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Recombinant Human Bone Morphogenetic Protein-2-Augmented Transforaminal Lumbar Interbody Fusion for the Treatment of Chronic Low Back Pain Secondary to the Homogeneous Diagnosis of Discogenic Pain Syndrome

Two-Year Outcomes

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Study Design. A retrospective observational study.

Objective. To assess clinical outcomes, perioperative complications, revision surgery rates, and recombinant human bone morphogenetic protein-2 (BMP-2)-related osteolysis, heterotopic bone, and unexplained postoperative radiculitis (BMPP) in a group of patients treated with BMP-2-augmented transforaminal lumbar interbody fusion (bTLIF) for the homogeneous diagnosis of discogenic pain syndrome (DPS) and to put forth the algorithm used to make the diagnosis.

Summary of Background Data. There is a paucity of literature describing outcomes of TLIF for the homogeneous diagnosis of DPS, an old but controversial member of the lumbar degenerative disease family.

Methods. The registry from a single surgeon was queried for patients who had undergone bTLIF for the homogeneous diagnosis of DPS, which was made *via* specific diagnostic algorithm. Clinical outcomes were determined by analyzing point improvement from typical outcome questionnaires and the data from Patient Satisfaction and Return to Work questionnaires. Independent record review was used to assess all outcomes.

Results. Eighty percent of the cohort (36/45) completed preoperative and postoperative outcome questionnaires at an average follow-up of 41.9 ± 11.9 months, which demonstrated significant clinical improvement: Oswestry Disability Index = 16.4 ($P < 0.0001$), 12-Item Short Form Health Survey physical component summary score = 10.0 ($P < 0.0001$), and a Numeric Rating Scale for back pain = 2.3 ($P < 0.0001$). The median patient satisfaction score was 9.0 (10 = complete satisfaction), and 84.4% (27/32) of the cohort were able to return to their preoperative job, with or without modification. There were 3 perioperative complications, 4 revision surgical procedures, and 11 cases of benign BMPP. There were no incidents of the intraoperative dural tears or nerve root injury, and litigation involvement (11/36, $P > 0.17$), preoperative depression (15/36, $P > 0.19$) or prior discectomy/decompression (14/36, $P < 0.37$) was not a predictor of outcomes.

Conclusion. Although limited by retrospective design and small cohort, the results of this investigation suggest that bTLIF is a reasonable treatment option for patients who experience DPS and affords high patient satisfaction. A larger study is needed to confirm these findings.

Key words: transforaminal lumbar interbody fusion, recombinant human bone morphogenetic protein-2, clinical outcomes, discogenic pain syndrome, internal disc disruption, isolated disc resorption, chronic low back pain, BMP phenomena, perioperative complications, revision surgery, pseudoarthrosis.

Level of Evidence: 4

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Spinal arthrodesis (fusion) is one option for the management of debilitating degenerative disorders of the lumbar spine, which were refractory to nonoperative care.[1–3] During the past decade, one particular fusion technique, transforaminal lumbar interbody fusion (TLIF), has gained popularity within the surgical community[4–6] secondary to purported lower rates of perioperative patient morbidity[7–11] with the equivalent clinical outcomes as compared with the other techniques for lumbar fusion.[12–14]

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First described by Harms and Jeszenszky in 1998,[4] TLIF has been advocated as a less invasive technique that allows for fusion of the anterior and posterior columns from a unilateral, extracanalar approach, which in turn affords less destruction of the posterior arch, allows for better access to the neuroforamina, and reduces retraction of the dural sac and nerve roots.

Of the lumbar diagnoses along the degenerative cascade, discogenic pain syndrome (DPS) has been found particularly resistant to all forms of treatment[2,15–23] and has an estimated prevalence between 26% and 42% of patients with chronic low back pain.[24–26] Originally described in the 1970s,[27] DPS, which has also been called "symptomatic disc degeneration,[12,28] symptomatic degenerative disc disease,[29] degenerative disc disease,[30] disc degeneration,[31] isolated disc resorption,[27] spondylosis,[32] internal disc disruption,[33] and/or disc pathology,"[15] remains poorly understood and even controversial. Although not active in every diseased disc (for reasons yet to be elucidated), DPS occurs when nociceptors within the periphery of the disc and/or vertebral endplates[27] become chronically activated secondary to pathological biomechanical[34,35] and/or biochemical[36,37] mechanisms.

Although investigational treatments exist,[38,39] interbody fusion remains the "gold standard," in which much of the pain-generating disc/endplates are removed, and the anterior and posterior columns of the affected motion segment(s) are fused into 1 unit, thereby eliminating pain-generated micromotion.[28,20]

Perhaps secondary to its controversial nature, there remains a paucity of literature regarding the clinical outcomes of TLIF for the treatment of patients with the homogeneous diagnosis of DPS. In fact, results of a literature review discovered only 1 limited TLIF investigation on the subject,[16] because the majority used cohorts with heterogeneous diagnoses.[6,28,32,40–45] Therefore, the purpose of our investigation was to assess, *via* independent review, clinical outcomes; perioperative complications; revision surgery rates; and the prevalence of recombinant human bone morphogenetic protein-2 (BMP-2)-related heterotopic bone, osteolysis, and unexplained postoperative radiculitis, collectively called "BMP phenomena (BMPP)," from a group of patients who had undergone BMP-2-augmented TLIF (bTLIF) for the homogeneous diagnosis of DPS. A secondary purpose was to put forth our specific algorithm for making the diagnosis of DPS.

MATERIALS AND METHODS

Inclusion and Exclusion Criteria

With institutional review board approval, the registry from a single-surgeon spine clinic was queried for patients who had undergone open TLIF for the homogeneous diagnosis of DPS between January 2005 and August 2010. Further inclusion criteria were patient age between 18 and 72 years, complaints of lower back pain greater than lower extremity pain, and failure of at least 6 months of conservative care. Exclusion criteria included greater than 2 levels of involvement, lumbar scoliosis greater than 10°, significant stenosis, spondylolysis or spondylolisthesis, instability, and disc herniation that resulted in lower extremity pain greater than low back pain.

Making the Diagnosis

To make the diagnosis of DPS, there must have been a history of chronic debilitating low back pain that failed at least 6 months of conservative care. In addition, at least 2 of the following criteria must have been met: (1) severe patient intolerance to loading of the lumbar spine (especially the combination of sitting and vibration), with dramatic relief after unloading; (2) positive discography (see the next paragraph); (3) failed diagnostic blocks of the facet and/or sacroiliac joints; and/or (4) imaging findings of severe disc space collapse, endplate sclerosis, or Modic changes (i.e., internal disc resorption).

In the majority of the cases (30/36), standard provocative discography with computed tomographic (CT) follow-up was used and deemed positive if the following criteria were satisfied: (1) the intended surgical level(s) demonstrate at least 6/10 concordant pain upon pressurization, (2) an adjacent disc was found to be nonpainful, and (3) CT follow-up demonstrated the presence of a full-thickness annular tear.

Data Gathering

After independent review of pertinent medical and imaging records by a doctor not associated with patient care (D.M.G.), the rate of perioperative complications (complications occurring during or up to 6 wk status post), revision surgical procedures, and BMPP were gathered. Perioperative complications were defined as dural tear, nerve root injury, iatrogenic fracture, infection, seroma, hematoma, deep vein thrombosis, pulmonary embolism, and cage subsidence/extrusion.

The success of early fusion was assessed *via* postoperative CT scans as interpreted by the senior author, which, as part of our standard of care, were obtained from all patients between 4 and 7 months status post. Patients who failed to demonstrate cortical struts spanning the disc space or solid fusion of at least one the facet regions and intertransverse fusion beds were declared nonfused and followed to see whether or not solid fusion ever occurred.

Surgical Procedure

All patients underwent a single- or double-level TLIF by the senior author, which was augmented by posterolateral fusion, Texas Scottish Rite Hospital (TSRH) posterior pedicle screw-rod instrumentation (Medtronic Sofamor Danek, Memphis, TN) and a Boomerang polyetheretherketone interbody device (Medtronic Sofamor Danek, Memphis, TN). The generalities of this surgical procedure have been described previously[4,46] and will not be presented in this article. In addition, all procedures were augmented, in an off-labeled manner, with the osteobiologic BMP-2 (Medtronic Sofamor Danek, Memphis, TN) to reduce the time for solid fusion and obviate chances of pseudoarthrosis.

BMP-2 Preparation and Distribution

At each level of fusion, a large kit II of BMP-2 was used and prepared in accord with the manufacturer's instructions by soaking the BMP-2 solution into the type I absorbable collagen sponge (InFUSE; Medtronic Sofamor Danek, Memphis, TN) for 30 minutes. The BMP-soaked sponge was then morselized with locally harvested bone, which created an easy-to-work with BMP paste. The dosage of BMP-2 within the paste was 12 mg per motion segment at a standard concentration of 1.5 mg/mL. No allograft or autologous iliac crest bone were used, and the typical distribution of BMP paste per level was 6 mg in the interbody space, which was placed anterior to the cage, against the annulus fibrosis and not in the cage itself; 4 mg in the contralateral decorticated facet and intertransverse fusion bed; and 2 mg ipsilaterally in the intertransverse fusion bed and facetectomy region.

Outcome Assessment Tools

Preoperative and postoperative patient-completed outcome questionnaires (PCOQs) included the Oswestry Disability Index, a 0- to 10-point numeric rating scale for back pain (10 = worst imaginable pain), and the physical component of the 12-Item Short Form Health Survey (SF-12 PCS). Two other questionnaires were also used: a 0- to 10-point patient satisfaction instrument (10 = complete satisfaction), and a 0- to 4-point return to work instrument designed to assess the patients' ability to return to their preoperative job (0 = unable to return at all, 4 = return without limitations). The patients were also divided into a light work group and a heavy work group, based upon the physicality of their preoperative employment. Clinical outcomes were assessed by comparing preoperative with postoperative point improvement on the PCOQs, as well as analyzing patient satisfaction and return to work data.

Statistical Analysis

Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY). All continuous variables were found to be normally distributed, which allowed for parametric testing. Possible predictors of clinical outcomes included demographics as well as preoperative variables, whereas postoperative improvement in PCOQs was used as response variables. Independent sample *t* tests (2-tailed) were used to test associations between binary predictors and continuous outcomes. Pearson correlations were used to investigate the relationship between continuous predictors and clinical outcomes.

RESULTS

Demographic Data Analysis

Analysis of typical demographic variables and preoperative job classification (Tables 1–3) demonstrated that being female ($P = 0.03$) or young in age ($P = 0.02$; $r = -0.40$) were predictors of clinical outcomes. None of the other variables were predictive of clinical outcomes (Table 4).

TABLE 1. Patient Demographics

Demographics	Mean	Range
Age, yr	43.9	26.7–66.5
Height	69 in.	61–79 in.
Weight	166.7 lb	115–230 lb
BMI	24.6 kg/m^2	19.1–33.0 kg/m^2

BMI indicates body mass index.

Procedural Data Analysis

All patients underwent either a single- (24/36) or double-level (12/36) TLIF with the following frequency distributions: L2–L3 (1/36), L3–L4 (3/36), L4–L5 (13/36), and L5–S1 (31/36) for a total of 48 lumbar levels fused.

Perioperative Complications, Revision Surgery, BMPP, and Fusion Status

Perioperative complications were experienced in 8.3% (3/36) of the cohort and included 2 cases of pedicle screw placement failure (secondary to osteoporosis) and 1 case of postoperative peridiscal hematoma with associated cage extrusion (this ultimately went on to revision surgery); however, there were no cases of infection, nerve root injury, or dural tear. Revision surgery (Table 5) was necessitated in 11.1% (4/36) of the cohort; however, statistical analysis revealed no difference in clinical outcomes between the revision surgery group and rest of the cohort ($P > 0.13$). BMPP (ectopic bone, n = 3; osteolysis, n = 8; and radiculitis, n = 0) were observed collectively in 30.6% (11/36) of the cohort; however, its manifestation was not associated with any known adverse effects, such as the need for revision surgery, or change in health status and as a group demonstrated an equivalent clinical outcome on all PCOQs ($P > 0.48$).

As demonstrated on CT scan, delayed early fusion occurred in 8.3% of the cohort (4/36) secondary to the appearance of only woven bone in the disc space. However, all of these patients eventually went on to solid fusion as demonstrated on radiographs (n = 2) and CT scans (n = 2), at an average time point of 14.9 months (range, 12.4–18.4 months).

TABLE 2. Patient Demographics and Preoperative Medical Conditions

Demographics	
Males	61.1% (n = 22)
Females	38.9% (n = 14)
Smoking history	52.8% (n = 19)
Previous surgery	30.9% (n = 14)
Litigation	30.6% (n = 11)
Low back pain only	13.9% (n = 5)
Depression	41.7% (n = 15)

TABLE 3. Job Categorization (n = 32)

Heavy Preoperative Jobs (n = 7)	Return to Work Score	Light Preoperative Jobs (n = 25)	Return to Work Score
General contractor (n = 1)	4	Physician assistant	4
Mason (n = 1)	1	Security guard	0
Ski patrol (n = 1)	2	Architect	4
Landscaper (n = 2)	4, 4	College professor	4
Labor/construction (n = 1)	1	Firefighting management (n = 2)	4, 0
Law enforcement (n = 1)	4	Account executive	4
		Light-duty truck driver	1
		Administrative/desk work (n = 2)	4, 4
		Construction management	4
		Catering management	4
		Real estate agent/broker	4
		Property management (n = 2)	3, 2
		City administrations	4
		Office equipment service technician	0
		Film industry (props)	0
		Golf operations	4
		Interior designer	3
		Computer technician	4
		Medical technologist	2
		Teacher	4
		Bookkeeper	0
		Flight attendant	4

TABLE 4. Demographic Effect on Clinical Outcome

Variable	n =	ODI *P*	SF-12 (PCS) *P*	NRS–LBP *P*	Statistical Test
Age* (younger age = better improvement)	36	0.47	0.02*,†	0.86	2-tailed *t* test and Pearson correlation
Sex* (female = better improvement)	36	0.16	0.03*	0.13	2-tailed *t* test for each
Smoking history	19	0.43	0.83	0.73	2-tailed *t* test, Welch test, and 2-tailed *t* test
BMI*	36	0.81	0.91	0.88	2-tailed *t* test and Pearson correlation
Compensation	11	0.28	0.17	0.65	2-tailed *t* test for each
Depression	15	0.19	0.44	0.76	2-tailed *t* test for each
Previous surgery	14	0.37	0.70	0.87	Welch test, 2-tailed *t* test, and 2-tailed *t* test
Back pain only	5	0.55	0.87	0.79	2-tailed *t* test for each

Total cohort = 36.

**Statistically significant positive influence on clinical outcome.*

†r = − 0.402.

ODI indicates Oswestry Disability Index; SF-12, 12-Item Short Form Health Survey; PCS, physical component summary score; NRS, numeric rating scale; LBP, low back plain; BMI, body mass index.

TABLE 5. Revision Surgery Data

Case	Sex (Age in Years)	BMI (kg/m²)	Smoking History	Index Procedure	Revision Procedures	Elapsed Time (mo)	Pt. Improvement on the ODI, SF-12 PCS, and the bNRS. (Group Average)	Notes
#1	Male (30.0)	22.53	No	L5–S1 TLIF	Hardware removal	20.9	−9.0 (17.7) −4.9 (9.8) 0.0 (2.4)	*The patient had continued low back pain for which hardware removal was completed.
#2	Female (56.7)	25.01	No	L3–L4 TLIF	(1) Adjacent-level discectomy (2) Same adjacent-level TLIF for collapse and recurrent HNP	3.9 and 9.4	−8.0 (17.7) 6.7 (9.8) 2.0 (2.4)	*4 mo after index procedure, HNP occurred in right IVF at the inferior adjacent level. After failed microdiscectomy, TLIF was performed for recurrent herniation and foraminal collapse.
#3	Female (27.2)	21.7	Yes	L5–S1 TLIF	Hardware removal	16.1	22.0 (17.7) 30.9 (9.8) 3.0 (2.4)	*After 1 yr of pain relief, patient developed low back pain secondary to barometric change; instrumentation removal was completed as a treatment intervention.
#4	Female (34.2)	26.6	Yes	L5–S1 TLIF	(1) Decompression for cage extrusion (2) Second decompression and instrumentation removal	2 and 15.9	20.0 (17.7) 14.0 (9.8) 2.0 (2.4)	*2 mo after the index procedure, decompressive revision surgery was necessitated secondary to a cage extrusion and bone spur into the IVF. 15.9 mo status post, a second decompressive surgery, with instrumentation removal, was necessitated for scar tissue and bone spur removal secondary to continued complaints of radiculitis.
	Average: 37.0	Average: 24.0				Average: 11.4	Group averages: 21.0 (17.7) 22.5 (9.8) 2.5 (2.4) *P* values: 0.78, 0.14, and 0.95	

BMI indicates body mass index; ODI, Oswestry Disability Index; SF-12, 12-Item Short Form Health Survey; PCS, physical component summary score; bNRS, numeric rating scale for back pain; TLIF, transforaminal lumbar interbody fusion; HNP, mental component summary score; IVF, intervertebral foramen.

Clinical Outcome Data Analysis

Postoperative PCOQs, which were successfully completed by 80% of the cohort (36/45) at an average time point of 41.9 ± 11.9 months, demonstrated significant point improvement from baseline (Table 6). Patient satisfaction data demonstrated a median score of 9 (10 = complete satisfaction), and 83.3% of the patients (30/36) were considered to be satisfied with the results of their procedure (*i.e.*, scores >5). Analysis of return to work scores, which were applicable in 88.9% (32/36) of the cohort, demonstrated that 84.4% (27/32) of participants in the cohort were able to return to their preoperative job, either with or without limitations. All patients (7/7) in the heavy work group and 80% (20/25) in the light work group were able to return to their preoperative job with or without limitations (Table 7), and neither group demonstrated superior clinical outcome ($P > 0.50$), mean return to work scores

TABLE 6. Clinical Improvement at Follow-up

Outcome Instrument	Preoperative Mean Score	Postoperative Mean Score	Point Change (Improvement)	Percent Change	*P*
ODI	37.8	21.4	16.4	42.1	<0.01
SF-12 (PCS)	34.9	44.9	10.0	33.3	<0.01
SF-12 (MCS)	45.9	50.5	4.6	16.8	0.018
NRS for LBP	4.9	2.6	2.3	42.8	<0.01

ODI indicates Oswestry Disability Index; SF-12, 12-Item Short Form Health Survey; PCS, physical component summary score; MCS, mental component summary score; NRS, numeric rating scale; LBP, low back plain.

($P > 0.95$), or the ability to return to preoperative job without any limitations ($P = 1.0$).

Being involved in litigation (*via* the Workers' or Personal Injury system) (11/36), experiencing preoperative depression (15/36), or undergoing prior microdiscectomy/decompressive surgery (14/36) was not a predictor of clinical outcomes ($P > 0.15$).

DISCUSSION

Despite the increasing popularity of TLIF, its efficacy for the treatment of DPS has not been fully elucidated, secondary to a paucity of investigations on the subject. A thorough search of the PubMed database in the English language for TLIF outcome studies that used cohorts homogeneously diagnosed with DPS produced only 1 qualifying article,[16] because most semiqualifying investigations were eliminated secondary to the inclusion of cohorts with mixed diagnoses (especially spondylolisthesis).[6,28,32,40–45]

In a small retrospective study with 1-year minimum follow-up, Takahashi *et al*[16] reported the clinical outcomes of 21 patients who had undergone TLIF for the homogeneous diagnosis of DPS. Clinical outcomes, which were assessed with the Oswestry Disability Index, a 0 to 10 visual analogue scale, and the Japanese Orthopedic Association Score, revealed significant improvement between preoperative and postoperative scores on all outcome assessment tools. The perioperative complication rate was 23.8%, and there was 1 reported revision surgery (1/21; 4.8%). Although limited by its retrospective design, small cohort, and unknown percent participation at follow-up, the authors concluded that TLIF was a "safe and effective technique for lumbar interbody fusion in patients with chronic lumbar discogenic pain...."[16(p106)]

We studied clinical outcomes, perioperative complications, revision surgery rates, and BMPP prevalence in patients who had undergone open bTLIF for the homogeneous diagnosis of DPS, which was made *via* a very specific algorithm. At an average follow-up of 41.9 months, 80% of the patients had successfully completed postoperative PCOQs, which all demonstrated significant point improvement ($P < 0.01$) from baseline. Patient satisfaction data revealed a median value of 9 (10 = complete satisfaction), and Return to Work data demonstrated that 84.4% of the participating patients were able to return to their preoperative job in at least some capacity. Statistical analysis of the heavy *versus* light job groups revealed no significant difference between the groups with regard to clinical outcomes, mean Return to Work scores, or their ability to Return to Work without any limitations. Perioperative complications were experienced in 8.3% of the cohort, one of which resulted in revision surgery secondary to cage extrusion. Three additional revision surgical procedures were necessitated (Table 5); however, as a group, revision surgery was not a predictor of clinical outcome ($P > 0.13$). BMPP were observed in 30.6% of the patients, but their presence had no effect upon clinical outcomes, need for revision surgery, or postoperative health status. As demonstrated on CT scan, delayed early fusion was discovered in 8.3% of the cohort;

TABLE 7. Degree of Return to Work Status Post Transforaminal Lumbar Interbody Fusion

Degree of Return to Preoperative Job	Heavy Work (H), n = 7 Light Work (L), n = 25 N = 32 (32/36)*	Total Relative Frequency of Both Groups
Not at all (0)	5 (0 H, 5 L)	15.6% (5/32)
Less than somewhat (1)	3 (2H, 1 L)	9.4% (3/32)
Somewhat (2)	3 (1 H, 2 L)	9.4% (3/32)
Less than completely (3)	2 (0 H, 3 L)	9.4% (3/32)
Completely (4)	19 (4 H, 15 L)	59.4% (19/32)

**Four (4/36) patients did not participate, for they were retired (n = 1), homemakers (n = 1), or failed to complete the questionnaire (n = 2).*

however, all of these patients eventually achieved solid fusion at an average time point of 14.9 months.

The demographic variables of being female ($P < 0.03$) and young in age ($P < 0.02$) were predictors of superior clinical outcomes as measured solely by the SF-12 PCS; the significance of these findings is unknown. Also difficult to explain was the failure of litigation (11/36; $P > 0.17$), preoperative depression (15/36; $P > 0.19$), and prior decompressive surgery (20/36; $P > 0.37$) to predict clinical outcomes, for all of these factors have been previously demonstrated to be negative predictors of clinical outcomes after surgery.[47–55]

The significant magnitude of point improvement achieved by our cohort on all clinical outcome measures is not that extraordinary and has been reported previously.[15] However, the 90% median patient satisfaction score perhaps needs further explanation. We think that this high level of satisfaction stems from both the strict diagnostic algorithm used to make the diagnosis of DPS and an extensive patient education effort, during which we make the patient understand that TLIF does not typically afford 100% pain relief, there is a need for lifetime postoperative restrictions, and there is a chance for future adjacent-level fusion surgery. In fact, patients with unrealistic expectations are often referred out of the practice.

The notion of the disc as a pain generator is not new and was first described by Crock[27] more than 40 years ago; however, the diagnosis never gained full acceptance within the medical community, secondary perhaps to unanswered questions regarding its pathogenicity. For example, we still do not completely understand why some discs exhibit findings of DPS on imaging (*i.e.*, diminished disc height, endplate sclerosis/erosion, or annular tears), yet fail to be symptomatic. There remains the possibility of some yet to be elucidated mechanism and/or agent that, when coupled with the patient's unique biochemistry and/or immune system, ignites the nociceptors within the disc and/or endplates into a chronic inflammatory process, which in turn results in the chronic intractable low back pain of DPS.

Although provocative CT discography continues to be the "gold standard" for making the diagnosis of DPS,[56] the test remains controversial secondary to evidence demonstrating low specificity[57] and the association with long-term patient morbidity.[58] We suggest that discography, although still an important diagnostic tool, should not be used exclusively to make the diagnosis of DPS. In addition to a history of chronic intractable low back pain, which was refractory to conservative care, at least 2 additional factors must be met to make the diagnosis of DPS: (1) severe intolerance to loading of the spine (especially sitting with vibration), with dramatic relief after offloading; (2) positive discography; (3) failed diagnostic blocks of the facet and/or sacroiliac joints; and/or (4) imaging findings of internal disc resorption.

Although it is possible that other lumbar fusion techniques may afford results similar to those from our bTLIF investigation,[15] we have been unable to find studies that used a homogeneous cohort of patients with DPS and the diagnostic algorithm that we used to support that hypothesis. Perhaps this paper will be the impetus for further investigations from surgeons who use fusion techniques other than open TLIF.

In addition to the controversy surrounding the diagnosis of DPS, other weaknesses of this investigation included its retrospective design and small cohort (n = 36). However, notwithstanding these limitations, we think that our results make a significant contribution to DPS database and demonstrate that open bTLIF is a reasonable treatment option for DPS and affords high rates of patient satisfaction.

➢ Key Points

- ❑ The medical literature concerning clinical outcomes for BMP-2-augmented TLIF as a treatment intervention for the specific diagnosis of DPS is scarce and uncertain.
- ❑ To our knowledge, this is the first investigation into this subject matter that achieved a minimal 2-year follow-up, with 80% of the cohort successfully completing both preoperative and postoperative outcome assessment tools and assessed the prevalence of BMP phenomena.
- ❑ Data analysis revealed statistically significant clinical outcomes as measured by standard outcome assessment tools, as well as high patient satisfaction scores and return to work. Although more than 30% of the cohort experienced BMP phenomena (*i.e.*, osteolysis or ectopic bone formation), it was not associated with clinical outcome, revision surgery, or unexplained radiculopathy.
- ❑ A larger randomized controlled trial is needed to confirm these results.

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