High-grade spondylolisthesis treated using a modified Bohlman technique: results among multiple surgeons

Clinical article

ROBERT A. HART, M.D., M.A.,1 CHRISTOPHER M. DOMES, M.D.,2 BRADY GOODWIN, B.S.,1 CHARLES R. D’AMATO, M.D.,3 JUNG U. YOO, M.D.,1 RONALD J. TURKER, M.D.,4 AND MATTHEW F. HALSEY, M.D.1

1Orthopaedic Surgery, Oregon Health & Science University, Portland; 2Orthopaedic Surgery, Shriners Hospitals for Children, Portland; 3Orthopaedic Surgery, Kaiser Permanente, Portland, Oregon; and 4Orthopaedic Surgery, University of Washington, Seattle, Washington

Object. The ideal surgical management of high-grade spondylolisthesis remains unclear. Concerns regarding the original Bohlman transsacral interbody fusion technique with stand-alone autologous fibular strut include late graft fracture and incomplete reduction of lumbosacral kyphosis. The authors’ goal was to evaluate the radiographic and surgical outcomes of patients treated for high-grade spondylolisthesis with either transsacral S-1 screws or standard pedicle screw fixation augmenting the Bohlman posterior transsacral interbody fusion technique.

Methods. A retrospective review of patients who underwent fusion for high-grade spondylolisthesis in which a Bohlman oblique posterior interbody fusion augmented with either transsacral or standard pedicle screw fixation was performed by 4 spine surgeons was completed. Estimated blood loss, operating time, perioperative complications, and need for revision surgery were evaluated. Upright pre- and postsurgical lumbar spine radiographs were compared for slip percent and slip angle.

Results. Sixteen patients (12 female and 4 male) with an average age of 29 years (range 9–66 years) were evaluated. The average clinical follow-up was 78 months (range 5–137 months) and the average radiographic follow-up was 48 months (range 5–108 months). Ten L4–S1 and 6 L5–S1 fusions were performed. Five fibular struts and 11 titanium mesh cages were used for interbody fusion. Six patients had isolated transsacral screws placed, with 2 (33%) of the 6 requiring revision surgery for nonunion. No nonunions were observed in patients undergoing spanning pedicle screw fixation augmenting the interbody graft. Six patients experienced perioperative complications including 3 iliac crest site infections, 1 L-5 radiculopathy without motor involvement, 1 deep vein thrombosis, and 1 epidural hematoma requiring irrigation and debridement. The average estimated blood loss and operating times were 763 ml and 360 minutes, respectively. Slip percent improved from an average of 62% to 37% (n = 16; p < 0.01) and slip angle improved from an average of 18° to 8° (n = 16; p < 0.01). No patient experienced L-5 or other motor deficit postoperatively.

Conclusions. The modified Bohlman technique for treatment of high-grade spondylolisthesis has reproducible outcomes among multiple surgeons and results in significant improvements in slip percent and slip angle. Fusion rates were high (14 of 16; 88%), especially with spanning instrumentation augmenting the oblique interbody fusion. Rates of L-5 motor deficit were low in comparison with techniques involving reduction of the anterolisthesis.

(ftp://thejns.org/doi/abs/10.3171/2014.1.SPINE12904)

Key Words • spondylolisthesis • complications • technique

The optimal technique for surgical treatment of high-grade spondylolisthesis remains controversial. Options include in situ posterior fusion, stand-alone oblique interbody fusion, instrumented posterior fusion, anterior or posterior interbody fusion with instrumentation, and L-5 vertebrectomy with reduction and fusion of L4–S1.1,9,10,12,17–19,24,26,33–37 Reported surgical complications have included pseudarthrosis, progression of slip grade or angle, graft site morbidity, neurological compromise (especially L-5 motor deficit), and hardware failure.18,20,24,25 Speed13 described an anterior approach with an oblique fibular strut graft for interbody fusion for the treatment of spondylolisthesis. Smith and Bohlman15

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
and Bohlman and Cook\(^4\) proposed a modified technique performed via a 1-stage posterior procedure that included posterior decompression, posterolateral fusion, and oblique interbody fusion with an autologous fibular strut graft inserted from a starting point between the S-1 and S-2 nerve roots. Proposed benefits of the oblique interbody fusion include increasing surface area for graft incorporation and a stabilizing effect of the graft with respect to slip.\(^{33}\)

The Bohlman technique was described prior to widespread adoption of modern pedicle screw instrumentation. Concerns regarding the original Bohlman transsacral interbody fusion technique have included graft site morbidity, late graft fracture, and incomplete reduction of the slip angle of the spondylolisthesis.\(^{2,3,6,9,15,16,27,33,35}\) Given these issues, several authors have advocated complete reduction of anterolisthesis by using pedicle screw instrumentation. This approach has resulted in L-5 nerve root palsies in some patients, as well as instrumentation failures, particularly at the sacrum. Some authors now advocate supplementary pelvic fixation to avoid S-1 pedicle screw failures.\(^{7,13,25}\)

Addition of transsacral and/or pedicle screw instrumentation to supplement a Bohlman oblique interbody fusion may help address the previous issues of late graft failure and incomplete reduction of lumbosacral kyphosis.\(^{32}\) Titanium mesh cages used in place of the fibular graft may also reduce late failures. The objective of this study was to evaluate radiographic and clinical outcomes in adult and pediatric patients with high-grade spondylolisthesis who were treated with an augmented Bohlman procedure in which transsacral and/or pedicle screw fixation and either a fibular graft or titanium mesh cage were used for oblique posterior interbody fusion (Fig. 1).

**Methods**

After internal review board approval, a retrospective review of consecutive patients who underwent a modified Bohlman procedure for high-grade (Meyerding Grade 3 or 4) spondylolisthesis at 2 university-based centers between August 2001 and August 2011 was undertaken. The operations were performed by 4 surgeons. Given the widely variable approach to surgical management of high-grade spondylolisthesis, we believed that attempting a multicenter analysis was not viable.

Clinical variables included patient age and sex, primary presenting symptoms, neurological dysfunction prior to or after surgical correction, and any previous surgical procedures for the spondylolisthesis. Surgical variables collected included the level of fusion, type of interbody device (titanium mesh cage or fibular strut), instrumentation pattern (transsacral or pedicle screws), the use of bone morphogenetic protein–2 (BMP-2), estimated blood loss (EBL), operating time, Wiltse classification type,\(^{40}\) and perioperative complications (Table 1).

In all cases, the procedure consisted of a single-stage posterior approach, including complete resection of the L-5 lamina and inferior facets as well as a laminectomy of S-1. Posterior instrumentation was performed either from L-4 to S-1 or L-5 to S-1. Efforts were made to reduce lumbosacral kyphosis but not the anterolisthesis itself. In patients with neutral slip angles or in whom lumbosacral kyphosis reduced with positioning and laminectomy, oblique transsacral S-1 pedicle screws were placed (Fig. 2).\(^1\) If further reduction of the slip angle was required, this was performed using standard L-4 and S-1 pedicle screw instrumentation prior to the interbody fusion (Fig. 3). Oblique interbody fusion was performed using fibular strut autograft or allograft, or using a 50-mm × 10- to 12-mm-diameter titanium mesh cage filled with autograft or BMP-2.\(^{4,33}\) No BMP was used in interbody grafting performed with fibulae. No patient underwent placement of iliac fixation.

Upright spine radiographs were evaluated by a single independent reviewer (C.M.D.). Pelvic incidence was measured from preoperative digital radiographs. Slip percent and slip angle were measured digitally from standing presurgical and final follow-up evaluations by using standardized methods.\(^{28,46}\) Implant and fusion status were evaluated using plain film, flexion-extension, lateral radiographs, supplemented by CT scans for selected patients at the direction of the operating surgeon.

Statistical analysis of pre- and postoperative slip percent and slip angle was performed using paired t-tests with a level of significance set at 0.05. The primary outcomes evaluated were occurrence of perioperative complications and need for revision procedures. Final Oswestry Disability Index (ODI) and Short Form-12 Health Survey (SF-12) scores were obtained and compared with published normative values.

**Results**

Sixteen patients (12 female and 4 male; mean age at time of surgery 29.2 years; range 9–66 years) were identified. Fourteen of the 16 patients had isthmic spondylolisthesis, 1 patient had a dysplastic spondylolisthesis associated with trichorhinophalangeal syndrome Type II (Case 14), and 1 had a traumatic spondylolisthesis (Case

Fig. 1. Drawings showing L5–S1 spondylolisthesis treated with the modified Bohlman technique, in which a titanium mesh cage and posterior instrumentation are used. Copyright Robert A. Hart. Published with permission.
TABLE 1: Characteristics, surgical technique, outcome, and complications in 16 patients with high-grade spondylolisthesis*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Meyerding Grade</th>
<th>Pelvic Incidence (º)</th>
<th>Slip % Preop</th>
<th>Slip % Postop</th>
<th>Slip Angle Preop (º)</th>
<th>Slip Angle Postop (º)</th>
<th>Fusion Level</th>
<th>Screw Technique</th>
<th>BMP Used</th>
<th>Device Type</th>
<th>EBL (ml)</th>
<th>OR Time (hrs)</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27, M</td>
<td>3</td>
<td>66</td>
<td>56</td>
<td>48</td>
<td>25</td>
<td>7</td>
<td>L4–S1</td>
<td>pedicle</td>
<td>yes</td>
<td>cage</td>
<td>200</td>
<td>5.0</td>
<td>none</td>
</tr>
<tr>
<td>2</td>
<td>64, F</td>
<td>3</td>
<td>91</td>
<td>65</td>
<td>47</td>
<td>17</td>
<td>7</td>
<td>L4–S1</td>
<td>pedicle</td>
<td>yes</td>
<td>cage</td>
<td>1000</td>
<td>4.5</td>
<td>none</td>
</tr>
<tr>
<td>3</td>
<td>34, F</td>
<td>3</td>
<td>81</td>
<td>66</td>
<td>31</td>
<td>18</td>
<td>13</td>
<td>L4–S1</td>
<td>pedicle</td>
<td>yes</td>
<td>cage</td>
<td>700</td>
<td>7.0</td>
<td>none</td>
</tr>
<tr>
<td>4</td>
<td>17, F</td>
<td>3</td>
<td>70</td>
<td>70</td>
<td>25</td>
<td>23</td>
<td>6</td>
<td>L4–S1</td>
<td>pedicle</td>
<td>no</td>
<td>cage</td>
<td>500</td>
<td>8.0</td>
<td>none</td>
</tr>
<tr>
<td>5</td>
<td>14, F</td>
<td>3</td>
<td>83</td>
<td>65</td>
<td>29</td>
<td>16</td>
<td>9</td>
<td>L4–S1</td>
<td>pedicle</td>
<td>no</td>
<td>cage</td>
<td>1300</td>
<td>7.5</td>
<td>none</td>
</tr>
<tr>
<td>6</td>
<td>16, M</td>
<td>3</td>
<td>76</td>
<td>60</td>
<td>30</td>
<td>15</td>
<td>9</td>
<td>L5–S1 transsacral</td>
<td>no</td>
<td>cage</td>
<td>500</td>
<td>4.5</td>
<td>nonunion &amp; late hardware failure</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>66, F</td>
<td>4</td>
<td>86</td>
<td>76</td>
<td>48</td>
<td>13</td>
<td>6</td>
<td>L4–S1 transsacral + pedicle</td>
<td>no</td>
<td>cage</td>
<td>800</td>
<td>4.5</td>
<td>iliac crest site infection</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>43, F</td>
<td>3</td>
<td>80</td>
<td>65</td>
<td>47</td>
<td>22</td>
<td>7</td>
<td>L4–S1 transsacral + pedicle</td>
<td>no</td>
<td>cage</td>
<td>1500</td>
<td>5.25</td>
<td>postop unilat leg radiculopathy w/o motor deficit</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>50, F</td>
<td>3</td>
<td>80</td>
<td>61</td>
<td>35</td>
<td>17</td>
<td>13</td>
<td>L4–S1 transsacral + pedicle</td>
<td>no</td>
<td>fibular strut</td>
<td>NA</td>
<td>NA</td>
<td>superficial iliac incision infection</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>19, F</td>
<td>3</td>
<td>79</td>
<td>61</td>
<td>44</td>
<td>16</td>
<td>7</td>
<td>L5–S1 transsacral + pedicle</td>
<td>no</td>
<td>fibular strut</td>
<td>NA</td>
<td>NA</td>
<td>fibular graft fracture</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>26, F</td>
<td>3</td>
<td>76</td>
<td>62</td>
<td>40</td>
<td>14</td>
<td>7</td>
<td>L5–S1 transsacral + pedicle</td>
<td>no</td>
<td>fibular strut</td>
<td>NA</td>
<td>NA</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18, M</td>
<td>3</td>
<td>83</td>
<td>58</td>
<td>30</td>
<td>21</td>
<td>4</td>
<td>L5–S1 transsacral + pedicle</td>
<td>no</td>
<td>fibular strut</td>
<td>NA</td>
<td>NA</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>12, F</td>
<td>3</td>
<td>80</td>
<td>56</td>
<td>33</td>
<td>13</td>
<td>6</td>
<td>L5–S1 transsacral + pedicle</td>
<td>no</td>
<td>fibular strut</td>
<td>NA</td>
<td>NA</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>39, M</td>
<td>3</td>
<td>99</td>
<td>54</td>
<td>39</td>
<td>18</td>
<td>10</td>
<td>L4–S1 transsacral + pedicle</td>
<td>no</td>
<td>cage</td>
<td>800</td>
<td>7.5</td>
<td>postop DVT, superficial iliac crest incision infection</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>12, F</td>
<td>3</td>
<td>80</td>
<td>65</td>
<td>31</td>
<td>18</td>
<td>7</td>
<td>L4–S1 pedicle</td>
<td>no</td>
<td>cage</td>
<td>1000</td>
<td>6.5</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>9, F</td>
<td>3</td>
<td>70</td>
<td>53</td>
<td>30</td>
<td>17</td>
<td>5</td>
<td>L5–S1 transsacral + pedicle</td>
<td>no</td>
<td>cage</td>
<td>700</td>
<td>4.0</td>
<td>postop EDH requiring irrigation</td>
<td></td>
</tr>
</tbody>
</table>

* DVT = deep vein thrombosis; EDH = epidural hematoma; NA = not applicable.
One patient had previously undergone laminotomies at L5-S1 prior to being seen in our clinic (Case 7). No patient had had prior lumbar arthrodesis. Fourteen patients reported severe axial and back pain, 5 patients had radicular pain, 2 had lower-extremity sensory deficits, and 1 had a unilateral lower-extremity motor deficit (foot drop). The mean pelvic incidence measured preoperatively was 80°, consistent with prior reports of high pelvic incidence among patients with high-grade spondylolisthesis.\textsuperscript{14,21,23}

Ten patients underwent fusion of L4–S1 and 6 underwent fusion of L5–S1. Six patients underwent placement of transsacral screws alone (Fig. 2), 7 had standard pedicle screw fixation (Fig. 3), and 3 had transsacral screws at S-1 attached to standard pedicle screws in L-4. Four patients received fibular allografts and 1 patient received a fibular autograft; 11 patients received titanium mesh cages. Four patients received BMP-2. The mean duration of surgery was 360 minutes (range 240–480 minutes), with mean intraoperative blood loss of 763 ml (range 200–1500 ml). The mean hospital stay was 5.8 days (range 2–10 days).

There were no intraoperative complications during the index fusion procedures. Postoperatively, 3 patients developed iliac crest donor site infections requiring irrigation and debridement. One patient developed deep vein thrombosis requiring readmission to the hospital for evaluation and management. One patient had persistent L-5 radicular pain and paresthesia with positive electromyographic change but without motor weakness. This failed to resolve despite revision foraminal decompression. One patient developed an epidural hematoma that required a return to the operating room for evacuation.

There were 2 interbody graft failures among the 6 patients treated with isolated transsacral screws (2 [33%] of 6). One 19-year-old patient (Case 10) (Fig. 4) developed worsening back pain at the 6-month postoperative follow-up. Her CT scans at that time showed failure of the cannulated transsacral screws and midshaft fracture of the fibular allograft, despite apparent incorporation of the ends of the graft at both L-5 and S-1. The patient underwent a successful revision procedure consisting of anterior discectomy and fusion with BMP-2, along with posterior spinal fusion with pedicle screw instrumentation at L5–S1. The second construct failure occurred in a 16-year-old male patient who developed worsening back pain 3.3 years after undergoing transsacral screw fixation with a titanium mesh cage for interbody fusion (Case 16).
Modified Bohlman technique

6). At that follow-up, radiographs revealed a fracture of the titanium mesh cage with nonunion. The patient underwent revision of instrumentation and successful posterolateral arthrodesis. As a result of these failures, the authors now reserve isolated transsacral screws only for young children (Fig. 2).

The mean preoperative anterolisthesis improved from 62% to 37% (p < 0.01) at the final follow-up in the 16 patients. The mean slip angle improved from 18° (range 13–25°) preoperatively to 8° (p < 0.01) postoperatively in these patients (Table 1).

Outcome scores at final 2-year minimum follow-up were obtainable from 13 (81%) of 16 patients; 3 patients were lost to follow-up. Final postoperative ODI scores were 16.8 ± 18.1, compared with a US population norm of 10.2.11 The SF-12 physical component score (PCS) was 48.9 ± 9.8, and the mental component score (MCS) was 48.4 ± 10.6. Population norms for both PCS and MCS scores are 50 (Table 2).28

No nonunions or late failures were seen in patients receiving pedicle screw instrumentation augmenting the oblique interbody fusion (Fig. 3). No patient experienced a postoperative motor deficit in L-5 or other neurological distribution.

**Discussion**

The natural history of high-grade spondylolisthesis is not favorable, and many authors have concluded that surgical management is appropriate for symptomatic patients.5,17,20,24,26,31,37 Although the surgical goals of achieving solid arthrodesis, reduction of lumbosacral kyphosis,
TABLE 2. Summary of final clinical and radiographic outcomes in 16 patients with high-grade spondylolisthesis*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Clinical FU (yrs)</th>
<th>ODI Score</th>
<th>SF-12 Score</th>
<th>Length of Radio FU (yrs)</th>
<th>Fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>PCS</td>
<td>MCS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>59.6 ± 39.8</td>
<td>51.7 ± 1.1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.1</td>
<td>6</td>
<td>0.5</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>2</td>
<td>3.2</td>
<td>10</td>
<td>1.1</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>3</td>
<td>2.3</td>
<td>14</td>
<td>2.3</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>7.9</td>
<td>10</td>
<td>2.2</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>5</td>
<td>8.7</td>
<td>16</td>
<td>4.5</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>6</td>
<td>6.7</td>
<td>24</td>
<td>1.9</td>
<td>NA</td>
<td>no</td>
</tr>
<tr>
<td>7</td>
<td>8.7</td>
<td>18</td>
<td>6.1</td>
<td>1.0</td>
<td>yes</td>
</tr>
<tr>
<td>8</td>
<td>5.4</td>
<td>72</td>
<td>1.1</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>9</td>
<td>9.0†</td>
<td>NA</td>
<td>9.0</td>
<td>9.0</td>
<td>yes</td>
</tr>
<tr>
<td>10</td>
<td>11.4</td>
<td>24</td>
<td>9.0</td>
<td>1.9</td>
<td>no</td>
</tr>
<tr>
<td>11</td>
<td>0.4†</td>
<td>NA</td>
<td>0.4</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>12</td>
<td>11.3</td>
<td>14</td>
<td>2.3</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>13</td>
<td>0.4†</td>
<td>NA</td>
<td>0.4</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td>14</td>
<td>9.2</td>
<td>0</td>
<td>8.7</td>
<td>8.7</td>
<td>yes</td>
</tr>
<tr>
<td>15</td>
<td>9.8</td>
<td>4</td>
<td>7.3</td>
<td>4.4</td>
<td>yes</td>
</tr>
<tr>
<td>16</td>
<td>6.3</td>
<td>7</td>
<td>6.3</td>
<td>NA</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>mean ± SD</td>
<td>6.5 ± 3.7</td>
<td>16.8 ± 18.1</td>
<td>48.9 ± 9.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pop norm</td>
<td>10.2</td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

* FU = follow-up; pop = population; radio = radiographic.
† Lost to follow-up. Value represents duration of follow-up at time of last appearance in clinic.
‡ Fourteen of 16 patients had fusion.

and neurological decompression are widely agreed on, the optimal surgical technique remains in dispute. Given the relatively small number of affected patients, retrospective comparisons of fusion and complication rates may be the best means available of evaluating treatment outcomes.18,20,25,30,32

Successful use of a fibular strut for oblique interbody fusion in surgical management for high-grade spondylolisthesis has been well documented in the literature.10,20,29,33–35 However, graft failure and recurrent instability are recognized complications of this approach.25,32 These failures probably represent a fatigue fracture due to the high loads encountered, along with weakening of the graft by bone resorption following healing.8,22,39 In addition, placement of an oblique interbody device without reduction of the slip angle effectively fixes the spine in a position of lumbar sacral kyphosis, with potential long-term detrimental effects.

Recognition of these limitations has led several authors to propose modifications to the original Bohlman technique. These have included replacement of the fibular strut graft with a titanium mesh cage,2,3,31 as well as reduction and augmentation with pedicle screw or transsacral screw instrumentation.25,32

Modern instrumentation techniques allow complete reduction of the anterolisthesis, presenting the option of using standard interbody fusion techniques. In fact, complete reduction of the anterolisthesis makes placement of an oblique cage impossible. Although advocates of reduction argue for the benefits of increased surface area for fusion, we are aware of no evidence that residual anterolisthesis affects long-term outcomes as long as stable arthrodesis and kyphosis reduction are achieved. However, reduction of anterolisthesis has been associated with increased rates of neurological complications, especially L-5 motor deficit (foot drop).24,28 In addition, the resulting forces on the instrumentation have led to implant failures, with a resulting need for revision and extension of the primary construct or addition of pelvic fixation.7,25

The modified Bohlman technique described here has resulted in successful fusion in the majority of our patients, with no occurrences of motor deficit. The technique is readily learned by most spine surgeons, whether treating pediatric or adult cases, as demonstrated by its adoption by multiple practitioners in our community. Another attractive aspect of the technique is the reduced need for L-5 pedicle screws, because the oblique interbody device provides some stability of L-5. The high fusion rates reported support this idea.

The only nonunions in our cohort occurred in 2 patients treated with isolated transsacral instrumentation (Fig. 4). Despite these failures, there may still be a role for this technique using solid shank instead of cannulated screws (Fig. 2) in younger, smaller patients. One potential advantage of this approach is a limitation of the fusion to a single segment as well as an avoidance of surgical insult to L-4/5 facets during the procedure.

The limitations of this study include a relatively small patient cohort and lack of long-term follow-up for some patients. Given these limitations, our data lack the power needed to make statistical comparisons of techniques, and should thus be considered a descriptive, Level IV re-
Modified Bohlman technique

view. Nonetheless, the size of this cohort and follow-up duration are comparable to those in many published series, reflecting the rarity of high-grade spondylolisthesis.

Patients with high-grade spondylolisthesis remain a rare but challenging group. A modified Bohlman procedure, with replacement of the autologous fibular strut by a titanium mesh cage and addition of spanning pedicle screw and/or transsacral screw fixation, results in satisfactorily reproducible clinical outcomes across multiple surgeons. Rates of neurological deficit appear to be reduced by limiting efforts at reduction to the lumbosacral kyphosis only, without attempting complete reduction of anteriorolisthesis.

Conclusions

The modified Bohlman technique for treatment of high-grade spondylolisthesis had reproducible outcomes among multiple surgeons, and resulted in significant improvements in slip percent and slip angle. Fusion rates were high, especially with spanning instrumentation augmenting the oblique interbody fusion, and rates of L-5 motor deficit were low in comparison with techniques involving reduction of the anteriorolisthesis.

Acknowledgments

We thank Marie Kane, M.S., and Erin Coburn, B.S., for editorial assistance. We also thank Lynn Kitagawa at the VA Hospital in Portland for creating Fig. 1.

Disclosure

Dr. Hart is a consultant for DePuy Spine, Medtronic, and Eli Lilly. He owns stock in SpineConnect, and is a patent holder with Oregon Health & Science University. He receives support for nonstudy-related clinical research from Medtronic and ISSG. He is a member of the speaker’s bureau for DePuy Spine. He also receives royalties from DePuy Spine and from SeaSpine. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Hart. Acquisition of data: Hart, Domes, Goodwin. Analysis and interpretation of data: all authors. Drafting the article: Hart, Domes, Goodwin, D’Amato. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Hart. Statistical analysis: Goodwin. Administrative/technical/material support: Goodwin, Yoo. Study supervision: Hart, Goodwin.

References

26. Peek RD, Wiltse LL, Reynolds JB, Thomas JC, Guyer DW,

Manuscript submitted October 1, 2012. Accepted January 14, 2014. Please include this information when citing this paper; published online February 21, 2014; DOI: 10.3171/2014.1.SPINE12904. Address correspondence to: Robert A. Hart, M.D., M.A., Orthopaedic Surgery, Oregon Health & Science University, Sam Jackson Hall, Ste. 2360, 3181 SW Sam Jackson Park Rd., Portland, OR 97239. email: harto@ohsu.edu.