40.0%) reported ASA II. Of the 25 extended-profile patients reviewed, 15 of 25 (60.0%) had no history of smoking, 10 of 25 (40.0%) had a history of smoking. Of those with a history of smoking, 8 of 10 (80.0%) responded as former smokers (cessation of smoking activity > 12M) and with one patient quitting prior to surgery and a single patient responding as an active smoker included in the recent and/or active smoker category or 2/10 (20.0%) as noted in (Table 2f).

Regarding the extended profile feature BMI reviewed on 25 of the 102 patients, 2 of 25 (8.0%) were within normal weight standards reporting a BMI

Table 1a. Classification of interbody fusion success: Brantigan Steffee Fraser (BSF).

(BSF) BSF-3: Radiographical fusion: Bone bridges at least half of the fusion area with at least the density originally achieved at surgery, radiographical fusion through one cage (half of the fusion area) is considered to be mechanically solid fusion even if there is lucency on the opposite side
BSF-2: Radiographical locked: Pseudoarthrosis is indicated by lucency visible in the middle of the cages with solid bone growing into the cage from each vertebral endplate
BSF-1: Radiographical pseudoarthrosis is indicated by collapse of the construct, loss of disc height, vertebral slip, broken screws, displacement of carbon cage, or significant resorption of the bone graft, or lucency visible around the periphery of the graft or cage

Table 2a. Cohort diagnosis pool (n=102).

Pain	88/102 (86.3%)
Stenosis	64/102 (62.7%)
Radiculopathy	58/102 (56.9%)
Instability	52/102 (51.0%)
Kyphosis	40/102 (39.2%)
Spondylolisthesis	31/102 (30.4%)
Scoliosis	7/102 (6.9%)
HNP	3/102 (2.9%)
Priorpseudoarthrosis	2/102 (2.0%)
Imbalance(sagittal)	1/102 (1.0%)

Table 2b. Breakdown by level (n=124).

L1-L2	1 (0.8%)
L2-L3	1 (0.8%)
L3-L4	7 (5.6%)
L4-L5	62 (50.0%)
L5-S1	53 (42.7%)
L1-L2	1 (0.8%)
Total	124

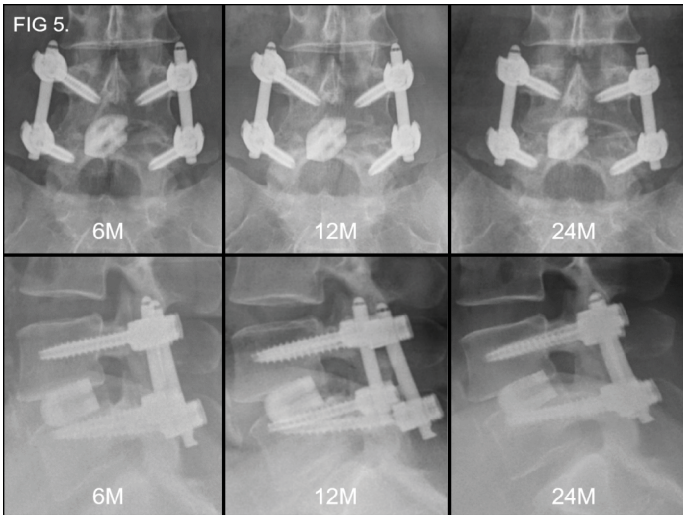

Figure 1. Radiograph series: GRAFT_0496 L4-L5 DOS 02/11/21 5cc ProteiOS/5cc Collagen-mineral putty.

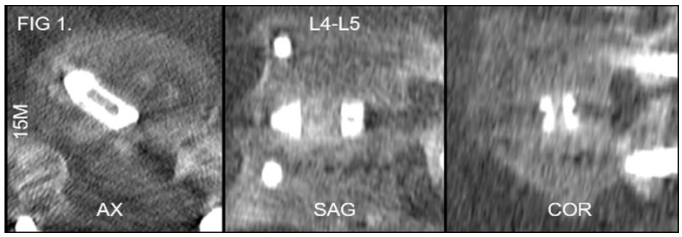

Figure 2. CT series: GRAFT_0025 L5-S1 DOS 04/30/19 5cc ProteiOS/5cc Collagen-mineral putty @15M.

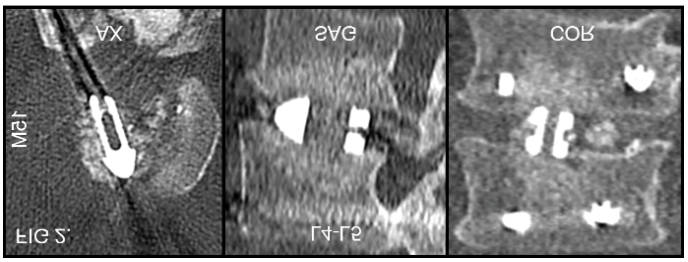

Figure 3. CT series: GRAFT_0092 L4-L5 DOS 12/31/19 5cc ProteiOS/5cc Collagen-mineral putty @12M.

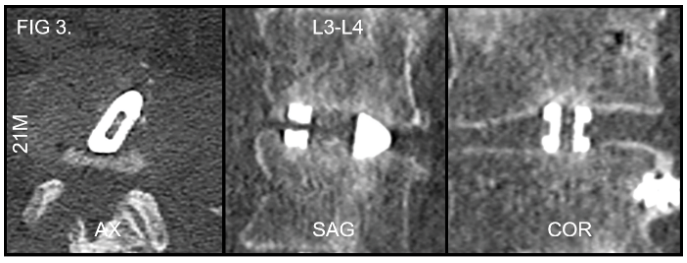

Figure 4. CT series: GRAFT_0187A L3-L4 DOS 11/07/20 5cc ProteiOS/5cc Collagen-mineral putty @21M.

greater than or equal to 18.5 to 24.9 kg/m^2, additionally 8 of 25 (32.0%) were classified as overweight reporting a BMI greater than or equal to 25 to 29.9 kg/m^2, finally 15 of 25 (60.0%) were classified as obese reporting a BMI great than or equal to 30 kg/m^2. Within the subcategory of those classified with obesity, 6 of 15 (40.0%) are classified as Obesity class I reporting a BMI 30 to 34.9 kg/m^2, 5 of 15 (33.3%) are classified as Obesity class II reporting a BMI 35 to 39.9 kg/m^2, and finally 4 of 15 (26.7%) are classified as Obesity class III reporting a BMI greater than or equal to 40 kg/m^2 (also referred to as severe, extreme or massive obesity) as noted with (Table 2g).

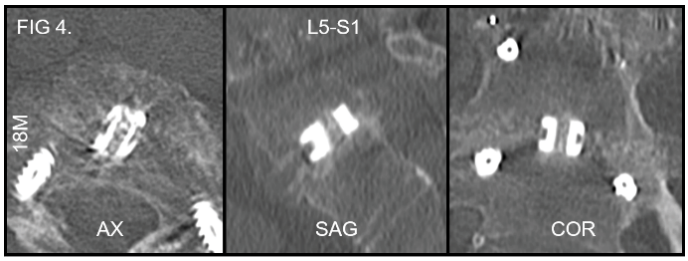

Figure 5. CT series: GRAFT_0404 L5-S1 DOS 03/25/21 5cc ProteiOS/5cc Collagen-mineral putty @ 18M.

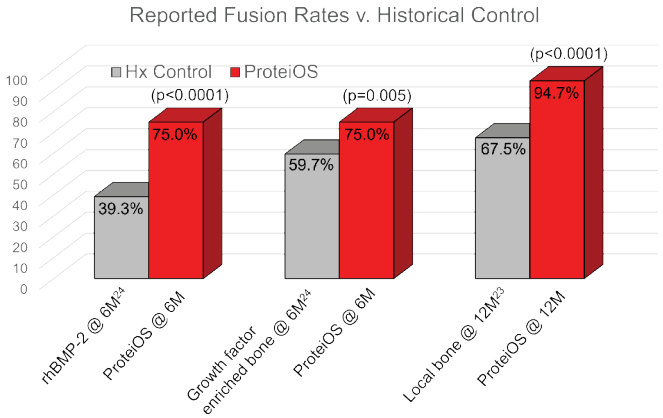

Figure 6. Reported fusion rates *vs.* reported historical control.

Table 2c. Breakdown by level (n=124).

Collagen-cineralputty	75 (73.5%)
Demineralizedbonefiber	22 (21.6%)
DBMw/cancellouschips	1 (1.0%)
DBMputty	1 (1.0%)
Collagen-mineral putty w/Demineralized bone fibers	3 (2.9%)
Total Procedures	102

Table 2d. Breakdown by scaffold (n=102).

20-34.9 years	4	3.9%
35-49.9 years	16	15.7%
50-64.9 years	37	36.3%
65-79.9 years	38	37.3%
80-94.9 years	7	6.9%
Total	102	-

Table 2e. Breakdown by age at date of procedure (n=102).

HBP	31/102 (30.4%)
Hypertension	12/102 (11.8%)
Thyroid	11/102 (10.8%)
Heart disease	10/102 (9.8%)
Osteoporosis	9/102 (8.8%)
Rheumatoid arthritis	7/102 (6.9%)
Lung disease	5/102 (4.9%)
Diabetes	4/102 (3.9%)
Osteoarthritis	3/102 (2.9%)
Kidney disease	2/102 (2.0%)
Stroke	2/102 (2.0%)
Asthma	2/102 (2.0%)
History of cancer	2/102 (2.0%)
Multiple myeloma	1/102 (1.0%)
Lyme disease	1/102 (1.0%)
Meneire's disease	1/102 (1.0%)
Myocardial infarction	1/102 (1.0%)

Table 2f. Limited profile breakdown regarding smoker *vs.* non-smoker (n=25).

Non-smoker	15 (60.0%)
History of smoking	10 (40.0%)
Former smoker (quit >1y)	8/10 (80.0%)
Active/Recent	2/10 (20.0%)
Total	25

Table 2g. Limited breakdown of bmi classification at time of procedure (n=25).

Normalweight(BMI ≥ 18.5to24.9 kg/m^3)	2	(8.0%)
Overweight(BMI ≥ 25to29.9 kg/m^3)	8	(32.0%)
ObesityclassI(BMI ≥ 30to34.9 kg/m^2)	6	(24.0%)
ObesityclassII(BMI ≥ 35to39.9 kg/m^2)	5	(20%)
Obesity class III (BMI ≥ 40 kg/m^3)	4	(16.0%)
Total	25	-

From the cohort of n=102, of the 25 patients with extended profile details available reviewed accounted for a total of 3594 minutes (59.9 hours) of surgery time or 5306 minutes (88.4 hours) of time booked in the operating room. The median surgery time was 136 minutes (2.3 hours) with the shortest reporting 63 minutes (1.0 hours) and the longest reporting 358 minutes (6.0 hours). Of the 25 reviewed, 1 of 25 (4.0%) returned to the OR for dehiscence, vac/closure, 1 of 25 (4.0%) returned to the OR with infection presenting after four months and 1 of 25 (4.0%) was re-admitted one-week post-operatively for observation with no additional surgery required; additionally one patient of the 25 reviewed (4.0%) presented to the ER with back pain at 18 months and underwent subsequent foraminotomy and spinal cord stimulator implantation at adjacent level and a final one of 25 patients (4.0%) returned to the ER and OR at 3.5 weeks post-operatively for subsequent revision to the operative level [20-23].

Results

At three months, 72 of 104 (69.2%) levels assessed were deemed to be fused, 28 of 104 (26.9%) levels demonstrated partial fusion and 4 of 104 (3.8%) presented with limited evidence of fusion and 20 levels did not include imaging for assessment at the three month interval. At six months 87 of 116 (75.0%) levels assessed were deemed to be fused, 26 of 116 (22.4%) levels demonstrated partial fusion and 3 of 116 (2.6%) presenting with limited evidence of fusion. At twelve months 107 of 113 (94.7%) levels assessed were deemed to be fused, with 5 of 113 (4.4%) demonstrating partial fusion and 1 of 113 (0.9%) presenting with limited evidence of fusion. At eighteen months 107 of 109 (98.2%) levels assessed were deemed to be fused with the remaining 2 of 109 (1.8%) levels demonstrating partial fusion. At twenty-one months all 108 of 108 (100%) levels reviewed were deemed to be fused as presented with (Table 3a).

Regarding those patients for which an extended profile was collected (n=25), a comparative analysis was produced regarding fusion rates between those with a history of smoking *vs.* those without. 5 of 10 (50.0%) reported fused at three months for those with a history of smoking *vs.* 11 of 15 (73.3%) reported fused at three months for those without a history of smoking. At six months, 7 of 10 (70%) reported as fused for those with a history of smoking *vs.* 13 of 15 (86.7%) for those without a history of smoking. At twelve months, 8 of 10 (80.0%) reported as fused for those patients with a history of smoking with all 15 of 15 (100.0%) of those reported with no history of smoking reported as fused. The remaining smokers reported as fused at eighteen and twenty-one months respectively. Ultimately, all those for which extended profile information was made available reported as fused (25/25, 100%) regardless of smoking status as noted in (Table 3b). A chi-square test of independence showed no significant association between smoking status and fusion outcome (p=0.285).

Discussion

MI-TLIF procedures utilizing the novel allograft growth factor resulted in superior fusion rates as compared to reported fusion rates for autograft and other advanced orthobiologics products. Fusion rates for MI-TLIF procedures utilizing local bone were reported by Kasliwal MK, et al. at 12 months were 67.5%. Fusion rates of rhBMP-2 and a growth factor enriched allograft reported by Roh JS, et al. at 6 months were 39.3% and 59.7%, respectively. Using a chi-square test to compare the studies, utilization of ProteiOS resulted in higher fusion rates than local bone (p<0.0001), rhBMP-2 (p<0.0001), and growth factor enriched allograft bone (p=0.005). While context may be limited due to the variables each of these studies may have in common, this comparison suggests that successful fusion is not only more prevalent in ProteiOS treated cases but also may occur at a faster rate than the other alternatives mentioned in Figure 1.

Table 3a. Limited profile breakdown regarding smoker *vs.* non-smoker (n=25).

Reporting window	3M	6M	12M	18M	24M
BSF-3:	72	87	107	107	108
BSF-2:	28	26	5	2	0
# of levels	104	116	113	109	108
BSF-3 @	69.2%	75.0%	94.7%	98.2%	100.0%
BSF-2 @	26.9%	22.4%	4.4%	1.8%	0.0%
BSF-1 @	3.8%	2.6%	0.9%	0.0%	0.0%

Table 3b. Limited fusion results comparing non-smoker *vs.* smoker by month (n=25).

Duration	BSF-3 @ 3 months*	BSF-3 @ 6 months*	BSF-3 @ 12 months*	BSF-3 @ 18 months*	BSF-3 @ 21 months*
Non-smoker	11/15 (73.3%)	13/1 (86.7%)	15/5 (100%)	15/5 (100%)	15/5 (100%)
Hx of smoking	5/10 (50.0%)	7/100 (70.0%)	8/10 (80.0%)	9/10 (90.0%)	10/10 (100%)

Bone remodeling and repair is a complex process that requires the cooperative functions of a myriad of cells and growth factors that occur over a regulated spaciotemporal framework. An ideal biomaterial used in these procedures would be well served to recapitulate this environment as much as possible. It has been shown that BMP-2, BMP-4 and TGF-β are instrumental in recruiting precursor cells to where bony remodeling is needed and encourage proliferation and differentiation [13,18,19]. Additionally, IGF-1 and PDGF-BB have been shown to induce migration of bone cells critical to all phases of bony remodeling and induce osteogenesis [13,20,21]. Acknowledging the need for ample blood supply to facilitate healing, FGF and VEGF are known angiogenic factors required for neovascularization [2,22]. The necessity and integration of each of these growth factors within the cascades proven to be instrumental to bony healing imply a benefit beyond what a singular protein might provide.

Furthermore, when considering those individuals diagnosed with existing comorbidities such as tobacco use, diabetes and/or other vascular disease, the inherent benefit of a providing a multi-factored graft in amounts consistent with native tissue to support bony healing should not be underestimated. Within the cohort, a number of these patients had known comorbidities each of which individually contribute to the potential for interruption to multiple remodeling cascades. The advent of an allograft solution that provides these native factors may be of value in those patients with evidence of these comorbidities.

In recognition of the limitations of this review, the analyses were retrospective case reviews with a relatively small patient cohort. Absent patient demographics and control groups, limited correlations with time to fusion can be reached. Additionally, an evaluation of the operative time associated with this allograft as compared to other common grafts routinely employed with equivalent procedures could provide additional value. Continued research into this novel biologic will be beneficial as additional data becomes available.

Conclusion

The novel allograft growth factor used to support bony fusion was found to be efficacious in this retrospective study of interbody fusions done in the

lumbar spine. This donor-derived growth factor offers an allograft solution that provides a safe, effective alternative in scenarios where autograft availability is limited or contraindicated. Additionally, this allograft tissue option contains a myriad of growth factors involved in bone healing which may be more successful in a bone fusion surgical setting as compared to single-factor recombinant options currently available.

HCA Healthcare Disclaimer

This research was supported (in whole or in part) by HCA Healthcare and/or an HCA Healthcare affiliated entity. The views expressed in this publication represent those of the author(s) and do not necessarily represent the official views of HCA Healthcare or any of its affiliated entities.

References

1. Parajón, Avelino, Marjan Alimi, Rodrigo Navarro-Ramirez and Paul Christos, et al. "Minimally invasive transforaminal lumbar interbody fusion: Meta-analysis of the fusion rates. What is the optimal graft material?" *Neurosurg* 81 (2017): 958-971.
2. Zhang, Wenjie, Chao Zhu, Yiqun Wu and Dongxia Ye, et al. "VEGF and BMP-2 promote bone regeneration by facilitating bone marrow stem cell homing and differentiation." *Eur Cell Mater* 27 (2014): 1.
3. Caggiari, Gianfilippo, Giulia R. Mosele, Leonardo Puddu and Emanuele Ciurlia, et al. "Efficacy of platelet-rich plasma in experimental instrumented interbody spinal fusion." *Euro Mediterranean Biomed J* 11 (2016).
4. Roberts, Timothy T and Andrew J. Rosenbaum. "Bone grafts, bone substitutes and orthobiologics: The bridge between basic science and clinical advancements in fracture healing." *Organogenesis* 8 (2012): 114-124.
5. Finkemeier, Christopher G. "Bone-grafting and bone-graft substitutes." *JBJS 84* (2002): 454-464.
6. Zhang, Dapeng, Keya Mao and Xiaojun Qiang. "Comparing minimally invasive transforaminal lumbar interbody fusion and posterior lumbar interbody fusion for spondylolisthesis: A STROBE-compliant observational study." *Medicine* 96 (2017).
7. Huang, Peng, Yiguo Wang, Jiao Xu and Bo Xiao, et al. "Minimally invasive unilateral pedicle screws and a translaminar facet screw fixation and interbody fusion for treatment of single-segment lower lumbar vertebral disease: Surgical technique and preliminary clinical results." *J Orthop Surg Res* 12 (2017): 1-8.
8. Yang, Yang, Bin Liu, Li-Min Rong and Rui-Qiang Chen, et al. "Microendoscopy-assisted minimally invasive transforaminal lumbar interbody fusion for lumbar degenerative disease: Short-term and medium-term outcomes." *Int J Clin Exp* 8 (2015): 21319.
9. Greene, Allison C and Wellington K. Hsu. "Orthobiologics in minimally invasive lumbar fusion." *J Spine Surg* 5 (2019): S11.
10. Mokawem, Michael, Galateia Katzouraki, Clare L. Harman and Robert Lee. "Lumbar interbody fusion rates with 3D-printed lamellar titanium cages using a silicate-substituted calcium phosphate bone graft." *J Clin Neurosci* 68 (2019): 134-139.
11. Egashira, Kazuhiro, Yoshinori Sumita, Weijian Zhong and Takashi I, et al. "Bone marrow concentrate promotes bone regeneration with a suboptimal-dose of rhBMP-2." *PLoS One* 13 (2018): e0191099.
12. Schmidmaier, Gerhard, Britt Wildemann, Daniel Ostapowicz and Frank Kandziora, et al. "Long-term effects of local growth factor (IGF-I and TGF-β1) treatment on fracture healing: A safety study for using growth factors." *J Orthop Res* 22 (2004): 514-519.
13. Singh, Kern, Sreeharsha V. Nandyala, Alejandro Marquez-Lara and Thomas D. Cha, et al. "Clinical sequelae after rhBMP-2 use in a minimally invasive transforaminal lumbar interbody fusion." *Spine J* 13 (2013): 1118-1125.
14. Hsu, Wellington K., Mahesh Polavarapu, Rehan Riaz and Gilbert C. Roc, et al. "Nanocomposite therapy as a more efficacious and less inflammatory alternative to bone morphogenetic protein-2 in a rodent arthrodesis model." *J Orthop Res* 29 (2011): 1812-1819.
15. Hoffmann, Martin F., Clifford B. Jones and Debra L. Sietsema. "Complications of rhBMP-2 utilization for posterolateral lumbar fusions requiring reoperation: A single practice, retrospective case series report." *Spine J* 13 (2013): 1244-1252.
16. Tang, Yi, Xiangwei Wu, Weiqi Lei and Lijuan Pang, et al. "TGF-β1–induced migration of bone mesenchymal stem cells couples bone resorption with formation." *Nat Med* 15 (2009): 757-765.
17. Chen, Guiqian, Chuxia Deng and Yi-Ping Li. "TGF-β and BMP signaling in osteoblast differentiation and bone formation." *Int J Biol Sci* 8 (2012): 272.
18. Granero-Molto, Froilan, Timothy J. Myers, Jared A. Weis and Lara Longobardi, et al. "Mesenchymal Stem Cells expressing Insulin-like Growth Factor-I (MSCIGF) promote fracture healing and restore new bone formation in Irs1 knockout mice: Analyses of MSCIGF autocrine and paracrine regenerative effects." *Stem Cells* 29 (2011): 1537-1548.
19. Hock, Janet M., Michael Centrella and Ernesto Canalis. "Insulin-like growth factor I has independent effects on bone matrix formation and cell replication." *Endocrinology* 122 (1988): 254-260.
20. Pearson, Hope B., Devon E. Mason, Christopher D. Kegelman and Liming Zhao, et al. "Effects of bone morphogenetic protein-2 on neovascularization during large bone defect regeneration." *TEA Epub* 25 (2019): 1623-1634.
21. Kasliwal, Manish K and Harel Deutsch. "Clinical and radiographic outcomes using local bone shavings as autograft in minimally invasive transforaminal lumbar interbody fusion." *World Neurosurgery* 78 (2012): 185-190.
22. Roh, Jeffrey S., Christopher A. Yeung, Justin S. Field and R. Trigg McClellan. "Allogeneic morphogenetic protein *vs.* recombinant human bone morphogenetic protein-2 in lumbar interbody fusion procedures: A radiographic and economic analysis." *J Orthop Surg Res* 8 (2013): 1-7.
23. Gavaskar, Ashok S and Naveen T. Chowdary. "Valgus sliding subtrochanteric osteotomy for neglected fractures of the proximal femur; Surgical technique and a retrospective case series." *J Orthop Surg Res* 8 (2013): 1-6.

How to cite this article: Joseph, Samuel and Lauren Edge. "Radiographic Evaluation of MI-TLIF Procedures Utilizing Novel Allograft Growth Factor." *J Spine* 12 (2023): 606.