Minimally invasive direct pars repair with cannulated screws and recombinant human bone morphogenetic protein: case series and review of the literature

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OBJECTIVE The objective of this study was to describe the use of a minimally invasive surgical treatment of lumbar spondylolysis in athletes by a fluoroscopically guided direct pars screw placement with recombinant human bone morphogenetic protein-2 (rhBMP-2) and to report on clinical and radiographic outcomes.

METHODS A retrospective review was conducted of all patients treated surgically for lumbar spondylolysis via a minimally invasive direct pars repair with cannulated screws. Demographic information, clinical features of presentation, perioperative and intraoperative radiographic imaging, and postoperative data were collected. A 1-cm midline incision was performed for the placement of bilateral pars screws utilizing biplanar fluoroscopy, followed by placement of a fully threaded 4.0-mm-diameter titanium cannulated screw. A tubular table-mounted retractor was utilized for direct pars fracture visualization and debridement through a separate incision. The now-visualized pars fracture could then be decorrelated, with care taken not to damage the titanium screw when using a high-speed drill. Local bone obtained from the curettage was then placed in the defect with 1.05 mg rhBMP-2 divided equally between the bilateral pars defects.

RESULTS Nine patients were identified (mean age 17.7 ± 3.42 years, range 14–25 years; 6 male and 3 female). All patients had bilateral pars fractures of L-4 ($n = 4$) or L-5 ($n = 5$). The mean duration of preoperative symptoms was 17.22 ± 13.2 months (range 9–48 months). The mean operative duration was 189 ± 29 minutes (range 151–228 minutes). The mean intraoperative blood loss was 17.5 ± 10 ml (range 10–30 ml). Radiographic follow-up was available in all cases; the mean length of time from surgery to the most recent imaging study was 30.8 ± 23.3 months (range 3–59 months). The mean hospital length of stay was 1.13 ± 0.35 days (range 1–2 days). There were no intraoperative complications.

CONCLUSIONS Lumbar spondylolysis treatment with a minimally invasive direct pars repair is a safe and technically feasible option that minimizes muscle and soft-tissue dissection, which may particularly benefit adolescent patients with a desire to return to a high level of physical activity.

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KEY WORDS spondylolysis; athletes; minimally invasive; direct pars repair; adolescent

WHILE lumbar spondylolysis in the general adult population may reach as high as 5%–7% in select studies,^{3,6,7,12,16,19,31,32,38,45,46,67} the actual incidence of spondylolysis in pediatric patients presenting with axial low-back pain may approach 50%.^{3,36} Numerous prior studies have described the presentation and management of lumbar spondylolysis, most commonly present-

ing at L-5 in up to 95% of cases and followed by L-4 in 5%–15%.^{12,36,37,56} The vertebral segments of greatest lordosis and flexibility in the lumbar spine are the L4–5 and L5–S1 motion segments, where the points of greatest facet overhang occur and the greatest biomechanical forces are applied to the posterior elements. Moreover, the coronal orientation of the L5–S1 facet joints has been found to

ABBREVIATIONS AP = anteroposterior; rhBMP-2 = recombinant human bone morphogenetic protein-2.

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greatly impede horizontal translation, transmitting greater stresses at the pars interarticularis of L-5.^{33,66} Lumbar spondylolysis is highly prevalent in collegiate athletes involved in collision and endurance sports in which the transfer of energy through high-impact forces results in frequent lumbar hyperextension.^{24–26,47,48,65} Pain typically manifests as axial low-back pain but often is noted to have radiculopathic features exacerbated by hyperextension.⁵⁸

Diagnosis is most commonly performed by oblique radiographs of the lumbar spine. However, many nondisplaced pars fractures may not be evident on plain radiographs, and CT has been the mainstay of fracture identification and preoperative planning (Fig. 1). The initial management of lumbar spondylolysis is nonsurgical, and treatment that includes bracing, activity modification, and targeted physical therapy most often leads to a good response.⁵⁶ Early recognition of surgery as an option for repair of the pars defect was first described by Buck in 1970, who used open subperiosteal exposure and curettage of the pars defect and intralaminar stabilization across the fracture. Interestingly, due to the lack of image-guided techniques of modern spinal instrumentation, malpositioning of screws in the L4–5 rostral disc space and radiculopathy attributed to compression of the L-5 spinal nerve in the superior aspect of the L5–S1 neural foramen were encountered in 1 (6.3%) of the 16 cases described.⁵

Extensive modifications to this technique have been subsequently reported, such as the incorporation of combinations of wires,^{52,53} intralaminar and cortical screws,^{52,53} and pedicle screw–hook constructs²⁹ to achieve fracture stabilization. Arguably, the most clinically important modification has been the introduction of image guidance and muscle-sparing approaches. The use of minimally invasive techniques for the surgical management of spinal disorders has gained considerable popularity with the goal of decreasing hospital length of stay by lowering blood loss and limiting disabling perioperative pain.^{2,30,41,49,54}

Previously, we reported on successful direct pars repair in 3 patients.⁶³ The authors present a clinical case series of the further use of percutaneous direct pars screw repair for lumbar spondylolysis with the use of a minimally invasive tubular approach for curettage and bone grafting of the fracture defect.

Methods

This study was approved by the University of Miami Miller School of Medicine institutional review board.

A single-surgeon database was searched for all cases in which patients were treated surgically for lumbar spondylolysis without spondylolisthesis via a minimally invasive approach. Summary demographic information, clinical features of presentation, perioperative and intraoperative radiographic imaging, data on postoperative narcotic consumption, and visual analog scale back pain scores were collected and analyzed.

Operative Technique

This technique has been previously described.⁶³ The patient was positioned prone and secured to a radiolucent Jackson surgical table (OSI). Neurophysiological monitor-

FIG. 1. Case 6. Chronic L-5 pars fracture. Sagittal CT reconstruction of the lumbar spine demonstrating chronic L-5 pars fracture. Increased density of the cortical margins of the L-5 pars is indicative of a nonunion, as seen here. The ideal trajectory for planning a direct screw repair is perpendicular to this fracture site and through the long axis of the lamina (labeled A). The entry point and skin incision are then traced backward after an ideal screw trajectory is measured (labeled B).

ing was carried out with somatosensory and motor evoked potentials as well as continuous electromyography. The skin must be disinfected preoperatively all the way to the intergluteal fold. This is important because the trajectory can be very steep in certain patients requiring a caudal entry site. To achieve a single 1-cm incision for the bilateral placement of pars screws, a midline incision is performed, with the precise rostral-caudal location determined with the use of biplanar fluoroscopy (Siemens). The location of the skin incision is identified by extending an imaginary line from the lamina to the skin on a lateral spine radiograph. The ideal trajectory under anteroposterior (AP) visualization forms a path entering the lateral inferior edge of the lamina and bisects the pedicle traversing the middle of the pars. The ideal trajectory has been recently described in one radiographic study of normal laminae in 100 volunteers by CT imaging of the lumbar spine by Menga et al.³⁵

When the specific lateral trajectory is determined, the skin incision is made as well as a small fascial incision, followed by insertion of a Medtronic UCSS (Universal Cannulated Screw Set) guide along with the cannulated trocar, both of which are docked on the inferior entry point of the lamina. A 24-inch disposable threaded guidewire is secured to a drill and advanced through the cannulated trocar, into the lamina (Fig. 2), and across the pars fracture, ending in the pedicle (Fig. 3). With great care, the drill and drill bit are removed over the guidewire without moving the guidewire, and then the cannulated trocar is removed. An intraoperative CT scan is performed to confirm the desired location of the guidewire within the lamina (O-arm, Medtronic). A cannulated drill bit is now

FIG. 2. Intraoperative docking of the UCSS guide and threaded guidewire advancement, as shown in an intraoperative photograph demonstrating the surgical setup and use of biplanar fluoroscopy. After incision, the UCSS guide and cannulated trocar are advanced through the fascia and docked on bone; this is followed by advancement of a threaded wire with a cannulated drill, as seen here. An ideal trajectory is achieved with a starting point beginning on the inferior bony edge of the lamina (visualized on screens in background).

advanced over the guidewire and the process repeated, followed by the cannulated tap. The guidewire can be measured with a provided cannulated depth gauge, or a second guidewire can be docked on the lamina, and the difference in height between the 2 guidewires at the proximal end can then be measured. A fully threaded 4.0-mm-diameter titanium cannulated lag screw is placed; lengths of 30–50 mm can be accommodated with this system (Fig. 4). Next, using lateral fluoroscopy, parasagittal incisions are made over the bilateral pars fractures. A METRx tubular table-mounted retractor (Medtronic) is placed using sequential

dilators to a final working channel of 18 mm. The now-visualized pars fracture can then be decorticated, with care taken to avoid damaging the titanium screw when using a high-speed drill. Local bone obtained from the curettage is then placed in the defect with 1.05 mg of recombinant human bone morphogenetic protein-2 (rhBMP-2; Infuse, Medtronic) divided equally between the bilateral pars defects. The incisions are then closed in layers.

Follow-Up

Postoperative upright radiographs were obtained in all patients 6 weeks after surgery (Fig. 5). Confirmation of the final hardware positioning was performed intraoperatively with a fluoroscopic 3D reconstruction of the lumbar vertebrae of interest (using an O-arm). Routine assessment of fusion and clinical follow-up was performed by the senior author (A.D.L.), and fusion was defined as the bridging of bone across the pars defect as interpreted on lumbar plain radiographs and CT imaging (Fig. 6).

Results

Nine patients were identified (mean age [$\pm$ SD] 17.7 ± 3.42 years, range 14–20 years), 3 of whom were female (33%). All patients presented with bilateral pars fractures at the L-4 ($n = 4$) or L-5 ($n = 5$) level (Table 1). The mean duration of preoperative symptoms was 17.22 ± 13.2 months (range 9–48 months). The mean operative duration was 189 ± 29 minutes (range 151–228 minutes). The mean intraoperative blood loss was 17.5 ± 10 ml (range 10–30 ml). Radiographic follow-up was performed in all 9 cases. The mean length of time from surgery to the most recent imaging study was 30.8 ± 23.3 months (range 3–59 months). The mean length of hospital stay was 1.13 ± 0.35 days (range 1–2 days). The mean visual analog scale score for back pain improved from 7.33 ± 2.35 preoperatively to 0.11 ± 0.33 on the first postoperative examination (Table 2). Follow-up radiographs were available in all cases. Both

FIG. 3. Placement of bilateral L-5 intralaminar threaded guidewires. Intraoperative fluoroscopic views demonstrating bilateral placement of threaded guidewires in the lateral (left) and AP (right) projections. Note that on the AP projection the guidewires demonstrate lateral lamina entry and bisect the pedicle. On the lateral projection there is appropriate clearance of the L5–S1 neural foramen, and the rostral endplate or foramen is not violated.

FIG. 4. Pars screw placement and fracture debridement. Intraoperative fluoroscopic views in the AP (**left**) and lateral (**right**) projection demonstrating bilateral placement of cannulated pars screws over threaded guidewires (**left**) and subsequent bilateral exposure of the pars fracture. Tubular-based retractors (**right**) allow for decortication.

CT and radiographic evidence of fusion were noted in all 6 patients with more than 1 year of follow-up (66.7%). There were no intraoperative complications. In 1 case, the position of a threaded guidewire was considered to be too lateral within the lamina and fracture line under AP fluoroscopic visualization; a new trajectory was confirmed and a guidewire was placed in a satisfactory location. In that same patient, at 19 months' follow-up, despite complete relief of axial low-back pain, asymptomatic unilateral screw backout (8 mm) was noted on the right side.

Discussion

Due to the benign natural history of spondylolisthesis,³ patients with this condition should, in general, be treated with nonsurgical therapies and only considered for surgical treatment in the event of persistent or progressive symp-

toms after all other options have been exhausted. However, it has been observed that physically active adolescents with a history of participation in competitive sports may develop nonunion.⁵⁸ This was the case for 6 (75%) of the 8 patients in our series who could recall the onset of their symptoms in correlation with competitive sporting activity (Table 1).

Numerous surgical options are available for the treatment of lumbar pars fractures. Among the earliest reported techniques and most similar to the surgical treatment in this series was that reported in 1970 by Buck, who described intralaminar screw placement across the lumbar pars fracture.⁵ This technique was developed out of the desire for a motion-sparing surgical treatment, as prior surgical treatments involved posterolateral arthrodesis with or without laminectomy or multilevel laminar wiring.²³ Additionally, use of sublaminar wires, intralaminar screws, pedicle screws, and screw-hook constructs had been found to result in a moderate-to-high rate of pseudarthrosis.²⁹ Surgical wiring, also referred to as Scott's wiring technique, involves wiring from the transverse process to the spinous process of the affected level and has been reported with varying degrees of success, due to the limited biomechanical fixation.^{1,28,39} Modifications to these aforementioned techniques have shown promise by providing incremental improvement in biomechanical strength, such as with wiring in combination with pedicle screw or hook placement.⁶¹ Moreover, compared with Scott's wiring technique and pedicle screw-cable constructs, the pedicle screw-hook construct had the highest degree of torsional and flexion/extension stiffness in a biomechanical study by Ulibarri et al.⁶¹ Deguchi and colleagues¹⁰ tested various constructs in a cadaveric biomechanical study, comparing Scott's and Buck's techniques, as well as a pedicle screw-wiring construct and a screw-rod-hook construct. The screw-rod-hook construct again was noted to have the greatest stiffness and the least motion across the pars defect.¹⁰ Interestingly, this finding goes against earlier biomechanical work by Crawford and colleagues,⁷ who found that greater stiffness and yield strength were achieved with Buck's technique than with the Morscher hook-screw construct and wiring technique. In the present series, we

FIG. 5. Postoperative AP (**left**) and lateral (**right**) upright standing radiographs demonstrating bilateral placement of cannulated, fully threaded titanium cortical lag screws 4.0 mm in diameter and 46 mm long (UCSS).

FIG. 6. Case 8. Chronic L-4 pars fracture in a 15-year-old girl. Sagittal CT reconstruction of the lumbar spine, demonstrating a chronic left L-4 pars fracture (**left**) treated with a cannulated screw placed across the fracture. Follow-up CT (**right**) obtained at 3 months demonstrating bridging fusion across the fracture diastasis.

used a fully threaded lag screw, fluoroscopic guidance, and placement of rhBMP-2 across the fracture site. In another report, Wilson et al.⁶⁴ described the use of a threaded dynamic compression screw, which provides chronic compression on the fracture and bone graft. Similarly, Snyder et al.⁵¹ used a Buck screw technique with a dynamic compression screw system.

Other surgeons have adapted lumbar instrumentation techniques and applied them to pars fracture fixation. Most recently, Goldstein et al.¹⁴ reported the use of cortical screws and a spinous-process modular link in a minimally invasive fashion using intraoperative CT navigation. A midline incision was made, and pars screws were placed bilaterally under guidance with a standard inferomedial to superolateral trajectory, as previously described, with cortical screw fixation for spondylolisthesis. The cortical screw trajectory passed through the pars fracture and was able to fixate the fracture in this manner. A titanium rod was passed underneath the spinous process connecting the bilateral cortical screws, and the spinous process was compressed to the rod before final tightening. This compressed the fracture site before final tightening. Operating via a similar mechanism of fracture loading, Gillis et al.¹³ used pedicle screws connected bilaterally with a polymer

cord (Dynesys, Zimmer Biomet) passed beneath the spinous process in 4 competitive athletes. The advantage of this technique is a unified single incision and potentially shorter operative duration, as compared with the 3 incisions and multiple systems of UCSS and METRx tubular access. However, we feel that the extensive subperiosteal exposure contributes to significant pain at the operative site that would not be encountered otherwise, even with 3 incisions, as muscle-splitting approaches with an 18-mm tube preserve the muscle insertions. Another modification of an old technique involves the use of the translamina screw from a contralateral percutaneous entry with intraoperative CT guidance.⁴⁰ This is not much different from the starting approach with the translamina facet screw initially popularized for the treatment of spondylolisthesis,^{15,22,34} with the exception that the trajectory limits placement of bilateral pars screws, greatly limiting the utility of their technique.

The safe use of intralaminar direct screw placement across the pars was reported by Buck,⁵ and then in 1988 by Pedersen et al.⁴⁴ in 18 patients. It has been proposed by Kakiuchi²⁹ as well as by Pedersen and colleagues that the cause of the high pseudarthrosis rate (33%) seen with intralaminar screw placement was hardware positioning.

TABLE 1. Summary of patient presentations

Case No.	Age (yrs), Sex	Level	Symptoms	Duration of Symptoms (mos)	Postop Radiographic Surveillance (mos)
1	17, F	L-5	Fall while playing field hockey, LBP	12	54
2	16, M	L-4	Collision while playing ice hockey, LBP	12	59
3	25, M	L-4	Left buttock & gluteal pain	12	50
4	16, M	L-5	LBP	48	24
5	14, M	L-5	Progressive LBP related to competitive running	12	8
6	20, M	L-5	LBP related to lacrosse & football	30	19
7	16, M	L-4	LBP attributed to football	12	6
8	15, F	L-4	LBP related to track & field	9	3
9	20, F	L-5	LBP related to multiple sports	8	54

LBP = low-back pain.

TABLE 2. Clinical follow-up and inpatient narcotic usage

Case No.	VAS Score–Back Pain		LOS (days)	Inpatient Narcotic Usage (MED in mg)
	Preop	Postop*		
1	9	1	1	217.5
2	4	0	2	83.7
3	10	0	1	22.5
4	4	0	1	42.5
5	5	0	1	5
6	9	0	1	50
7	8	0	1	21.5
8	9	0	1	7.5
9	8	0	1	60

LOS = length of stay; MED = morphine equivalent dosage; VAS = visual analog scale.

* Most recent follow-up.

This is not surprising; as with the use of direct visualization alone, Buck described the technique as directed “... upward, forward, and slightly outward.”⁵ In the present series, there were no instances of pseudarthrosis, with fusion demonstrated as early as 3 months postoperatively (Fig. 6). This high rate of fusion can be attributed to the patient population and technique: young patients, good bone quality, meticulous decortication at the fracture site, placement of a total of 1.05 mg rhBMP-2, and compression loading of the fracture diastasis by lag screws. Recent series using laminar screw starting points have reported fusion rates ranging from 80% to 100%.^{8,9,18} This can be compared with 86%–100% using Scott’s technique, 56%–82% with the Morscher technique (a pedicle screw-hook construct introduced by Hefti and colleagues^{20,21}), and 83% with screw-rod-hook constructs.^{4,11,17,18,20,21,27,39,42–44,55,59,60,62} Hardcastle¹⁸ identified 23 patients who reported a preferred pitching-style in cricket termed “fast bowling,” which is a technique requiring lumbar extension and thoracolumbar rotation, occurring approximately 600 times per week for 6 months a year. Of the 23 patients with low-back pain, 50% had a pars defect (5 unilateral and 5 bilateral) and 10 were successfully treated with direct pars screw repair and posterior iliac crest graft placement, leading to fusion in all 10 cases. In our series, only local bone obtained from the decortication was collected and placed at the fracture site. In Buck’s series, posterior iliac crest was harvested and placed at the fracture site.⁵ However, the overall philosophy of this surgical approach is based on the minimization of tissue disruption, blood loss, pain, and length of hospital stay, and we found in our case series that the use of rhBMP-2 to avoid iliac crest bone graft harvesting was associated with a short hospital length of stay (mean 1.13 ± 0.35 days), low blood loss (17.5 ± 10 ml), and very little if any opiate use. The use of rhBMP-2 in young patients should be accompanied by a thorough dialogue about the potential risk of cancer, radiculopathy, heterotopic bone formation, and elevated rates of surgical site infection.⁵⁰

Complications

Numerous complications and a steep learning curve have been reported with the Buck technique. Reported

complications include nerve injury, screw protrusion/backout, screw malpositioning, screw loosening, pseudarthrosis, and iliac crest graft donor-site pain.^{10,57,61} Overall, complication rates have been reported to be as high as 40% with the Buck technique, 14% with Scott’s wiring, and 44% with Morscher’s technique.^{4,5,11,27,43,44,60} The authors report no intraoperative complications in the present series. In 1 case, screw backout was noted in a patient in whom intraoperative repositioning of the threaded guidewire was required prior to drilling and tapping of the cortical bone. We confirm guidewire positioning prior to drilling and tapping laminar bone, as there is only one opportunity for adequate intraoperative fixation. Regardless, successful fusion occurred in all patients with follow-up, and no recurrent painful symptoms were noted.

Conclusions

Lumbar spondylolysis treatment with a minimally invasive direct pars repair is a safe and technically feasible option that minimizes muscle and soft tissue dissection. This may be of particular benefit in cases involving adolescents with a desire to return to a high level of physical activity.

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Author Contributions

Conception and design: Levi. Acquisition of data: Levi, Ghobrial, Lau. Analysis and interpretation of data: Levi, Ghobrial, Lau. Drafting the article: Levi, Ghobrial, Crandall, Williams. Critically revising the article: Levi. Reviewed submitted version of manuscript: Levi, Ghobrial. Approved the final version of the manuscript on behalf of all authors: Levi. Administrative/technical/material support: Levi. Study supervision: Levi.

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