Adult Deformity Correction Through Minimally Invasive Lateral Approach Techniques

Gregory M. Mundis, MD,* Behrooz A. Akbarnia, MD,† and Frank M. Phillips, MD‡

Study Design. Review of the available literature, authors’ opinion.

Objective. To review the literature on minimally invasive lateral approach for interbody fusion in treatment of adult deformity. To describe the key points of pertinent surgical anatomy and outline the results of our experience with this technique.

Summary of Background Data. Minimally invasive surgery in the management of adult spinal deformity has been introduced to minimize the postoperative morbidity and facilitate earlier recovery in a group of medically fragile patients.

Methods. Literature review.

Results. Both patient-centered outcome measures (including Oswestry Disability Index, Visual Analogue Scale, and SRS-22) and objective results (correction of coronal and sagittal deformity) are significantly improved in most studies. Reported complication rates differ from one study to another but major complications are low. Infrequent neurologic complications occurred; however, most surgical sequelae were transient and had resolved at later follow-up. The lower blood loss and shorter hospital stay are further benefits of the minimally invasive techniques when compared with results reported for open anterior surgeries for patients with adult deformity.

Conclusion. The current expertise of minimally invasive techniques in the management of adult spinal deformity is exponentially evolving, even yet the preliminary outcomes seem quite promising. Acknowledging the details of meticulous surgical technique and local anatomy (e.g., lumbosacral plexus and blood vessels) is the essential key to improving outcomes and reducing the risk of complications.

Key words: minimally invasive lateral approach, adult scoliosis, lumbosacral plexus, degenerative scoliosis. Spine 2010;35:S312–S321

Adult scoliosis (AS) is defined as lateral curvature of the spine of more than 10° in a skeletally mature patient.1,2 Adult scoliosis can be broken down into 2 broad categories; De Novo or Degenerative Scoliosis (DS) and adult idiopathic scoliosis (IS). De novo or adult degenerative scoliosis (DS) is defined as spinal deformity that has developed in adulthood with no evidence of spinal deformity in childhood or adolescence.1,2 In contrast, adult IS results from the effect of the degenerative process on an already existent adolescent scoliosis.

Adult degenerative scoliosis (DS) develops as the result of a degenerative cascade that terminates in asymmetric disc collapse, vertebral body wedging, facet degeneration, spondylolisthesis, and rotary subluxation. This cascade has the potential to lead to spinal instability with progressive biplanar (coronal, sagittal) deformity, loss of lumbar lordosis, and development of a sagittal imbalance. This bony deformity frequently results in the development of spinal stenosis with symptoms consistent with radiculopathy and/or claudication. It is these symptoms, not their spinal deformity, that frequently drive patients to seek medical care, and prompt referring physicians to send them to the surgeon for definitive management.

Understanding the etiology, anatomic features, and clinical presentation of the adult patient with scoliosis is important in determining an appropriate surgical strategy. Patients with IS frequently have a more severe rotational deformity leading to progressive back pain as well as significant coronal and sagittal decompensation. These patients frequently require longer fusions, often extending into the thoracic spine, to obtain surgical goals of stabilization, fusion, and deformity correction. De novo scoliosis (DS) typically has less rotational deformity but more frequent rotary subluxation, especially at L3–L4. The curves lack congenital anomalies and are located in the lumbar spine as opposed to often having a thoracic curve in addition to the lumbar. The age at presentation is usually older for de novo curves. It has been reported that up to 68% of adults over the age of 60 have a newly developed curve.3 Kobayashi et al4 followed 60 patients between the ages of 50 and 84 prospectively and found that 22 of them developed scoliosis within a 12-year period.

The decision for surgical intervention in this older group is rarely driven by curve magnitude but rather by clinical symptoms, a declining quality of life, and increasing disability.5 Patients frequently present with neurogenic claudication, radiculopathy, and progressive back pain. Pain is often associated with advanced disc and facet degeneration, progressive subluxation and listhesis, or convex pain associated with muscle fatigue. A progressive forward lean, or sagittal imbalance, has been
closely linked to a decrease quality of life by Glassman et al. Patients with greater than 5 cm of anterior sagittal imbalance can experience a significant decline in function. The energy requirements by this patient to stand and ambulate are greater than for patients in sagittal homeostasis. They experience early fatigue, intolerance of standing and walking with compensation through other joints. Their hip extensors and quadriceps work in eccentric contraction leading to intolerance for most activities.

Traditional surgical approaches to the patient with spinal deformity have included open posterior only and open anterior/posterior surgical correction. These techniques have been found to be reliable in radiographic correction of the deformity and sagittal alignment, however, carry with them a very significant perioperative risk profile. Open posterior surgery for deformity has a 25% to 80% risk of postoperative complication including excessive blood loss, infection, neurologic injury, and medical complications.7,8 Traditional open anterior thoracoabdominal approach is associated with up to 40% risk of complications including incisional pain, abdominal hernia, vascular injury, retrograde ejaculation, ureteral and bladder injury, and ilioinguinal and iliohypogastric nerve injuries.9 There is clearly a need to reduce the extent of this surgery particularly given the typically elderly patient population often with significant comorbidities. Over the past decade, less invasive surgical approaches to neural decompression and fusion have been popularized and have recently been applied in the treatment of adult deformity. The less invasive lateral approach to the spine is an attempt to accomplish this. The lateral approach may be used as part of a minimally invasive anterior-only or anterior-posterior procedure in the management of DS, or may be combined with open posterior fusion with osteotomies to achieve sagittal and coronal balance in IS patients. The use of the minimally invasive lateral approach may decrease the morbidity of the traditional anterior approach, and often makes the extent of posterior correction less invasive. The goal of this article is to provide the reader with a succinct review of the literature and report on preliminary results and evolution of the surgical treatment of adult deformity from the leading authors.

Evaluation

Radiographic evaluation is imperative for successful surgical management of adults with scoliosis. We highly recommend anterior-posterior and lateral full length 36” radiographs to adequately evaluate global sagittal and coronal balance. The use of flexion and extension lateral lumbar spine radiographs can be useful for determining dynamic instability. Flexibility radiographs, though helpful in adolescent scoliosis, have only a very limited role in adult deformity. The standing lateral radiograph must include the base of the occiput and bilateral femoral heads to adequately evaluate both the sagittal balance and pelvic parameters. Global alignment is directly related to restoring lumbopelvic anatomy. Lumbopelvic anatomy is assessed by measuring the sagittal vertical axis (SVA), pelvic tilt (PT), pelvic incidence (PI), sacral slope (SS), lumbar lordosis (LL), and T1 tilt (TT). The sagittal vertical axis is measured on the full-length lateral radiograph by drawing a perpendicular line from the posterior superior corner of the S1 superior endplate. The SVA is the distance between this line and the C7. Pelvic tilt (PT) is the angle drawn between a perpendicular line to the femoral heads and the midpoint of the S1 superior endplate (S1SE). T1 tilt is the angle of the T1 superior endplate to the horizontal plane. The pelvic incidence is the angle created between the femoral heads to the midpoint of S1SE and a line drawn perpendicular to the S1SE. Postoperative sagittal alignment variables have been defined in Table 1. Postoperative sagittal alignment parameters of SVA < ±5 cm, PT < 25°, T1 tilt of < 0°, and lumbar lordosis ± 9° of pelvic incidence are desirable.

Preoperative planning should include a magnetic resonance imaging to evaluate spinal neuroanatomy, intervertebral disc pathology, and vascular anatomy of the levels to be operated. Osteoporosis screening or monitoring is also recommended for those at risk. It will identify a patient population at higher risk for complications with interbody grafting.

Anatomic Considerations

Understanding the regional anatomy of the lumbar spine as it relates to the lateral retroperitoneal approach (LRA) especially in patients with scoliosis is essential in avoiding neurologic complications. It also explains the natural morbidity of this approach. In deformity correction via the LRA multiple holes are made in the psoas and the retroperitoneum is dissected out sometimes the length of the entire lateral abdominal wall. There are, therefore, morbidities that can be expected and discussion of these signs and symptoms should be included in preoperative counseling. These morbidities include groin pain and hip

### Table 1. The Definition of Lumbopelvic Parameters That Are Important in Evaluation of Sagittal Lumbar Deformity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal vertical axis (SVA)</td>
<td>The plumb line drawn from the center of the C7 vertebra ideally should be in ± 5 cm from the superior posterior corner of the sacral endplate.</td>
</tr>
<tr>
<td>Pelvic incidence (PI)</td>
<td>An angle subtended by a line which is drawn from the center of the femoral head to the midpoint of the sacral endplate and a line perpendicular to the midpoint of the sacral endplate.</td>
</tr>
<tr>
<td>Pelvic tilt (PT)</td>
<td>An angle subtended by a vertical line originating from the center of the femoral head and the midpoint of the sacral endplate.</td>
</tr>
<tr>
<td>Sagittal T1 tilt (TT)</td>
<td>The angle subtended by a line passing from mid-point of upper T1 endplate to the femoral head and a vertical line to the femoral head.</td>
</tr>
<tr>
<td>Lumbar lordosis (LL)</td>
<td>The angle between 2 lines drawn tangential to the superior end plate of T12 and S1.</td>
</tr>
</tbody>
</table>
flexor weakness ipsilateral to the LRA, anterior, lateral, inguinal, or genital paresthesias depending on the levels approached.

The lumbosacral plexus is derived from the primary ventral rami of the lumbar and sacral spine, which find their way to the peripheral nervous system via the psoas muscle. There are 4 named sensory nerves that arise from the lumbar plexus: (1) Iliohypogastric, (2) ilioinguinal, (3) Genitofemoral, and (4) Lateral femoral cutaneous nerve (LFCN). The iliohypogastric and ilioinguinal nerves find their origin at L1. Close to their origin, these nerves pierce the abdominal wall dorsally and course around the abdominal wall to eventually innervate the sensation to the lower abdominal wall, the groin, and a portion of the scrotum. These nerves are at risk during the approach to the lateral spine when a large dissection of the retroperitoneum is performed to gain access to the spine. These nerves are at higher risk at L4–L5 when the nerves lie directly in line with the incision and course on the undersurface of the ventral abdominal wall. The LFCN (L2/L3) pierces and courses along the abdominal wall. It then crosses the ilium posterior to the ASIS to innervate the lateral thigh. The LFCN is most vulnerable at this location, during a L4–L5 lateral approach secondary to compression of the nerve between the retractor and the ilium. Injury can lead to the well-described disorder of meralgia paresthetica. Finally, the genitofemoral nerve (L1–L2) lies more posterior on the concavity. The superficial sensory nerves including the genitofemoral and lateral femoral cutaneous nerves take the same course, making them more prone to injury (Figure 1). Detailed review of preoperatively obtained magnetic imaging resonance or computed tomography scan is essential in understanding the location of the vasculature during the lateral approach. This becomes particularly important when the anterior margin of the vertebral body in a rotated segment must be identified.

Benglis et al11 performed dissections on 3 fresh-frozen cadavers with the primary intent to identify the course of the lumbar plexus in relation to the lateral interbody approach. He reported his results as a ratio of the location of the plexus in relation to the posterior endplate to the total length of the disc space as seen on radiographs. He found that the plexus lies posteriorly at L1–L2 with a ratio of 0 and migrates ventrally the further caudad you go with a ratio of 0.28 at L4–L5. They did not dissect out the genitofemoral nerve to evaluate its relation to these structures. Moro et al12 attempted to define the safe zones during lateral endoscopic spine surgery by performing cadaveric dissections. Specifically, they used 6 cadavers to identify the lumbar plexus and 24 specimens to evaluate the course of the genitofemoral nerve. They concluded that the safe zone for the lumbar plexus was greatest at the L2–L3 interspace and cephalad. When working caudad to this level, the plexus trends to lie more ventral and is at highest risk at L4–L5. The genitofemoral nerve lies at the mid disc level and anteriorly at L3–L4 and lies slightly more anterior on the left side versus the right.

Figure 1. A, Apex-right scoliosis with counterclockwise (right) rotation of the vertebra resulted in a relative anterior position of the right nerve root and posterior position of the left vessel and nerve root. B, Apex-left with clockwise (left) rotation of the vertebra resulted in a relative anterior position of the left nerve root and a relative posterior position of the right vessel and nerve root (arrows pointing at the concave side of the deformity). LN, left nerve root; RN, Right nerve root; VC, Vena Cava; AO, Aorta. (Reprinted with permission from Spine.10 Copyright 2009, Lippincott Williams & Wilkins).
Park et al\textsuperscript{13} examined 10 cadaveric specimens to locate the trunk of the nerve roots as they relate to the radiographic center of the disc. They found that the most at risk level was L4–L5. The mean distance to the nerve trunk was posteriorly 14 mm (range, mean of 16.4 mm at L2–L3 to 10.6 mm at the L4–L5 level).

Further study of the applied anatomy to this region is needed to continue to improve the safety of this less invasive approach especially in patients with adult deformity to ultimately improve patient outcomes as well as patient and surgeon satisfaction.

\section*{The Surgical Procedure}

The lateral surgical approach for interbody fusion and deformity correction in the scoliotic spine can be more complicated than that of degenerative spinal conditions. The anatomic variations, stiffness, rotary olisthesis, and extensive osteophyte formation make attention to detail extremely important. This approach relies on excellent preoperative imaging studies to make appropriate technical decisions and to ensure safety when approaching the spine. True lateral and AP radiographs are essential to guide the surgeon to the optimal trajectory to the interspace in the safe corridor between the nervous and vascular structures. Interbody fusion should begin at the most caudad level (foundation) and the reconstruction continued to the most cephalad level. Given the segmental deformities often seen in scoliosis, the operating table and fluoroscopy may need to be adjusted at each level to ensure optimal radiographic imaging. It is recommended to use as wide of a graft as possible that engages the stronger ring apophysis to avoid subsidence as well as lordotic grafts as needed throughout the lumbar spine as many of these patients have a flat spine before surgery.

We recommend approaching the spine from the concavity for several reasons. It allows for a more comprehensive soft tissue release on the side of the spine that is contracted. The concavity is the site of foraminal narrowing, bony compression, and soft-tissue contracture. Releasing the deformity here will allow for improved deformity correction and more importantly restoration of foraminal height and indirect neural decompression. It also decreases the number of incisions needed to treat the surgical levels (up to 6 levels through 2 small lateral incisions). In addition, access from the concavity, allows for an easier approach to L4–L5 where the iliac crest typically obstructs access form the convexity. Breaking the table with the concavity up will also facilitate intraoperative correction of scoliosis.

In order to ensure correction of the spinal deformity, it is essential to release the annulus on the far-side of the disc space. This should be confirmed with fluoroscopy. A Cobb elevator may be useful to facilitate this. Care should be taken to avoid violation of the vertebral endplates to ensure that good disc space distraction is achieved by the interbody implant. This is particularly apropos in the older osteoporotic patient. Fluoroscopy during discectomy and endplate preparation is essential to reduce the risk of endplate injuries (Figures 2 and 3).

Figure 2. A, Anteroposterior and (B) lateral views of a 74-year-old female with idiopathic scoliosis managed non-operatively with brace until the age of 18. She developed debilitating LBP and lost 4 inches of her height. C, Anteroposterior view of the patient after first stage lateral interbody fusion (T12–L5). D, Twelve months after LIF (T12–L5) and posterior spinal fusion (T3-Pelvis), the anteroposterior and (E) lateral views show final sagittal and coronal balance and curve correction.
Akbarnia et al. recently reviewed their experience of patients with advanced scoliosis (minimum 30°) who underwent anterior reconstruction with lateral approach for interbody fusion followed by a formal posterior open approach. All 16 patients had minimum of 2-year follow-up with significant improvements seen in all clinical parameters, including Visual Analogue Scale (VAS), Oswestry Disability Index (ODI), and SRS-22 scores. Furthermore, they found on average a 45% correction of the coronal deformity with lateral interbody fusion alone and nearly 70% correction after second-stage posterior instrumentation and fusion. The coronal Cobb measurement improved from average 47° preoperative to 17° at 2-year follow-up. The sagittal parameters on average improved by restoring more normal lordosis from 31° preoperative to 44° postoperative. Coronal L4 tilt improved to 10° from 23° preoperative. When evaluating their segmental correction, the L1–L2 and L2–L3 levels seemed most amenable to correction in both coronal and sagittal planes (Figures 4 and 5).

Anand et al. reported their initial results in 2008 and their 2-year follow-up in 2010 of minimally invasive correction for adult deformity with average Cobb of 22°. They used a lateral interbody fusion technique anteriorly and percutaneous screws posteriorly. Average blood loss was 241 mL for the anterior surgery and 231 mL for the posterior portion. Coronal Cobb improved from 22° to 7° at final follow-up. VAS and ODI improved from 7.05 and 53.5 to 3.03 and 25.88, respectively. Their overall complication rate was 21%, which compares favorably to historic controls.

Tormenti et al. recently reported on their initial experience and complications among 8 patients undergoing transpsoas interbody fusion followed by open posterior correction with an average of 10.5 months follow-up. They compared these results with those of 4 other patients undergoing all posterior reconstruction during the same time period. The preoperative Cobb improved from 38.5° to 10° postoperative, and lumbar lordosis was maintained within normal limits. The apical vertebral translation was improved to a greater extent with posterior only surgery, whereas deformity correction was better with combined anterior and posterior surgery. They found improvement in VAS from 8.8 to 3.5 at final follow-up in the combined group and 9.5 to 4 in the posterior only group. Other HRQOL data were not available. Sixteen complications were reported among 8 patients; however, 6 of these were postoperative sensory radiculopathies. Wang and Mummaneni recently published their experience among 23 patients using the lateral minimally invasive approach for spine deformity. The mean Cobb angle improved from 31.4° to 11.5° at 13.5 months follow-up. Average blood loss was 477 mL and overall complication rate was reported as 39% (9/23), however, 6 of these were transient thigh pain, dysesthesia, or paresthesias. The mean VAS improved from 7.3 to 3.3 at final follow-up. Dakwar et al. recently published their early results treating 25 patients for DS with lateral interbody fusion (LIF). They found a mean
Figure 4. A, Anteroposterior and (B, C) lateral radiographs of 35-year-old female with history of idiopathic scoliosis who previously underwent posterior spinal fusion with instrumentation from T3 to L4, presenting with severe midline lower back pain and right sided radiculopathy and transitional syndrome. D. The patient underwent L4–L5 LIF with a lordotic cage and posterior spinal fusion (L2–L5) with restoration of lumbar lordosis. E, Sagittal computerized tomography (CT) showing the amount of lumbar lordosis restored. F, Final anteroposterior and (G) lateral views of the patient at her latest follow-up showing maintained correction of L4–L5.
improvement in VAS of 5.7 points and 23.7% of ODI. Their overall complication rate was very low with 1 patient developing rhabdomyolysis requiring hemodialysis, 1 with asymptomatic graft subsidence, and 1 asymptomatic implant failure. Of 25 patients, 3 (12%) developed transient thigh numbness ipsilateral to the approach, which are categorized as expected morbidity of the lateral retroperitoneal approach. The results of several recent studies have been summarized in Table 2.

Isaacs et al\textsuperscript{20} prospectively studied 107 patients treated with LIF for DS with emphasis on complications (published in this issue). Of total, 28% of patients had at least 1 comorbidity. A mean of 4.4 levels/patient (range,
1–9) were treated. Supplemental pedicle screw fixation was used in 75.7% of patients, 5.6% had lateral fixation, and 18.7% had stand-alone LIF. Mean operative time was 178 minutes (58 min/level) and blood loss 50 to 100 mL. Mean hospital stay was 2.9 days for single setting combined anterior-posterior surgery. Five patients (4.7%) received a transfusion, 3 (2.8%) required intensive care unit admission, 1 (0.9%) required rehabilitation services. Major complications occurred in 13 patients (12.1%): 2 (1.9%) medical, 12 (11.2%) surgical. Of procedures that involved only less invasive techniques (LIF stand-alone or with percutaneous instrumentation), 9.0% had 1 or more major complications. In those with supplemental open posterior instrumentation, 20.7% had 1 or more major complication. In this series most of the patients had DS, and posterior osteotomies were not typically performed (Figure 6).

The overall clinical outcomes data are very promising with the minimally invasive LIF technique. Not only are the radiographic parameters significantly improved but more importantly the early clinical results indicate significant improvements with a lower complication profile compared to traditional open approaches. This is especially true when considering the complications encountered during open anterior approaches.

### Complications

Complications have been well studied in the adult deformity population. Their occurrence ranges from 29% to 80% in the literature for traditional open (anterior or posterior) approaches.\(^7\)\(^–\)\(^9\)\(^,\)\(^21\)\(^–\)\(^29\)

Before discussing the incidence of complications, it is important to define what a complication is. If the result of the surgical approach is consistently a temporary event then the authors would suggest that the occurrence

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**Table 2. Summary of the Results of Various Recent Studies**

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Mean Operative Levels</th>
<th>Estimated Blood Loss</th>
<th>Average Correction (Coronal Deformity)</th>
<th>Average Correction (Sagittal Deformity)</th>
<th>Sagittal Balance</th>
<th>Coronal Balance</th>
<th>Average VAS Improvement</th>
<th>Other Outcome Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akbarnia et al(^4)</td>
<td>16</td>
<td>2.9</td>
<td>&gt;24</td>
<td>103 Ant</td>
<td>47</td>
<td>17</td>
<td>—</td>
<td>31</td>
<td>44</td>
</tr>
<tr>
<td>Tormenti et al(^7)</td>
<td>8</td>
<td>2.8</td>
<td>10.5</td>
<td>—</td>
<td>38.5</td>
<td>10</td>
<td>—</td>
<td>47.3</td>
<td>40.4</td>
</tr>
<tr>
<td>Anand et al(^8)</td>
<td>28</td>
<td>3.5</td>
<td>22</td>
<td>241 Ant</td>
<td>22</td>
<td>7</td>
<td>222</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Gokawar et al(^9)</td>
<td>17</td>
<td>4.0</td>
<td>21</td>
<td>64</td>
<td>106/level</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Wang and Mummaneni(^18)</td>
<td>23</td>
<td>3.7</td>
<td>13.4</td>
<td>477 Tot</td>
<td>31.4</td>
<td>11.5</td>
<td>401 Tot</td>
<td>37.4</td>
<td>45.5</td>
</tr>
</tbody>
</table>

F/U indicates follow-up; Ant, anterior approach; Tot., total estimated blood loss in both anterior and posterior approaches; AVT, apical vertebral translation; ODI, Oswestry Disability Index; VAS, Visual Analogue Scale; SRS-22, Scoliosis Research Society Outcome questionnaire No. 22; SF-36, Short Form No. 36; TIS, Treatment Intensity Scale.

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Figure 6. A, B, Anteroposterior and lateral view of lumbar spine in a patient with severe multi-level degenerative changes with coronal deformity and loss of lumbar lordosis. C, D, Final anteroposterior and lateral radiographs after 3 level (L2–L5) LIF and posterior spinal fusion (L1–S1) with instrumentation.
of such an event is not complication but rather a predictable consequence of the surgical procedure. For instance, most knee arthroplasty patients have some weakness in their quadriceps muscle as a result of the surgical approach. Similarly in lateral access surgery in the lumbar spine, the occurrence of a thigh paresthesia and iliopsoas weakness is the result of the surgical approach. If these symptoms are temporary then they should be considered an expected outcome secondary to surgical approach.

Temporary paresthesias were reported among 9 of 16 patients by Akbarnia et al.14 Of these 2/16 (12.5%) had persistent symptoms at 2-year follow-up. Anand et al16 found that 17 of his 28 patients (61%) had temporary thigh numbness after surgery with all having resolution at 6 weeks follow-up. Tormenti et al17 found that 6 of 8 (75%) patients had postoperative thigh dysesthesia or paresthesia and only 1 had resolution at 2 months with 5/8 (62.5%) having persistent symptoms at final follow-up. The high rates of occurrence of these temporary clinical symptoms furthermore indicate the nature of the approach rather than a true complication.

Postoperative motor deficits are a concern during the lateral approach as the femoral nerve and the lumbar plexus nerve roots are at risk during the approach. Akbarnia et al14 reported on 3 patients with postoperative quadriceps weakness all of which resolved by 3 months after surgery. Anand et al16 similarly reported on 2 quadriceps palsies both of which resolved by 6 months. Tormenti et al17 had 2 patients in their series with a motor radiculopathy. One resolved by 2 months postoperative and the other had persistent symptoms at 3 months. Longer follow-up is required to see if these resolve as our experience14 indicates that motor radiculopathy frequently persists beyond 3 months but resolves by the 6-month follow-up visit.

Isaacs et al20 reported that of 107 patients treated with LIF for scoliosis, 29 had isolated postoperative hip flexor weakness felt to be related to passage of retractors through the psoas muscle to access the spine. By the 6-week, 3-month, and 6-month examinations, respectively, 32.1%, 60.7%, and 82.1% of those with 1 grade of weakness initially had fully resolved. Only 1 patient had a major (4/5) weakness of the proximal muscles of the lower extremity that could be attributable to a lumbar plexus injury (0.9% of cases, or 0.3% of levels approached), and this improved to 4/5 by the 6-month visit.

The possibility of vascular and visceral complications is of great concern in minimally invasive correction of adult scoliosis. The anatomy in these patients is severely altered especially with more severe curves. The rotational component of the curve frequently places the visceral organs and vascular structures in direct line with the surgical approach to the spine. The more rotation of the spine the more important it is to pay attention to ideal fluoroscopic imaging and to make appropriate clinical adjustments intraoperatively to avoid injury to these vital structures. The potential retroperitoneal space exists in these patients just as in other patients. If the spinal ap approach on the concavity of the curve then the skin incision and approach is more anterior. The peritoneum is not as well defined at this location and as such makes it prone to injury. Tormenti et al17 sustained 1 bowel injury among 8 patients in their series and aborted the anterior approach because of the proximity of bowel on another case. The patient with a cecal perforation had an emergency laparotomy and eventually would undergo a posterior only approach for deformity correction without any long-term sequelae reported.

The pulmonary system is at risk of injury anytime the lateral approach is applied to the L2–L3 level and above. The ribs and diaphragm are frequently in the way of the approach and it is possible that the lung parenchyma can be violated. More frequently, tears in the parietal pleura occur, which does not lead to long-term sequelae if appropriately addressed.

Tormenti et al17 had 2 of 8 patients with a postoperative pleural effusion that required chest tube placement with no further complications reported. Akbarnia et al14 similarly reported on 1 patient requiring chest tube placement for persistent pleural effusion. The patient

<table>
<thead>
<tr>
<th>Complications</th>
<th>Akbarnia et al14</th>
<th>Tormenti et al17</th>
<th>Anand et al16</th>
<th>Dakwar et al19</th>
<th>Wang and Mummaneni20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor (weakness, palsy)</td>
<td>3/16 (19)</td>
<td>2/8 (25)</td>
<td>2/23* (8.7)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Sensory (hypoaesthesia)</td>
<td>9/16 (56)</td>
<td>6/8 (75)</td>
<td>17/23* (74)</td>
<td>3/25 (12)</td>
<td>6/23 (28)</td>
</tr>
<tr>
<td>Thoracic/abdominal organ injury/problem</td>
<td>1/16 (6.2)</td>
<td>3/8 (37.5) (1 cecal)</td>
<td>1/28 (3.6)</td>
<td>1/28 (3.6)</td>
<td>1/23 (4.3)</td>
</tr>
<tr>
<td>Motor (weakness, palsy)</td>
<td>—</td>
<td>—</td>
<td>(reocapsular hematoma)</td>
<td>—</td>
<td>(pneumothorax)</td>
</tr>
<tr>
<td>Thoracic/abdominal organ injury/problem</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Percutaneous needle injections</td>
<td>1 (1 pleural effusion)</td>
<td>2 (1 pleural effusion)</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Others</td>
<td>1/16 (6.2)</td>
<td>1/28 (3.6)</td>
<td>2/28 (8.7)</td>
<td>1/23</td>
<td>CSF leak 1/23, late vertebralFx 1/23, thigh pain 5/23, pseudarthrosis 1/23</td>
</tr>
</tbody>
</table>

*The data were available for only 23 patients.
Perm. indicates permanent complication.

Table 3. Summary of Complications in Various Recent Studies
eventually had a full recovery. The complication rate reported in different recent studies has been summarized in Table 3.

Significant complications exist with adult spinal deformity surgery. The patients are naturally at higher risk because of their age, medical comorbidities, and extent of surgery required to correct their deformity and to address their disability. It could be argued that the complication rates reported are higher than in actual practice. Most of the literature reports on cases done during the early phases of the development of lateral access surgery. Although a learning curve certainly exists in treating patients with this technique, even preliminary results, have an overall complication rate that is favorable when comparing to historic controls of open anterior surgery, with the added benefit of good early clinical outcomes.

**Key Points**

- Minimally invasive lateral interbody fusion is an effective surgical strategy for the treatment of adult (degenerative and idiopathic) deformity.
- Coronal and sagittal plane deformity correction is achieved with an acceptable complication profile.
- Larger cohort of patients, longer follow-up, and higher level of evidence are essential to critically interpret the outcomes of this technique.

**References**