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Original Article

“Reverse Bohlman” technique for the treatment of high grade spondylolisthesis in an adult population

Angel E. Macagno^a, Saqib Hasan^b, Cyrus M. Jalai^b, Nancy Worley^b,
Alexandre B. de Moura^b, Jeffrey Spivak^b, John A. Bendo^b,
Peter G. Passias^{a,*}

^a NY Spine Institute/NYU Medical Center Hospital for Joint Diseases, New York, NY, United States

^b Orthopaedic Surgery, NYU Hospital for Joint Diseases, New York, NY, United States

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ABSTRACT

Background/aims: Surgical techniques for effective high-grade spondylolisthesis (HGS) remain controversial. This study aims to evaluate radiographic/clinical outcomes in HGS patients treated using modified “Reverse Bohlman” (RB) technique.

Methods: Review of consecutive HGS patients undergoing RB at a single university-center from 2006 to 2013. Clinical, surgical, radiographic parameters collected.

Results: Six patients identified: five with L5-S1 HGS with L4-L5 instability and one had an L4-5 isthmic spondylolisthesis and grade 1 L5-S1 isthmic spondylolisthesis. Two interbody graft failures and one L5-S1 pseudoarthrosis. Postoperative improvement of anterolisthesis (62.3% vs. 49.6%, $p = 0.003$), slip angle (10 vs. 5°, $p = 0.005$), and lumbar lordosis (49 vs. 57.5°, $p = 0.049$).

Conclusions: RB technique for HGS recommended when addressing adjacent level instability/slip.

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1. Introduction

Isthmic spondylolisthesis, described by Kilian in 1854¹ and refined by Taillard in 1957,² is forward slippage of the vertebral body, its pedicles, transverse process, and upper articular process engendered by a break in continuity or elongation of the pars interarticularis. High-grade spondylolisthesis (HGS) is

defined as greater than 50% slippage of a spinal vertebral body relative to an adjacent vertebral body as per the Meyerding classification (Grades III–V),³ and most often affects alignment of the L5-S1 motion segment. Patients can present with intractable pain, neurological deficits, and significant spinopelvic malalignment and often undergo surgery. Despite evolution of spinal instrumentation, fusion techniques, and intraoperative neuromonitoring, surgery for HGS is challenging

* Corresponding author.

E-mail address: Peter.Passias@nyumc.org (P.G. Passias).

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and optimal surgical treatment remains controversial. Surgical goals include pain relief, neural decompression, correction of a kyphotic slip angle, and obtaining solid fusion.⁴

Surgical options include in situ posterior fusion, instrumented posterolateral fusion, circumferential interbody fusion, vertebral resection, sacral dome osteotomy, or a combination. Although circumferential fusion procedures often produce high rates of clinical and radiographic fusion, for higher-grade spondylolisthesis, slip severity may preclude direct anterior interbody fusion.⁵⁻⁸ In 1938, Speed reported experiences in performing in situ fusion through an anterior approach using a tibial autograft strut to stabilize L5-S1 spondylolisthesis.⁹ In 1982, Bohlman and Cook modified this protocol for spondylolisthesis using a single incision posterior approach via introducing a fibular autograft across S1 into the L5 vertebral body in conjunction with a decompression and uninstrumented L4-S1 posterolateral fusion allowing for three column spinal fixation.¹⁰

Although early results with this technique resulted in complications including fibular graft fracture, graft resorption, slip progression, and pseudoarthrosis,¹¹⁻¹³ Rodríguez-Olaverri and colleagues showed that this procedure may have similar outcomes with transforaminal lumbar interbody fusion,¹⁴ resulting in lumbosacral kyphosis improvement.¹⁵ With advances in techniques and instrumentation, supplementary methods of achieving three-column fixation include transsacral transvertebral screw fixation,^{16,17} transvertebral interbody cage fixation^{18,19} and use of intrasacral rods^{20,21} and custom-made screws.^{22,23} While many of these were performed via posterior approach for direct decompression and stabilization with pedicle screw fixation, an additional anterior approach is useful in increasing fusion rates by providing an optimal graft environment, restoring sagittal alignment via anterior column reconstruction to restore disk height and reducing the slip angle.²⁴ This obviates the requirement for a complete sacral laminectomy with retraction of the caudal dura, and the associated inherent risk, while simultaneously facilitating access to the L4-5 intervertebral disk from a single anterior approach.

This study evaluated radiographic and clinical outcomes in patients with HGS treated with a modified "Reverse Bohlman" (RB) procedure consisting of a combined anterior/posterior approach with transsacral and/or pedicle screw fixation and fibular graft or titanium mesh cage augmented with bone morphogenetic protein-2 (BMP-2) to allow for interbody fusion through an angled anterior approach.

2. Material and methods

2.1. Study design

A retrospective review of consecutive patients who underwent a modified "RB" procedure for HGS was performed at a single university-based center between November 2006 and October 2013. Primary outcomes evaluated were occurrence of perioperative complications and the need for revision procedures.

2.2. Data collection

Clinical parameters collected included patient age and sex, primary presenting symptoms, neurological dysfunction prior

to or after surgery, and previous surgical procedures for spondylolisthesis. Radiographic parameters included Wiltse classification, slip percentage (grade), and slip angle. Perisurgical parameters included fusion levels, type of interbody device (titanium mesh cage or fibular strut), posterior instrumentation pattern (transsacral or pedicle screws), use of BMP-2, estimated blood loss (EBL), and perioperative complications.

2.3. Reverse Bohlman procedure (Fig. 1)

All procedures consisted of a combined anterior/posterior approach, with anterior access performed by an experienced vascular access surgeon. Two levels (L4-5 and L5-S1) were addressed in all cases. L4-L5 was prepared as per regular anterior lumbar interbody fusion technique with radical discectomy and endplate preparation. Prior to placement of L4-5 cage, attention was turned to the L5-S1 level. Rigid cannulated reamers were utilized over a guide wire, which was placed under real-time fluoroscopy from the anterior cephalad portion of the L5 vertebral body angled across the spondylolisthetic disk space into the sacral vertebral body. The guide wire was oriented in a trajectory almost perpendicular to the L5-S1 disk space, which was typically perpendicular to the floor (Fig. 1).

With guide wire in place, a 10.5 mm reamer was passed under fluoroscopy to the desirable depth (40–50 mm). This allowed for creation of a direct channel across the disk space into the sacrum. A standard 1 cm diameter Pyramesh cage (or fibular dowel allograft) was used and cut to the pre-reamed length. BMP-2 sponge was placed inside the cage that was then impacted into position with the proximal portion recessed into L5, continuing across the L5-S1 disk space, and ending in the proximal sacrum. No BMP was used when procedure was performed with fibular graft. The L4-5 disk space was irrigated and filled with a lordotic cage or bone graft in a standard fashion.

Following closure of the anterior procedure, the patient was turned prone and an open posterior decompression and fusion from L4-S1 was performed. Iliac fixation was not used.

2.4. Radiographic evaluation

Upright spine radiographs were collected pre-operatively and at the last follow-up and were evaluated by a single independent reviewer. Pelvic incidence was measured from preoperative digital radiographs. Slip percent and slip angle were measured digitally from standing pre-operative and final follow-up evaluations. All measurements were performed digitally with SurgimapSpine (Nemaris Inc., New York, NY) digital software. Implant and fusion status were evaluated using plain film, flexion–extension, lateral radiographs, supplemented by CT scans for selected patients at discretion of the operating surgeon.

3. Results

Six patients were identified (4 female, 2 male); mean age was 43 years (range: 28–63) (Table 1). Four patients presented with

Fig. 1 – Case #2, 21 year male. (A, B) Preop. (C) Intraop. (D-F) 3 months postop. (G-I) 34 months postop.

high grade isthmic spondylolisthesis at L5-S1. One patient (patient #6) had isthmic spondylolisthesis at L4-L5 with instability as demonstrated by flexion extension X-rays and a grade 1 isthmic spondylolisthesis at L5-S1. The remaining patient (patient #4) (Fig. 2) had previously undergone a posterior instrumented fusion L5-S1 for isthmic spondylolisthesis at L5-S1 with later removal of broken hardware. She has since developed progressive low back and leg pain secondary to degenerative spondylolisthesis with stenosis at L4-5. CT scan revealed a solid bilateral posterolateral fusion at L5-S1. Surgery recommended was a standard anterior interbody fusion with lordotic cage at L4-5 followed by a posterior decompression and fusion with fixation. Due to new stress

applied from the L4-5 fusion as well as the kyphotic nature of her fused L5-S1 level, she was indicated for anterior strut interbody fusion and cage fixation across L5-S1.

All patients reported spinal stenosis symptoms with severe axial back pain referred in most cases to buttock, claudication relieved by flexion and exacerbated by extension. Three patients presented with unilateral radiculopathy without weakness. No patient presented with bladder disturbance. Mean pelvic incidence was 80° (Table 2), consistent with the literature.²⁵

All patients underwent non-staged circumferential fusion with an initial anterior approach with standard ALIF at L4-L5 and “RB” procedure at L5-S1. This modified Bohlman stage was performed with fibula allograft in 2 patients and with a

Fig. 1. (Continued)

titanium mesh cage packed with BMP-2 in the other 4 patients. Standard pedicle screws were used for the posterior procedure. Five patients were instrumented from L4-S1. The remaining patient (patient #4) received a posterior instrumentation only from L4-L5 since L5-S1 was demonstrated by CT to be fused, and her sacral screws had previously been removed due to pain. Mean intraoperative blood loss was 605 cc (350–1100). There were no intraoperative complications.

Mean follow-up was 20 months with a range of 9–34 months. There were two interbody cage failures. Patient #5 presented with pseudoarthrosis at L5-S1 and underwent a

posterior revision surgery with extension of instrumentation to S1 and allograft harvested from B/L iliac crest one year after the initial procedure. The anterior titanium cage was not revised. At most recent follow-up, the patient was noted to be doing clinically well at 4 months postop, without early radiologic signs of complications. The other patient with interbody cage failure (patient #4) (Fig. 2) was instrumented posteriorly only at L4-L5. After the procedure, she did well initially but eventually developed recurrent severe pain. Imaging studies revealed fracture of the titanium cage at the disk space level, and fracture of the posterior fusion at the

I

Fig. 1. (Continued).

base of the L5 pedicle screws. Solid fusion was obtained after revision posterior surgery, which consisted of extension of instrumentation to the ilium with placement of a new titanium cage traversing L5 and S1 from posterior, similar to original Bohlman technique, plus autograft.

Standard radiographic measurements were made on pre- and postoperative lumbar images (Table 2). Mean preoperative anterolisthesis improved from 62.3% to 49.6% ($p = 0.003$) and the slip angle improved from 11° of kyphosis to 2° of lordosis ($p = 0.005$). No spondylolisthesis translational reduction maneuvers were attempted intraoperatively. Lumbar lordosis improved from 49° to 57.5° postoperatively ($p = 0.049$).

4. Discussion

HGS is one of the most challenging spine deformities. Severe manifestations can leave patients with debilitating neurologic

deficiency and pain. There is a paucity of evidence-based studies comparing treatment of isthmic spondylolisthesis with fusion in situ, reduction followed by fusion, and vertebral resection. There are no Level 1 or Level 2 studies of such nature, making it difficult to develop clear guidelines for treatment of HGS based on the best evidence available in the published literature.²⁶

Several authors have recognized these limitations and proposed modifications to the original Bohlman technique, including replacing the fibular strut graft with a titanium mesh cage^{19,27} and reducing and augmenting with pedicle screw or trans-sacral screw instrumentation.^{28,29} Modern instrumentation techniques allow complete reduction of anterolisthesis, which presents the option of using standard interbody fusion techniques while making placement of an oblique cage impossible. Although advocates of reduction argue for the benefits of increased surface area for fusion, we are aware of the lack of evidence that residual anterolisthesis affects long-term outcomes as long as stable arthrodesis and kyphosis reduction are achieved. Reduction of anterolisthesis has been associated with increased neurological complication rates, especially L-5 motor deficit.²⁹ Sailhan and Roussouly reported 9.1% of neurologic complications following instrumented posterior reduction and fusion without decompression of the neural elements, with a 2.3% of definitive motor deficit represented by a foot drop.²⁸

In addition to neurological complications, resulting forces on instrumentation have led to implant failures, with a need for revision and extension of the primary construct or addition of pelvic fixation.

The “RB” technique described here is mostly indicated in patients with HGS when the adjacent segment is planned to be in the fusion as well. The anterior approach permits the standard ALIF of the adjacent segment and facilitates placement of a titanium cage through the body of L5 and S1. We use rigid cannulated reamers in a trajectory perpendicular to the remaining L5-S1 disk space to create the passage for a titanium cage or cortical allograft. An anterior approach surgeon, typically a vascular surgeon, works as co-surgeon for the anterior approach, making this part of the technique safe and reducing surgical time, allowing the complete anterior-posterior procedure to be performed on the same day. In terms of reduction, we do not perform any type of extemporary

Table 1 – Description and operative data for series patients.

Case #	Age/sex	FU	EBL	Ant/graft L5-S1	Posterior graft	Fusion
1	59 F	24 m	700 cc	Fibula dowel allograft	Iliac crest autograft	Yes
2	21 M	34 m	650 cc	Pyramesh 10 × 40 + BMP2	Mastergraft, BMP 2 and autograft for L4L5	Yes
3	63 F	12 m	375 cc	Fibula dowel allograft	Actifuse (Silicate calcium phosphate), bone marrow aspirate and allograft paste	Yes
4	42 F	26 m	350 cc	Pyramesh 10 × 40 + BMP 2	Mastergraft, BMP 2 and autograft for L4L5	Yes, needed 2nd procedure after initial non-union
5	39 M	14 m	550 cc	Pyramesh 10 × 50 mm. BMA and fresh frozen allograft	Allograft paste, Bone marrow aspirate, allograft/autograft	Yes, needed 2nd procedure after initial non-union
6	37 F	9 m	1100 cc	Pyramesh 10 × 50 + BMP 2	Mastergraft, BMP 2 and autograft	Yes
Mean	43	20 m	620 cc

Fig. 2 – Case #4, 42 year female. (A–C) Preop. (D–E) 3 months postop. (F, G) 1 year postop. (H, I) 1 month post-revision.

maneuver to reduce translation. The degree of reduction obtained is consistent with previous series with all posterior techniques, where slip reduction was not attempted with specific maneuvers as described by Hart³⁰ and Bartolozzi¹⁹ who performed reduction only in patients with more than 70% slip.

The significant improvement of the spondylolisthesis kyphotic angle and moderate recovery of slip grade are commonly related to positioning over the operating table and any mild instability coupled with viscoelastic properties of the intervertebral disk.²³ Intraoperative maneuvers can actively improve the slip angle with this technique. The surgeon can ream the L5 vertebra to the disk space and directly clean the disk space with angled curettes or disk preparation tools from the AxialIF procedure (Fig. 1 intraoperative images). The surgeon replaces the reamer to the disk space and raises his/her hand to the head, actively correcting the kyphosis, followed by replacing

the guide wire and reaming the second half of the channel into the sacrum. The cage or allograft is placed into the created channel in the kyphosis-corrected position.

Importantly, no neurological complications occurred in our series despite some improvement in slip angle and grade following surgery. Although the benefits of obtaining a reduction in translation and slip angle remain controversial, we emphasize obtaining a neurologically safe reduction of kyphosis as a paramount operative goal. Radiculopathy is the most common neurologic complication after spondylolisthesis reduction. This usually involves an L5 nerve root lesion with varying recovery rates. There is no real predictor of who might suffer one of these significant neurologic events. The etiology for these palsies is likely a combination of compression and nerve root stretch. Petraco et al., in a cadaveric anatomic model, found that complete translational reduction

Fig. 2. (Continued).

Table 2 – Pre- and post-operative radiographic evaluation of spondylolisthesis.

Case #	PI	Slip %		Slip angle		Lumbar lordosis	
		Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
1	70°	51	42	8	–6	43	60
2	77°	96	89	22	2	30	40
3	79°	74	55	7	–9	68	63
4	70°	67	56	26	22	46	51
5	80°	35	27	5	–4	51	59
6	105°	49	29	0	–17	56	72
Mean	80°	62	50	11	–2	49	57.5

causes excessive stretch on the L5 nerve root path, which likely contributes to increased risk of a neurologic complication clinically.³¹

Most neurologic complications are related to the degree of slip reduction; however, the literature shows disparity in results when evaluating neurologic complications after spondylolisthesis treatment. Hanson et al. did not report any permanent neurological deficits with partial slip reduction using a dowel fibular strut graft for high-grade slips.¹³ In contrast, acute postoperative cauda equina syndrome has been reported after a simple posterolateral fusion, without

decompression or reduction.^{32,33} This complication can occur after a midline or lateral muscle-splitting incision and with the patient prone or in the lateral position. The etiology of this complication is unclear. Development of cauda equina syndrome may be due to either neural stretch or acute neural compression. Patients with high-grade slips are at increased risk for neural compression at the time of surgery.

There were two patients needing reoperation secondary to pseudoarthrosis. One of these patients was initially not instrumented posteriorly at L5-S1 (patient #4) since a fusion at that level was present from a previous procedure as

demonstrated by CT scan, and her hardware was previously removed for pain (Fig. 2). This last case emphasizes the importance of posterior instrumentation in these complicated patients when additional fusion levels are surgically created. Both cases were resolved after extending instrumentation to pelvis and reinforcing the interbody fusion.

The pseudoarthrosis rate after fusion in the literature varies from 0% to 39% with the majority being under 15%.^{19,30,34} High pseudoarthrosis and complication rates have been associated with higher-grade spondylolisthesis and fusion in situ. Hart reported 2 nonunions in a series of 16 patients treated with an all posterior modified Bohlman technique using a transsacral titanium cage.³⁰ Bartolozzi reported no pseudoarthrosis in a series of 15 patients treated with partial reduction, posterior decompression, screw fixation and interbody fusion with a posteriorly inserted transsacral titanium cage.¹⁹ Karampalis had 1 pseudoarthrosis in a series of 7 patients treated with circumferential fusion after reduction with Margerl's external fixation.³⁵ However, we could not find HGS studies limited to adults with adjacent level needing stabilization too.

This study's limitations include a small patient sample and absence of long-term follow-up for some patients. Thus, the data from our case series lack the power to make statistical comparisons to other surgical fusion techniques. A descriptive Level IV evidence review should be considered. The size of this cohort and follow-up duration are comparable to those in many published series, reflecting the rarity of HGS treated with this technique.

5. Conclusions

HGS is one of the most challenging spine deformities. The "RB" technique described here is a novel procedure not referenced before in the literature. This technique was designed for treatment of high degree spondylolisthesis and is recommended when, besides the index pathology, an adjacent level instability or slip needs to be addressed. Partial slippage reduction and focal kyphosis improvement at the pathological level, decompression and 360° stabilization are key features of the procedure and seem to be effective for managing severe adult spondylolisthesis. Despite obtaining partial reduction and anterior stabilization without neurological consequences, supportive posterior instrumentation is needed. Further studies comparing the efficacy of this technique with previously described techniques are warranted.

Conflicts of interest

The authors have none to declare.

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