Adult Degenerative Lumbar Scoliosis

EUGENE WONG, MBBS, MMED; FARHAAN ALTAF, MBBS, FRCS; LAWRENCE J. OH, MD; RANDOLPH J. GRAY, MBBS, FRACS

Abstract

Adult degenerative lumbar scoliosis is a 3-dimensional deformity defined as a coronal deviation of greater than 10°. It causes significant pain and disability in the elderly. With the aging of the population, the incidence of adult degenerative lumbar scoliosis will continue to increase. During the past decade, advancements in surgical techniques and instrumentation have changed the management of adult spinal deformity and led to improved long-term outcomes. In this article, the authors provide a comprehensive review of the pathophysiology, diagnosis, and management of adult degenerative lumbar scoliosis. [Orthopedics. 201x; xx(x):xx-xx.]

Degenerative lumbar scoliosis is a 3-dimensional deformity of the spine with a coronal deviation of greater than 10°. The reported incidence of scoliosis in adulthood has varied from 1.5% to 29.4%. The aging of the population, coupled with an increasing focus on quality of life, has rendered degenerative scoliosis a considerable health care concern. Adult scoliosis, compared with the scoliosis of children and adolescents, is more frequently encountered in the general spine practice. Advancements in surgical techniques and instrumentation during the past decade, supported by improvements in anesthesia, have led to significant progress being made in the management of adult spinal deformity. The authors provide a comprehensive review of the pathophysiology, diagnosis, and management of adult degenerative scoliosis.

Etiopathogenesis

Adult scoliosis may result from the progression of an early onset scoliosis, idiopathic scoliosis, or a compensation to a deformity elsewhere, or may arise de novo without preexisting scoliosis. This review focuses on the latter—de novo or adult degenerative scoliosis.

Decreased bone density was previously associated with the etiopathogenesis of degenerative scoliosis. However, this was rejected based on the lack of supporting evidence. The pathophysiology of degenerative scoliosis involves the asymmetric degeneration of the intervertebral disks and the facet joints at different levels, leading to unequal loading of the spinal column. The asymmetric loading, together with degeneration, initiates a dynamic pattern of curve progression, producing a 3-dimensional deformity. It most commonly affects the lumbar spine, where there is a higher incidence of degenerative disk disease.

At a biological level, osteophytes are formed at the facet joint and vertebral end plates, further narrowing the spinal canal. This is compounded by ligamentum flavum hypertrophy and calcification. A reduction in the caliber of the spinal canal causes central and lateral recessal spinal stenosis. Instability and collapse of the disk height can cause foraminal stenosis.

Instability of the spinal column ensues secondary to the destruction of the facet joints and intervertebral disks. This can...
be manifested as a spondylolisthesis—anteroposterior translation of one vertebra in relation to the adjacent vertebra in the sagittal plane. The instability also leads to increased axial rotation of the vertebral bodies in relation to one another. This is most visible in the frontal plane as a lateral listhesis (lateral translation of one vertebra in relation to the adjacent vertebra).12

Spinal column instability caused by extensive facetectomies performed during spine surgery can also manifest as degenerative scoliosis. The vertebrae above the level of the facetectomies gradually progress toward forward translation and rotation, leading to the development of a scoliotic deformity.13,14

**Natural History**

Adult degenerative scoliosis is most commonly seen in patients older than 40 years.15,16 Although the incidence of degenerative scoliosis increases with age, the condition is not necessarily accompanied by a greater deformity with age. A higher prevalence exists in whites compared with other races.16

The spinal curvature seen in degenerative scoliosis tends to progress at a rate of 1° to 6° per year, with an average increase of 3° per year.13 Patient age and sex have not been found to be associated with the rate of curve progression. Curves of a greater magnitude (>30°), increased vertebral rotation at the apex of the curve, and more pronounced lateral listhesis (>6 mm) have been found to be associated with a higher degree of curve progression.17

**Clinical Presentation**

Both axial back pain and leg pain are commonly reported by adults presenting with a spinal deformity. Whether both symptoms are present and, if so, the relative severity of each need to be determined.

Back pain has been reported in 40% to 90% of patients with degenerative scoliosis.18 The etiology of the back pain is often multifactorial and can be attributed to muscle fatigue, facet arthropathy, and degenerative disk disease.5 Loss of lumbar lordosis, commonly seen in degenerative scoliosis, can cause muscle pain secondary to fatigue of spinal musculature.19

Leg pain occurs secondary to foraminal nerve root compression or from neurogenic claudication due to central spinal stenosis.20 It is important to elicit whether the pain is unilateral or bilateral and whether the symptoms are radicular or more consistent with neurogenic claudication.

**Radiographic Evaluation**

Full-length standing posteroanterior and lateral radiographs of the spine are required to accurately evaluate the entirety of the spinal deformity (Figure 1). Patients are instructed to remove their shoes. Any lower limb discrepancy is compensated with a shoe lift before the radiograph is obtained. Radiographs should also include the hip joints such that the pelvic parameters can also be measured.

Patients are asked to maintain their knees and hips in extension. For the posteroanterior view, the arms can be hanging or the hands can be held behind the cassette. For the lateral view, patients stand naturally, looking horizontally; their...
hands rest on a vertical support, their arms are bent, and their elbows are relaxed.\textsuperscript{21} Patients should not hold onto a railing, as doing so often leads to an underestimation of positive sagittal balance.

There is also an increasing role of EOS imaging (EOS Imaging, Paris France) of the spine. This is a biplanar image obtained while the patient is standing. The dose of radiation absorbed by the patient is reduced. EOS imaging allows quantitative assessment of the degree of compensatory mechanisms such as flexion of the knees and hips, permits measurement of pelvic parameters, and provides a 3-dimensional qualitative analysis of the degree of scoliosis.\textsuperscript{22}

If surgery is considered, lateral bending radiographs (full-length posteroanterior plain radiographs with the patient bending to the right and to the left) are first obtained to determine the flexibility of the scoliosis curvature.

Magnetic resonance imaging yields excellent soft tissue detail and is useful in revealing intervertebral disk disease, spondylotic changes, and intraspinal anomalies.\textsuperscript{23} Unless contraindicated, magnetic resonance imaging should be obtained in all cases of possible neurologic compromise.

Computed tomography provides information that is useful for preoperative surgical planning, such as which segments of the spine are fixed and which are mobile.\textsuperscript{24} Computed tomography myelography provides intraspinal information in addition to high-resolution bony detail, particularly when a patient has had surgery with spinal fixation. It is extremely useful for localizing sites of central and foraminal neural compression. A dual-energy x-ray absorptiometry scan is often obtained preoperatively to evaluate for osteoporosis, which causes osteoporotic fractures. Osteoporosis worsens the deformity and may require additional preoperative optimization such as medical management. The presence of osteoporosis is also important in the context of surgical planning because of the associated higher risk of instrumentation failure.

**SAGITTAL BALANCE**

Spinal deformity can create suboptimal spinal alignment and may lead to increased energy requirements to maintain appropriate posture and balance. Gait and posture are their best when the head and the trunk fall over the pelvis. In this ideal position, the body center of mass falls over the femoral axis, balancing the body in an upright posture. The sagittal vertical axis, a global measure of sagittal alignment, is the horizontal distance between the C7 plumb line and the posterosuperior corner of the sacrum. By convention, positive sagittal balance occurs when the C7 plumb line falls anterior to the posterosuperior corner of the S1 end plate. A line up to 5 cm anterior to the posterosuperior corner of the sacrum may be an acceptable range, as this is not likely to cause symptomatic sagittal imbalance.\textsuperscript{23}

Sagittal spinal alignment has been strongly correlated with measures of health-related quality of life.\textsuperscript{25-28} Glassman et al.\textsuperscript{26} in a retrospective review of 752 patients with adult scoliosis, found a strong linear correlation between the degree of positive sagittal balance and the prevalence of the symptoms of back pain.

Global spinal alignment may be subdivided into its component parts, namely lumbar lordosis and thoracic kyphosis. Lumbar lordosis is measured from the superior end plate of L1 to the superior end plate of S1 and has an important role in the maintenance of an upright posture. Normative values of 40° to 60° have been reported in the adult population.\textsuperscript{29} Lumbar lordosis is known to decrease with age and with spinal deformity. Decreasing lordosis or flat-back deformity has been associated with the inability to maintain spinal balance, resulting in pain and disability.\textsuperscript{19} Furthermore, thoracic kyphosis increases with age and therefore exacerbates an effect on global spinal alignment.

Previously, the relationship of the pelvis to the spine was ignored as contributing to sagittal balance. Recent studies have shown that the pelvis is critical to spinal alignment, as the morphology of the pelvis sets the magnitude of lumbar lordosis required to maintain sagittal balance.\textsuperscript{30-40}

Patients who have sagittal imbalance attempt to bring their head into alignment with their pelvis in the sagittal plane. These patients compensate with pelvic retroversion, which results in the acetabulum assuming a more anterior position. Mild pelvic retroversion may be accompanied by hip extension, whereas more severe or fixed deformities may be accompanied by hip and knee flexion. **Figure 2** illustrates the body’s compensatory mechanisms to maintain sagittal balance.

**Figure 2**: Illustration of the body’s compensatory mechanisms to sagittal imbalance.

Segmental compensatory mechanisms for sagittal imbalance may also be present. Segmental lumbar hyperlordosis of adjacent segments limits the consequences of lumbar kyphosis on the shift of axis gravity. Retrolisthesis in the immediate adjacent segments of approximately 2 to 3 mm may also occur, commonly resulting in severe foraminal stenosis and occasionally in central stenosis.\textsuperscript{41}

Pelvic parameters help define and measure the contribution of the pelvis...
to sagittal balance. Critical to the understanding of spinopelvic alignment is the recognition of the importance of pelvic parameters and how they interact with spinal regional curvatures (lumbar lordosis, thoracic kyphosis). Key measures of pelvic alignment include pelvic incidence, pelvic tilt, and sacral slope.

The pelvic incidence is an angle that is fixed in individuals once skeletal maturity has been reached; it does not depend on the position of the pelvis. It is a measure of the degree of pelvic retroversion. It is a compensatory mechanism that requires both effort and energy. Normative mean values for pelvic tilt range from 11° to 15°. A mathematical relationship exists among these pelvic parameters such that the pelvic incidence is the sum of the sacral slope and the pelvic tilt. As pelvic tilt increases (pelvic retroversion), sacral slope decreases and the sacral end plate becomes more horizontal.

Management

Nonoperative treatment is considered for adult spinal deformity in the absence of significant stenotic and/or radicular symptoms. Nonoperative management should also be tried first in patients with only mechanical back pain.

Nonoperative management involves prescribed analgesics and muscle-strengthening exercise. Epidural and/or selective nerve root injections are often used for the symptomatic management of back and/or leg pain. Little evidence exists supporting the effectiveness of the nonsurgical modes of treating symptomatic adult scoliosis.

Bracing is not well tolerated by patients and is not recommended in the management of adult scoliosis. Unlike the scoliosis seen in children and adolescents, which results from spinal growth, progression of spinal deformity in adults is secondary to transverse instability. Thus, bracing does not prevent progression of the deformity, and muscle deconditioning occurs with prolonged use.

Surgery is considered after all nonoperative means of treatment have been exhausted. Several challenges are encountered in the operative management of adult degenerative scoliosis. In adults, the scoliosis curves are more rigid secondary to associated degenerative changes. These patients tend to be older and to have multiple associated comorbidities; thus, their
surgical risk is increased. Patients must be carefully selected if surgery is to be successful.

Common indications for the operative management of adolescent scoliosis include the presence of a significant curve magnitude, progression of deformity, and cosmesis. The indications for operative treatment in adults are notably different, including the presence of a progressive neurological deficit, disability secondary to the deformity itself, and associated severe pain. Documented curve progression with coronal or sagittal plane imbalance and resulting disability is also an important indication for surgery in these patients. It has been found that preoperative sagittal imbalance correlates with pain and disability and that postoperative improvement in sagittal balance is an independent predictor of surgical result. Therefore, patients with a decompensated sagittal imbalance (sagittal vertical axis >5 cm) are more likely to receive more benefit from operative intervention than patients with a compensated sagittal imbalance (sagittal vertical axis <5 cm). In adult scoliosis, the magnitude of the deformity as measured by the Cobb angle of the curve has not been shown to correlate with symptom severity.

The goals of surgery for adult scoliosis are decompression of neural elements and achievement of a balanced and fused spine. Patients’ symptoms (eg, radicular pain, claudicant pain, and/or axial back pain) and the radiographic characteristics of the deformity are important surgical considerations. For example, a patient with a degenerative scoliosis having only radicular symptoms may be eligible for a limited focal decompression. Because surgery can range from a laminectomy alone to an arthrodesis of the spine with instrumentation using only a posterior or a combined anterior and posterior approach, the importance of carefully considering patients’ symptoms cannot be overstated.

Spinal decompression alone without arthrodesis can be considered for patients with symptomatic spinal stenosis at one or two spinal levels with a mild deformity (Cobb angle of scoliosis curve less than 20°), no instability (eg, spondylolisthesis/lateral listhesis), and a normal overall spinal balance. The decompression procedure should be avoided at the proximal and distal extents of the scoliosis curve and at the curve apex. Standalone decompression should only be performed in the above select group of patients to reduce the risk of the decompression procedure causing iatrogenic instability and thereby accelerating curve progression.

It is difficult to define a specific value for the Cobb angle that indicates an arthrodesis should be performed. Therefore, it is important to examine the clinical and the radiographic findings together. Patients who have significant axial back pain can be considered for an arthrodesis to augment the decompression. In cases in which signs of instability (spondylolisthesis, rotation, lateral listhesis greater than 6 mm) are present, decompression alone will invariably induce further instability by removing posterior column elements; therefore, arthrodesis should be considered.

Achieving a sagittally balanced spine, by correcting the lumbar lordosis as close to the pelvic incidence as possible, reduces the energy requirements for ambulation. Thus, if a patient undergoing surgical reconstruction has a low pelvic incidence, the surgeon must maintain a correspondingly low lumbar lordosis during reconstruction. Conversely, in a patient with a high pelvic incidence, the surgeon must aim to achieve a correspondingly high lumbar lordosis. A sagittally balanced spine also reduces pain from muscle fatigue and improves overall patient satisfaction. Historically, surgical treatment has focused more on the coronal alignment and less on the sagittal parameters. However, several studies have shown that proper sagittal alignment determines the outcome for adults undergoing spinal deformity surgery (Figure 6).

By understanding and measuring spinal and pelvic parameters, surgeons can more effectively determine the amount of correction necessary to achieve a good outcome. The flexibility of the spinal curvature will influence the choice of surgical procedure to correct the deformity. A rigid deformity is one that does not correct more than 50% on bending or traction radiographs. A rigid spine that is almost ankylosed often requires a thoracic release or an osteotomy. Less severe and more flexible deformities may be corrected posteriorly using Smith-Petersen or Ponte osteotomies. The Smith-Petersen osteotomy relies on a mobile disk space for correction. Resection of the spinous process, lamina, and facet joints is performed in this osteotomy. The Ponte osteotomy involves removal of the inferior part of the spinous process, lamina, and facet joints. The main difference between the Smith-Petersen osteotomy and the Ponte osteotomy is that the Smith-Petersen osteotomy was described for the treatment of already fused spines.

Fixed sagittal imbalance or fixed kyphotic deformities have been treated with Smith-Petersen and pedicle subtraction osteotomies. In a pedicle subtraction osteotomy, the vertebral body is decancelled through the partially resected pedicles and the lateral wall of the body by serially using curettes. The vertebral osteotomy is then closed in a controlled manner to achieve the required correction. Vertebral column resections are reserved for severe rigid deformities that would benefit from shortening as part of the correction. This challenging procedure, in which an entire vertebral body is resected to achieve deformity correction, has a significant complication rate.

More recently, procedures called pedicle subtraction osteotomy “variants” have been described. Because degenerative scoliosis is a 3-dimensional deformity, an asymmetrical or biplanar pedicle subtraction osteotomy may be performed (ie, the wedge is shorter on the side of coronal imbalance and longer on the op-
posite side). These pedicle subtraction osteotomy variants may provide biplanar correction of deformity. They have less morbidity than a classic vertebral column resection, and recent studies have shown good results in terms of correction. To obtain an acceptable correction, comprehensive preoperative planning must include assessment of the wedge parameters.62 Figure 1 shows such a 3-dimensional deformity in a patient who subsequently underwent an asymmetrical pedicle subtraction osteotomy and had a good outcome (Figure 7).

Patients with degenerative scoliosis who have coronal and sagittal imbalance in addition to a stiff large curve often require an anterior and posterior approach. Releases performed anteriorly, which involve performing thorough disектomies, reduce the stiffness of the spine, allowing for better deformity correction. Structural grafts placed in the anterior disk spaces provide anterior column support, achieve lordosis correction, and increase the rate of bony union.63-66

Minimally invasive approaches to correct spinal deformity have been gaining popularity. They reduce approach-related morbidity and enhance recovery, facilitating an early return to normal activity.67-76 Minimally invasive techniques, such as the transpsoas direct lateral approach, have been developed for the insertion of interbody cages. Minimally invasive techniques for pedicle screw insertion use percutaneous methods. Although there are no long-term studies regarding the outcomes of these techniques, short-term studies suggest that they can achieve satisfactory correction of scoliosis deformity in adults with less blood loss, a shorter inpatient hospital stay, and fewer complications compared with open approaches.77

**Complications and Surgical Outcomes**

An understanding of the risk factors for complications enables development of strategies to reduce them. Also, both surgeons and patients can make better clinical decisions pertaining to surgical treatment.

The incidence of complications is influenced by patients’ age and associated comorbidities and the approach and complexity of surgery.78,79 Outcomes have significantly improved with advancements in surgical instrumentation, blood salvage, anesthetic techniques, and preoperative patient optimization.

Rates of infection for scoliosis surgery in general are reported to be between 1% and 2%. Adults with scoliosis undergoing surgery have a higher infection rate, ranging from 3% to 5%.80 Neurological injury is seen in 1% to 5% of cases.81

A study involving the Scoliosis Research Society database82 evaluated the outcomes of 4980 cases of adult scoliosis from 2004 to 2007. There was an overall complication rate of 13.4%. The rate of superficial wound infection was 0.9%, and the rate of deep wound infection was 1.5%. The rate of acute neurological deficit was 1%. A systematic review that examined the outcomes of adult scoliosis patients undergoing surgery found a greater than 40% incidence of perioperative adverse events.83 This review included 49 articles with a total of 3299 patients and a mean follow-up of 3.6 years.

The complexity of the surgical procedure correlates with the risk of complications. Osteotomies and vertebral column resections have a higher risk of complications, including neurological complications.84,85 Intraoperative neuromonitoring must be used to minimize the risk of neurological complications.86,87

The risk of pseudarthrosis is significantly greater among adults with scolio-
sis than among the pediatric population with scoliosis. The pseudarthrosis rate for adults after long fusion procedures has been reported to be as high as 24%. Autograft remains the gold standard grafting material to achieve a solid arthrodesis. Alternatives to local autograft include allograft products, ceramics, synthetics, and the bone morphogenetic proteins.

Proximal junctional kyphosis is a recognized complication among patients undergoing segmental instrumented fusion for spinal deformity. Proximal junctional kyphosis has traditionally been defined by a 10° or greater increase in kyphosis at the proximal junction as measured by the Cobb angle from the caudal end plate of the uppermost instrumented vertebra to the cephalad end plate of the 2 vertebra segments cranial to the uppermost instrumented vertebra. The prevalence rate for radiographic proximal junctional kyphosis in adult deformity patients after surgery is reported to be between 20% and 39%. It has been suggested that proximal junctional kyphosis is infrequently associated with revision surgery.

Increasingly, proximal junctional failure has been distinguished from proximal junctional kyphosis in that proximal junctional failure includes not only an increase in kyphosis but also structural failure of either the uppermost instrumented vertebra or the vertebra immediately proximal to the fusion construct. Unlike traditionally defined proximal junctional kyphosis, proximal junctional failure has been clearly shown to be associated with higher morbidity, including increased pain, spinal instability, risk of neurologic injury, and need for revision surgery. Several preoperative risk factors have consistently emerged among adult deformity patients, including age and preoperative sagittal malalignment. Concordant with the preoperative sagittal malalignment of patients at highest risk for proximal junctional kyphosis is the demonstration that patients undergoing greater sagittal realignments are also at higher risk for proximal junctional kyphosis.

Studies that have used validated health-related quality of life outcome scores have shown significant improvements after surgery for adult scoliosis, with satisfaction rates of up to 94%. Those patients with a greater spinal deformity (loss of lumbar lordosis, spinal instability, positive sagittal balance) are most likely to have significant improvement in quality of life outcomes. Furthermore, those patients with more significant disability preoperatively may benefit the most, in terms of improvement in their quality of life, from surgery. Despite facing a greater risk of complications, elderly patients may gain a disproportionately greater improvement in disability and pain with surgery as compared with their younger counterparts. Patient-related factors such as obesity, depression/anxiety, and smoking can have a negative impact on operative outcomes.
CONCLUSION
Degenerative lumbar scoliosis is a debilitating condition affecting a growing number of people around the world. Given the limited evidence regarding preventive measures, a better understanding of the pathophysiology of degenerative lumbar scoliosis, coupled with advances in drug delivery techniques, may maximize non-operative management.

Innovations in technology along with careful patient selection and optimization could hold the key to improving surgical outcomes for this high-risk group. Pelvic parameters play a critical role in health-related quality of life outcomes and must be accounted for when planning spine surgery. Therefore, the authors suggest a structured approach to the management of adult degenerative scoliosis that incorporates patient and radiographic features (Figure 6). An understanding of the risk factors for complications permits the development of strategies to reduce them. It also allows both surgeons and patients to make better clinical decisions regarding surgical treatment for adult spine deformity.

REFERENCES


Raffo CS, Lauerman WC. Predicting morbid-