Aging Spine: Challenges and Emerging Techniques

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As our aging population continues to grow at an exponential rate, healthcare professionals are obliged to anticipate and attend to their mounting medical needs. This is particularly true for the contemporary spine surgeon. It is estimated that during the next 25 years, the number of people in the United States older than 65 years of age will increase by 125%, to approximately 70 million people, with a doubling of those older than age 85 years.[11] It is further estimated that up to 50% of this growing population will require basic nursing care or assistance with activities of daily living, thus, the number of disabled years for these individuals is growing substantially as well (*Fig. 3.1*).[54]

The older patient has unique characteristics that require differentiation from that of the archetypical adult, such as atypical presentation and response to disease and frailty from comorbidities and chronic disease. Furthermore, healthcare providers of the elderly must commonly focus efforts on maintenance or improvement in function and quality of life as opposed to the classic intent to cure disease. This population trend has inspired modern spine surgeons to pursue and develop a mounting body of evidence and research on the aging spine and the challenges that this patient population presents, both medically and economically. These investigations have centered around three major spinal disorders that afflict the aging population: osteoporotic fractures, degenerative scoliosis, and degenerative spondylolisthesis.

OSTEOPOROTIC FRACTURES

Osteoporosis is the most common bone disease in humans that affects both men and women.[31] The clinical and public health implications of this disease process are significant because of the morbidity, mortality, and cost of medical care associated with osteoporotic-related fractures and the vastly growing population at risk. In the United States alone, 28 million people have either osteopenia or osteoporosis. Approximately one-quarter of women older than the age of 70 years and up to one-third of those older than the age of 80 years are diagnosed with osteoporotic fractures. These fractures result in persistent back pain, physical activity restrictions, and psychosocial impairments[47] amounting to significant costs in health and social service expenditures.[49]

Each year there are 1.5 million osteoporotic fractures, 800,000 emergency department visits, 2,600,000 physician office visits, and 180,000 nursing home admissions from osteoporotic complications.[50] The economic impact regarding hospital and nursing home direct expenditures from these fractures was $18 billion in 2005 and is estimated to reach $60 billion in 2030.[35] Nearly one-quarter of these fractures remain refractory to nonoperative intervention, leading to more than 150,000 acute hospitalizations per year, with an average 8-day hospital stay.[32]

Osteoporosis is diagnosed on the basis of low-impact or fragility fractures and low bone mineral density assessed by dual-energy x-ray absorptiometry (DEXA).[25,40] Women aged 65 years or older and younger postmenopausal women with risk factors (see *Table 3.1*)[23] as well as men aged 70 years or older should undergo bone density testing. In the spine, the bone mineral density of L1 through L4 should be analyzed unless severe degenerative changes or compression fractures exist that may falsely increase this value. Evidence suggests that although the femur is the optimum site for predicting the risk of fracture,[30] the spine is the optimum site for monitoring response to treatment.[9] In obese patients and those in whom the hip or spine cannot be measured or interpreted, bone mineral density can be measured in the nondominant forearm.[9]

The DEXA test ultimately yields a T-score and a Z-score (*Fig. 3.2*). The T-score represents the standard deviations comparing a patient's bone mineral density to that of a young adult control and is used primarily for diagnostic purposes. The World Health Organization defines osteoporosis as a T-score of less than 2.5 in either the spine or the hip.[53] The Z-score compares a patient's bone mineral density to that of an age-matched control to provide a sense of the age-appropriateness of one's bone loss. A Z-score of less than 2.0 suggests and should prompt a search for secondary causes of osteoporosis (*Table 3.2*).

The T-score threshold of 2.5 was determined based on evidence revealing an unacceptably high risk of fractures in addition to a significant risk reduction with treatment associated with T-scores below this value.[51] The National Osteoporosis Foundation recommends initiating treatment to re-

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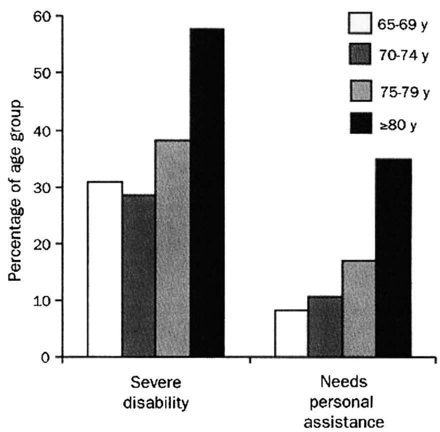

FIGURE 3.1. Prevalence of disability and necessity for personal assistance in the elderly population (*from,* Fleming KC, Evans JM, Chutka DS: Caregiver and clinician shortages in an aging nation. **Mayo Clin Proc** 78:1026–1040, 2003[11]).

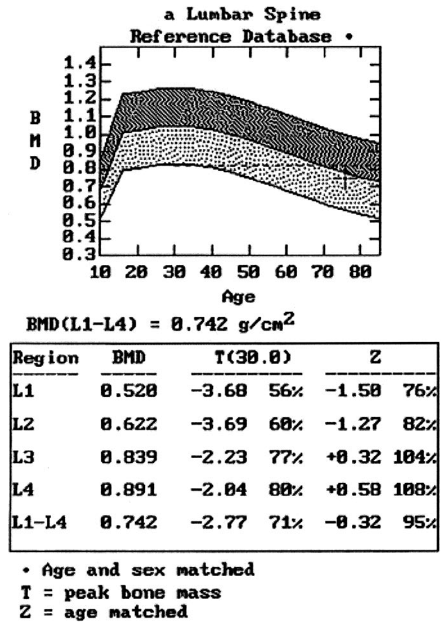

FIGURE 3.2. Example of a bone mineral density (BMD) reference database and scoring in a lumbar spine.

duce fracture risk in women with T-scores less than 2.0, even in the absence of risk factors, and in women with T-scores less than 1.5 in the presence of one or more risk factors.[34] Patients with previous vertebral or hip fractures are classified as severely osteoporotic and treatment should, thus, be initiated regardless of T-score.

It is incumbent on the spine clinician to not only treat the osteoporotic-related pathology but to educate and counsel patients to improve the underlying disease process. Patients must be edified regarding primary prevention measures and lifestyle changes to reduce bone loss and prevent falls in addition to the vigilant institution of antiresorptive and anabolic pharmacological agents for those at high risk (*Table 3.3*).[49] A strong inverse relationship exists between bone mineral density and the risk of osteoporotic-related fractures

TABLE 3.1. Risk factors for osteoporosis

Female sex
Early menopause (<45 yr)
span class=SpellEHypogonadism
Recent falls
Prolonged immobilization/inactivity
Steroid use (>3 mo)
High alcohol intake
High caffeine intake
History of smoking
Scoliosis
White, Northern European, or Asian
Fair complexion
Underweight (<127 lb) with small body frame
Family history
First-degree relative with fragility fracture
Dementia

TABLE 3.2. Secondary causes of osteoporosis

Vitamin D deficiency
Premature menopause
Male hypogonadism
Primary hyperparathyroidism
Hyperthyroidism
Glucocorticoid use
Celiac sprue
Inflammatory bowel disease
Idiopathic hypercalciuria
Chronic liver disease
Chronic renal disease
Chemotherapy
Rheumatoid arthritis
Poliomyelitis (immobility conditions)
Alcohol abuse
Transplantation
Lactase deficiency
Hyperprolactinemia
Multiple myeloma
Heparin
Phenytoin use
Paget's disease

TABLE 3.3. Medical treatment options

Oestrogen
Raloxifene
Bisphosphonates
Calcitonin
Calcium
Vitamin D
Parathyroid hormone
Hormone replacement therapy (HRT)

yielding up to a three-fold incidence increase for each standard deviation reduction in bone mineral density.[30]

Vertebral fractures are the most common pathological disorder consequent to osteoporotic disease,[7] with an increasing incidence with time,[2] particularly in the female population.[1,21,29] A recently published clinical investigation with an impressive 22-year follow-up period evaluating 257 patients (187 woman, 70 men; mean age, 70 yr) reported on the long-term morbidity and mortality associated with vertebral fractures in the elderly.[18] In comparison to an age- and sex-matched control population at risk, patients diagnosed with vertebral fractures had significantly increased morbidity and mortality rates. Specifically, impairment in functional health status increased from 17 to 44% in the years after sustaining a vertebral fracture, and the mortality rate rose from 62 per 1000 person-years to 95 per 1000 person-years. The kyphotic deformity created by a single-level vertebral compression fracture has been reported to yield as much as a 9% loss of forced vital capacity, resulting in severely compromised pulmonary function.[41] The results of these data and other previous studies with similar outcomes[5,6] implicate the need for evidence-based preventive measures and contemporary treatment practices for this rapidly growing disease phenomenon.

A growing body of evidence is accumulating for the treatment of osteoporotic-related vertebral body fractures. Hulme et al.[22] recently performed a systematic literature review of 69 peer-reviewed published clinical trials evaluating vertebroplasty and kyphoplasty for the treatment of vertebral body fractures. They reported significant pain relief (87% vertebroplasty; 92% kyphoplasty), improvement in physical function (Oswestry Disability Index fell from 60% preoperative to 32% postoperative), and reduction of kyphotic deformity with restoration of vertebral height (see *Fig. 3.3*), the latter is dependent on preoperative fracture mobility in vertebroplasty trials.

Clinically relevant complications occur in less than 4% of patients, the most common is leakage of the polymethyl methacrylate material. Despite leakage occurring approximately four times more often in the vertebroplasty (41%) than the kyphoplasty trials (9%), the vast majority of both were principally asymptomatic (89–96%). Another complication of the procedure is the occurrence of new fractures in adjacent vertebrae, most of which occur within the first 30 days after treatment. These fractures were more prevalent than those encountered in the general osteoporotic population, yet equivalent to those occurring in this same population after a previous vertebral fracture.

It is of note that the kyphosis correction achieved via vertebroplasty and kyphoplasty is limited to the vertebrae treated and does not significantly contribute to overall sagittal alignment.[39] This finding may limit the long-term efficacy of these less invasive procedures, thus, supporting a role for more complex surgical interventions that more reliably restore normal sagittal balance, reportedly the most reliable predictor of clinical symptomatology.[13] Yet, more often than not, these elderly patients are not ideal candidates for posterior pedicle subtraction osteotomy and the condition necessitates a combined front-to-back approach for thorough deformity correction. Kim et al.[26] recently evaluated 32 patients with osteoporotic spinal deformities, with 94% of patients

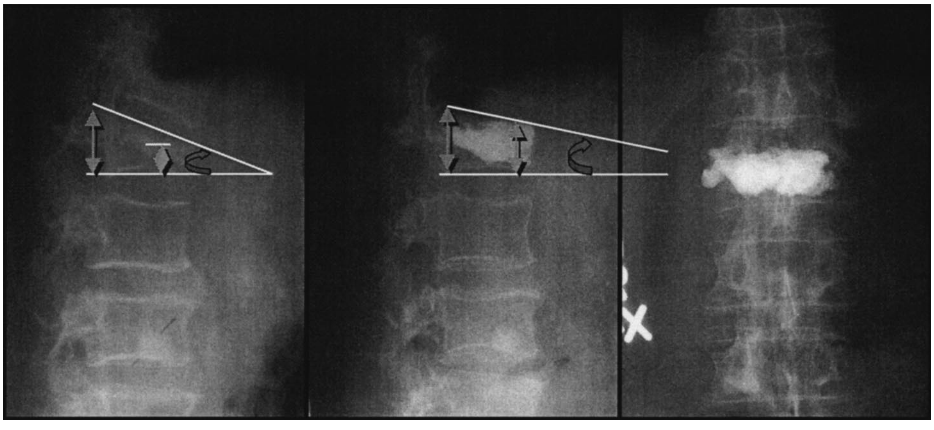

FIGURE 3.3. Results from kyphoplasty. Anterior vertebral body height increased from 12 mm to 29 mm after injection, resulting in a 15-degree correction of kyphosis. Imaging provided by Isador H. Lieberman, M.D., M.B.A.

reporting subjective improvement, a 54% decrement in Oswestry Disability Index, and a 70% decrement in visual analog scale pain score at 2 years of follow-up. Despite these positive long-term findings, an astounding 37.5% of patients experienced early complications, with three patients requiring additional surgery to treat the complications. In summary, osteoporotic spinal deformities with global sagittal imbalance can have devastating effects on patients, but their treatment involves a high risk of perioperative medical and mechanical complications, necessitating a thorough individualized risk-benefit analysis as a routine part of every patient assessment.

DEGENERATIVE SCOLIOSIS

Adult scoliosis is a common and sometimes disabling degenerative condition of the spine with an overall prevalence reported in up to 60% of the elderly population.[38] Multiple causes for its development after skeletal maturity are recognized but the most common by far is that of degenerative disease of the spinal column. Other causes include neuromuscular disorders, metabolic abnormalities (osteoporosis), leg length discrepancy, long-standing pelvic obliquity, and past surgical procedures. There are few studies on the natural history of degenerative scoliosis and its true prevalence is likely underappreciated. Unlike the slow progression of adolescent idiopathic scoliosis (AIS), degenerative scoliosis has been known to progress at rates of greater than 3 degrees per year, more than triple that of AIS rates. The subsequent loss of normal standing posture and associated functional inability has a dramatic impact on this population's social function and emotional state, particularly when independent living becomes compromised. The disease is often widespread and is typically associated with facet arthropathy, osteophyte formation, and ligamentum flavum hypertrophy. The majority of the clinical attention relating to this disease entity has been on that of nonsurgical treatment protocols. As the demographic shift in our country favors that of the aging population, the prevalence of scoliosis and the degree to which it burdens its sufferers does as well, thus, increasing the need for up-to-date surgical treatment options in this growing population.

The impact of adult scoliosis on patient's general medical health and well being has only recently been publicized via medical outcomes and health assessment studies using universal self-measurement questionnaires, such as the short form 36 (SF-36). A recent study by Schwab et al.[43] clearly revealed that scoliotic patients had a significantly depressed perception of their overall mental and physical health in comparison with the norms for the general United States population, even when compared with those with severe comorbidities, such as sciatica and hypertension. In addition to the aesthetic and subjectively morbid considerations of this progressive disease, severe pain and disability also abound in this population.[3,16]

In contrast to the pediatric scoliosis patient, the adult cohort has received relatively limited attention, which places it at the forefront of current healthcare concerns because of the demographic shift aforementioned. To properly clinically investigate and perform comparative analyses on prognostic markers, procedural technique, outcome measures, and treatment algorithms, a uniform definition and classification scheme is necessary. To adequately evaluate spinal deformity, a thorough global assessment is performed, including full-length upright 36-inch by 14-inch PA and lateral scoliosis films to determine sagittal and coronal balance (*Fig. 3.4*). Computed tomographic (CT) myelography, magnetic resonance imaging (MRI) scan and dynamic (flexion, extension, and side-bending) studies are used to evaluate for concomitant degenerative changes, such as spondylolisthesis and spinal rigidity that may necessitate simultaneous treatment. Cobb angle measurements are performed. Vertebral rotation is assessed to determine curvature rigidity, of which a linear relationship has been demonstrated. The Scoliosis Research Society, to provide this common language, defined scoliosis as a spinal deformity with a Cobb angle greater than 10 degrees as measured by a goniometer in the anteroposterior (AP) and lateral plane.[45] Coronal and lateral alignment is then assessed with a plumb line to determine whether compensation is present. In a normally balanced spine, the plumb line passes though the center of the sacrum on an AP x-ray and from the C7 vertebrae through the posterior aspect of the L5/S1 interspace on lateral views (*Fig. 3.5*).

Schwab et al.[42] proposed a three-tier classification system for adult scoliosis based on previously studied parameters of coronal and sagittal plane standing x-ray lumbar lordosis and frontal plane L3 obliquity. These radiographic criteria have been proven to accurately correlate with clinical significance. The classification system is outlined in *Table 3.4*. Briefly, Type I patients had the least deformity, minimal subjective pain and disability, and the fewest surgical treatments, with the converse being true of patients with Type III disease (*Table 3.4*). This system was used to classify both idiopathic adolescent and degenerative forms of scoliosis because the failure of anatomic stabilizing structures seemed to result in a final common pathway in the elderly patient, necessitating treatment. Thus, the groundwork was laid for standardization of a descriptive and clinically relevant system to diagnose and treat the aging scoliotic spine. The onus now lies on the practicing spine clinicians to refine further subcategories, add modern imaging parameters (e.g., MRI scan), establish prognostic values, and link classification to a working treatment algorithm and surgical strategy for those who may benefit from surgical intervention.[44]

The rate of disease progression is influenced by the magnitude of the curve, the degree of lateral listhesis, the quality of the bone, and the severity of the associated spondylotic disease. Korovessis et al.[28] evaluated 91 patients

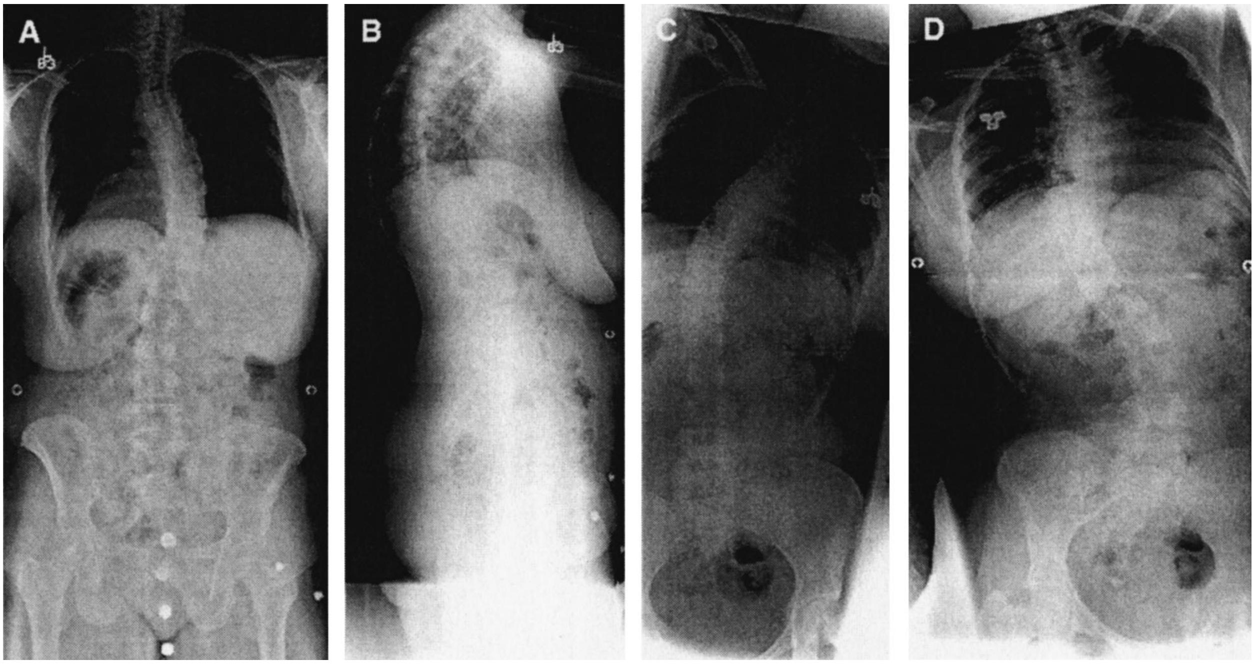

FIGURE 3.4. Deformity flexibility is measured by supine PA and lateral bending full-length scoliosis films to adequately assess spinal curvature and flexibility, a prerequisite for adequate surgical or nonoperative management and planning (*from,* Oskouian RJ, Shaffrey CI: Degenerative lumbar scoliosis. **Neurosurg Clin N Am** 17:299–315, 2006[37]).

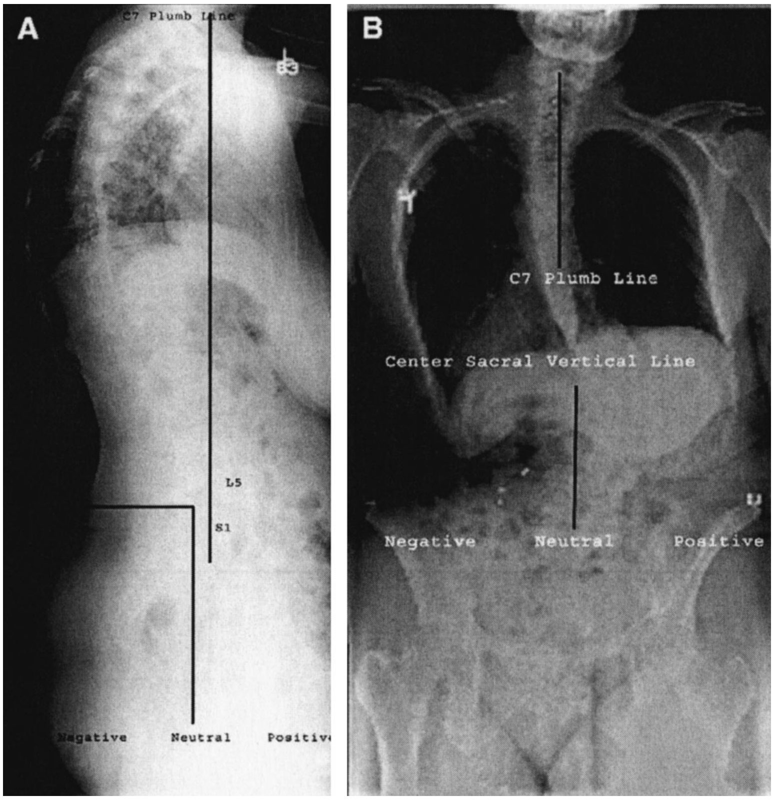

FIGURE 3.5. *A,* lateral view showing the sagittal alignment; *B*, AP view showing the coronal balance as assessed using a plumb line to determine spinal balance and decompensation. Sagittal balance is determined by the sagittal vertical axis through the middle of the C7 vertebral body to a horizontal line through the L5/S1 disc space. In a balanced spine, this line passes through the posterior third of the L5/S1 disc space. Coronal balance is assessed by a plumb line from the center of the C7 vertebral body through the pelvis (*from,* Oskouian RJ, Shaffrey CI: Degenerative lumbar scoliosis. **Neurosurg Clin N Am** 17:299–315, 2006[37]).

during a 2-year period to determine the greatest risk factors for progression: 1) curvature greater than 30 degrees, 2) apical vertebral rotation greater than 30%, 3) greater than 6 mm of lateral listhesis, and 4) degenerative disc disease at the lumbosacral junction. Additionally, and particularly of note in the aging population as a consequence of past spinal procedures and fusions (*Fig. 3.6*), scoliosis is progressing secondary to destabilizing procedures after decompression and ill-conceived instrumentation, resulting in pseudoarthrosis and paraspinal muscle devitalization. As mentioned, this disease process can be severely debilitating, and conservative measures are rarely successful. Dickson et al.[8] compared surgical versus conservative treatment in 81 scoliotic adults and reported an 80% improvement in pain after surgery compared with only 10% in nonoperated patients over time.

As discussed earlier, positive sagittal balance was identified as the one radiographic parameter that most significantly correlated with adverse health status outcomes. Rigid, fixed deformities associated with sagittal imbalance generally require a more aggressive and technically demanding surgical procedure, often involving combined anterior and posterior approaches, Glassman et al.[14] examined this specific patient population in an attempt to further define parameters to preferentially predict clinical symptoms. This multicenter study of 298 patients revealed a direct linear relationship between symptom severity and positive sagittal balance, with significantly less tolerance for this imbalance in the lumbar than the thoracic spine. It is critical for the deformity spine surgeon to focus on restoration of normal lumbar lordosis, particularly in patients with preoperative positive sagittal balance.

A balanced painless spine is, thus, created by a close interplay of an individual's anatomy, biomechanical properties, and surrounding structures, and the corrective capabilities of a surgical instrumentation technique.[37] A clear understanding of the symptomatology, neurological status, and radiographic findings are a prerequisite in the development of a surgical plan that very often involves a combination of decompression, deformity correction, stabilization, and fusion while minimizing complications and maximizing function and quality of life. *Figure 3.7* depicts such a case.

TABLE 3.4. Description of classification scheme[a]

Type	Lumbar lordosis	L3 obliquity
Type I	>55 degrees	<15 degrees
Type II	35 degrees–55 degrees	15 degrees–25 degrees
Type III	<35 degrees	>25 degrees

[a] The higher parameter determines the type (i.e., lordosis, >55 degrees; L3 obliquity, 18 degrees is Type II). *From,* Schwab F, Benchick el-Fegoun A, Gamez L, Goodman H, Farcy JP: A lumbar classification of scoliosis in the adult patient: Preliminary approach. **Spine** 30:1670–1673, 2005 (42).

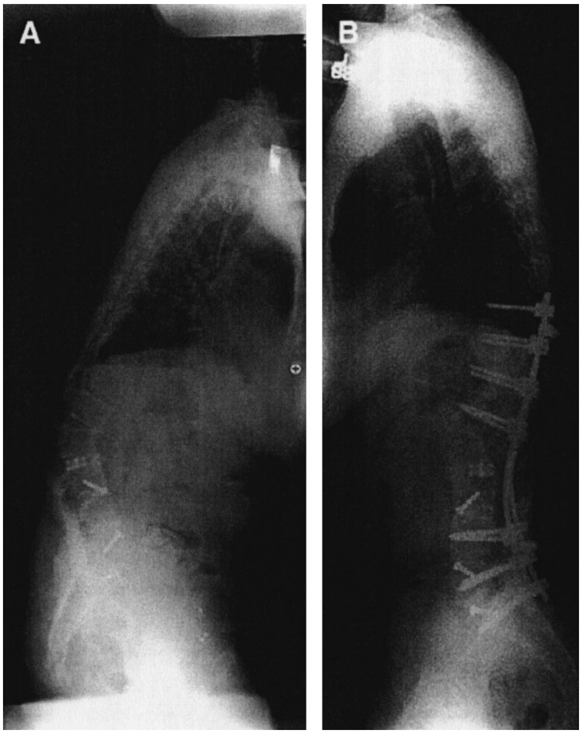

FIGURE 3.6. This patient had severe progressive thoracolumbar kyphoscoliosis, and had undergone five previous operations, including instrumentation and hardware removal at the thoracolumbar junction. Progressively worsening kyphoscoliosis with 20 cm of positive sagittal balance prompted repeat L1–L3 laminectomies, pedicle subtraction, and vertebral osteotomies with posterior segmental transpedicular instrumentation from T10–S1 and arthrodesis using a combination of local bone graft and recombinant human BMP (*from,* Oskouian RJ, Shaffrey CI: Degenerative lumbar scoliosis. **Neurosurg Clin N Am** 17:299–315, 2006[37]).

DEGENERATIVE SPONDYLOLISTHESIS

Spondylolisthesis most commonly occurs at the lumbosacral junction and is classified based on its etiology into five types: congenital dysplastic, isthmic, degenerative, traumatic, and pathological.[52] Most cases can be managed conservatively, but, as our afflicted aging population expands, the number of patients with slip abnormalities and disease progression resistant to nonoperative means grows steadily with it. Degenerative spondylolisthesis occurs most frequently in this patient population,[10] reportedly afflicting 12% of men and up to 30% of women. Because radiographic degenerative changes are ubiquitous in the aging population and because most patients remain asymptomatic, it is the role of the spine surgeon to focus interventions at the site of neural compromise as it correlates with symptomatology.[46] Surgery aims to decompress the neural elements and stabilize the slipping segment with restoration of normal sagittal alignment. The indications for surgery in this population were

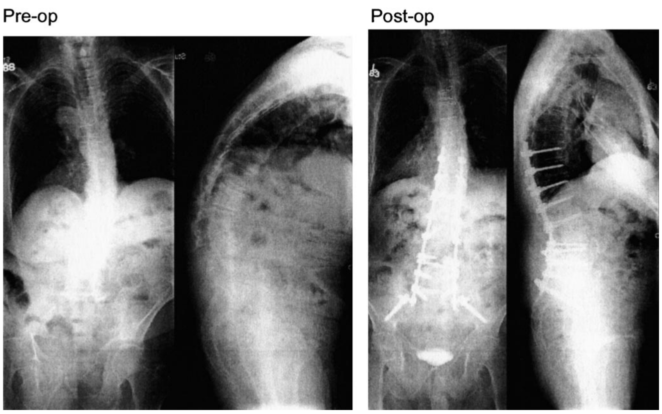

FIGURE 3.7. Seventy-year-old man with progressive low back pain, leg pain, and severe thoracolumbar kyphoscoliosis with marked sagittal imbalance and an inability to stand upright. X-rays revealed a 31-degree right scoliosis and a global 55-degree kyphosis, 21 cm of sagittal imbalance as well as 7 mm of coronal imbalance (*A* and *B*, preoperative). He underwent T10–S1 posterior segmental instrumentation with placement of bilateral iliac screws, T10–L1 Smith-Petersen osteotomies with L2–L5 redo laminectomies, and an L5/S1 diskectomy with transforaminal interbody lumbar fusion and arthrodesis with recombinant human BMP II and iliac crest bone graft. Additionally, an L3 pedicle subtraction osteotomy and L2 partial inferior vertebrectomy was required for satisfactory kyphoscoliosis correction (*C* and *D*, postoperative).

once limited to patients with severe gross instability and incapacitating pain. Recent studies have dramatically expanded the criteria for intervention in the elderly population because of the nearly equivalent relief outcomes in comparison with those observed in younger populations. Kalbarczky et al.[24] reported an 82% improvement in symptomatology after surgery in patients older than 70 years old. Vitaz et al. mirrored these findings reporting that 89% of their patients older than 75 years of age had significant improvement in their lifestyle after surgery. These studies and others[12] support the notion that limited surgery focused at significant disease is well tolerated and well deserved in the elderly population.

Degenerative spondylolisthesis is a result of both macroinstability and microinstability. It is acquired secondary to years of chronic disc degeneration and progressive facet incompetence resulting in segmental instability and slippage. Disc degeneration occurs normally as a part of the aging process as hydrated Type II collagen and proteoglycan material is progressively replaced with fibrous tissue. This dessication ultimately leads to disc collapse and bulging of the annulus fibrosis and posterior longitudinal ligament, thus, enabling the periosteum overlying the adjacent endplates to elevate and trigger subperiosteal osteophyte formation. Additionally, the articulating facet, which normally bears as much as 30% of the lumbar stress load, undergoes degenerative changes that alter stress load and alignment, resulting in significant hypertrophy with marked calcification and thickening of the ligamentum flavum. These changes eventually result in forward displacement of the posterior elements that, in combination with the degenerative changes aforementioned, results in severe narrowing of the spinal canal and neural foramen to cause symptoms of neurogenic claudication and radiculopathy.

The spine surgeon is increasingly confronted with the older patient and must decide on a suitable yet realistic treatment plan while considering the social and psychological factors affecting this unique patient population. Conservative attempts to alleviate these symptoms, including physical therapy and steroid injections, rarely yield satisfactory long-term results because the underlying pathology remains unchanged. If surgical intervention is undertaken, a central decompression is commonly augmented by posterolateral fusion and biomechanical interbody grafts to increase stability of the spinal segment by expanding the overall surface area of the bony fusion. Herkowitz[19] performed a prospective randomized study on patients with degenerative spondylolisthesis to support this hypothesis. Herkowitz[19] reported, at an average 3-year follow-up, that 96% of fused patients had good to excellent results in comparison with only 44% of patients without fusion who attained similar results. This approach has been shown to achieve higher rates of solid arthrodesis with a concomitant reduction in postoperative pain scores.[17,20,27] That said, all radiographic and technical successes of arthrodesis are not always predictive of a positive clinical outcome.

Okuda et al.[36] specifically investigated clinical and radiographic outcomes after posterior lumbar interbody fusion with pedicle screws in 101 patients older than 70 years of age and compared the results with those of a younger cohort treated for L4–L5 degenerative spondylolisthesis. At an average follow-up of 50 months, no significant difference in postoperative pain scores or radiographic segmental lordosis was observed between the two groups. The older group did have a higher prevalence of collapsed and delayed unions, but this did not significantly affect the postoperative clinical results. Bridwell et al.[4] further prospectively evaluated 44 patients with degenerative spondylolisthesis who underwent lumbar decompression with bilateral facet preservation. They subcategorized their treatment groups into those with 1) no fusion procedure, 2) transverse process fusion with autogenous iliac bone graft, or 3) transverse process fusion with autogenous iliac bone graft and pedicle screw instrumentation. They found that the addition of instrumentation in Group 3 imparted a significantly improved fusion rate ($P = 0.002$), significantly less spondylolisthesis progression ($P = 0.001$), and significant subjective symptom improvement (P 0.01) in comparison with Groups 1 and 2.[4]

Attempting to reduce the spondylolisthesis to improve sagittal alignment and spinal biomechanics, thus, provides the benefit of superior posture and diminished stress on the fusion mass, thus, reducing the incidence of nonunion and slip progression. This practice does not come without risk of nerve root injury, which has been reported in up to 30% of cases in which reduction of listhesis was attempted. As our knowledge in spinal instability and bone healing biology in the aged population continues to expand, we will become more adept at determining which patient populations will benefit most from lumbar spinal fusion and fixation.

EMERGING TREATMENTS

Surgical management of spinal disorders in the elderly poses challenges not faced in younger patients. Poor bone quality, the possibility of extensive spinal degenerative changes, and changes in sagittal alignment with increased thoracic kyphosis and loss of lumbar lordosis all complicate surgical management. The presence of multiple coexisting medical conditions, reduced wound healing potential, and malnutrition can markedly increase the risk of complications for extensive surgical procedures.

Osteoporosis and osteopenia complicate fixation options. Traditional pedicle screw fixation may result in inadequate fixation, particularly in high-demand cases, such as correction of kyphosis caused by osteoporotic fractures or treatment of degenerative scoliosis. Advanced fenestrated pedicle screws that permit additional fixation with methylmethacrylate or biological bone cement, pedicle screws with optimized thread patterns matched to achieve greater purchase in the pedicle of the osteoporotic spine, and hydroxyapatite-coated screws are all under laboratory or clinical investigation.

The availability of bone morphogenic proteins (BMPs) provides an option in cases of extensive surgical procedures and revision cases in which the options of harvesting large quantities of autogenous iliac crest bone graft is not practical. The use of BMPs for these cases is not a United States Food and Drug Administration-approved indication and the best type, dosage, and carrier has not been determined. Several current clinical studies are investigating the use of BMPs in posterior interbody and posterolateral fusion applications.

Adjacent segment degeneration and the development of junctional kyphosis are both recognized complications in fusion procedures in the elderly. Dynamic neutralization systems aim to provide nonrigid stabilizing forces to overcome the inherent disadvantages of solid fusions and adjacent level disease.[15,33,48] Instrumentation systems using rods with a reduced modulus of elasticity that more closely matches bone or that uses a gradient in the modulus of elasticity for the more rostral segments are under development and may reduce the incidence of transition syndrome.

Procedures with significantly reduced invasiveness, including a wide range of percutaneous and minimal access decompression and instrumentation procedures, are gaining more widespread acceptance. Until recently, these techniques were limited to cases of spinal or foraminal stenosis requiring only decompression. The development of multilevel MAST systems and interspinous fixation implants permits treatment of both degenerative spondylolisthesis and milder cases of degenerative scoliosis. Unfortunately, the amount of data comparing these techniques with more traditional procedures is limited.

Despite all of these technological advances, the most challenging task confronting contemporary spine surgeons and our aging population remains patient selection. Balancing benefits, risks, complications, and the durability of various interventions is difficult because of the limited number of prospective outcome studies of different interventions in this patient population. Optimally, further research will eventually permit stratification into optimal evidence-based management protocols. Demographic changes will make management of spinal disorders of the aging population a major focus for the neurosurgical community during the next 25 years.

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