OSTEOPOROSIS AND THE MANAGEMENT OF SPINAL DEGENERATIVE DISEASE (II)

Abstract

Osteoporosis has become a major medical problem as the aged population of the world rapidly grows. Osteoporosis predisposes patients to fracture, progressive spinal deformities, and stenosis, and is subject to be a major concern before performing spine surgery, especially with bone fusions and instrumentation. Osteoporosis has often been considered a contraindication for spinal surgery, while in some instances patients have undergone limited and inadequate procedures in order to avoid concomitant instrumentation. As the population ages and the expectations of older patients increase, the demand for surgical treatment in older patients with osteoporosis and spinal degenerative diseases becomes progressively more important. Nowadays, advances in surgical and anesthetic technology make it possible to operate successfully on elderly patients who no longer accept disabling physical conditions. This article discusses the biomechanics of the osteoporotic spine, the diagnosis and management of osteoporotic patients with spinal conditions, as well as the novel treatments, recommendations, surgical indications, strategies and instrumentation in patients with osteoporosis who need spine operations.

Key words: osteoporosis; fracture; stenosis; degenerative spondylolisthesis; degenerative scoliosis; instrumentation

OSTEOPOROSIS AND THE MANAGEMENT OF SPINAL DEGENERATIVE DISEASE (part II)

Clinical relevance of the osteoporotic aging spine

Osteoporosis itself is painless, and the biochemical, macroscopic, and biomechanical changes observed with aging are indistinguishable from those in degenerated spines of symptomatic subjects (1). However, profound inactivity from a progressive and painful degeneration and destabilization of the spine coupled with the pain of an osteoporotic compression fracture can lead to a vicious cycle of further bone loss and degeneration, more fractures, and more pain and inactivity.

Osteoporosis predisposes patients to fracture, deformity, and stenosis. Pain and disability may be the clinical expression of the presence of an osteoporotic aging spine. The role of the clinician is to relate the degenerative changes identified on the imaging studies to the clinical symptoms. It is recognized that a degenerated spinal unit may be totally asymptomatic and remain so. Imaging (X-ray, CT scan, magnetic resonance imaging [MRI]) and bone-scan studies are capable of detecting degenerative facet joints and/or disc changes but often have scant clinical correlation, as many of these changes appear in asymptomatic persons, particularly as people grow older (2).

Zygapophysial joint osteoarthritis, degenerative changes in the discs, intervertebral space narrowing, and bony remodeling due to osteoporosis are directly related to the changes of the aging spine (1). These degenerative changes lead to deformities in the vertebrae and changes in the stress distribution and the normal alienation of the spine, responsible for degenerative segmental instabilities and subluxations such as spinal stenosis, degenerative spondylolisthesis, and scoliosis. Degenerative spondylolisthesis and scoliosis are generally asymptomatic, but they can associate or aggravate a preexisting symptomatic spinal stenosis. (3)

As the population ages, fractures, stenosis, and deformities become more common. Many factors of degeneration of the spinal unit remain unknown. The role of a genetic predisposition appears crucial, but the physical environment is also an important factor. Proper nutrition, adequate physical exercise, and appropriate physical loads are at the present time the only means of prevention at our disposal.

Degenerative lumbar spinal stenosis

Spinal stenosis is a narrowing of the spinal canal with encroachment on the neural structures by surrounding bone and soft tissue. Stenosis in the elderly is the result of a combination of osteophyte formation from degenerated zygapophysial joints, ligamentum flavum hypertrophy, disc space narrowing, and circumferential bulging of disc osteophyte complex caused by remodeling of the adjacent vertebral bodies due to osteoporosis. And when a canal size is too narrow for the dural sac size that it contains, stenosis occurs (4). Central and lateral stenosis frequently develop together and are the most common reason for lumbar surgery in adults over the age of 65.

The classic presenting feature of lumbar spinal stenosis is neurogenic claudication, which refers to lower extremity pain and numbness that worsens with activity and is relieved by sitting or adopting a lumbar forward flexion posture while walking. Patients may also report lower back pain and severe cases can also result in motor disturbances and bladder or bowel dysfunction.

The pathogenesis of these symptoms is not completely understood but most likely involves compression of nerve roots and disruption of neural blood supply. Pain decreases with sitting and flexion of the spine, which is attributed to an increased diameter of the spinal canal and flattening of the ligamentum flavum, relieving compression on the neural elements and increasing microcirculation (5-7).

Compression at more than one spinal level produces venous congestion, insufficient arterial blood supply and an ischemic environment of the neural elements. Compromised autonomic innervations of the legs may inhibit the appropriate vasodilation response to increased muscle use, responsible for lower limbs pain and numbness (7).

Imaging studies of the spine in patients suspected of having lumbar degenerative spinal stenosis provide details regarding the location and extent of stenosis; however, it is important to remember that the severity of stenosis noted on imaging studies often does not correlate with the severity of symptoms. Schizas et al. (8) have recently proposed a classification of spinal stenosis based on the morphologic appearance of the dural sac as seen on MRI T2-weighted axial images of the lumbar spine. The grading is based on the cerebrospinal fluid (CSF)/rootlet ratio as seen in axial T2 images and was conceived following observation of the different patterns according to which the rootlets were disposed within the dural sac while the patient rested supine during the MRI procedure. Description of the grading goes from Grade A (none or minor stenosis) where there is clearly CSF visible inside the dural sac, but its distribution is inhomogeneous (type A1 to A4). Grade B (moderate stenosis), the rootlets occupy the whole of the dural sac, but they can still be individualized and some CSF is still present. Grade C (severe stenosis) where no rootlets can be recognized, the dural sac demonstrates a homogeneous gray signal with no CSF signal visible and epidural fat is present posteriorly. Grade D (extreme stenosis) no rootlets being recognizable and there is no epidural fat posteriorly.

The natural history of lumbar spinal stenosis is not completely known because of a lack of longitudinal prospective studies documenting the clinical course of the disease in untreated spinal patients. Nevertheless, previous studies have shown that the outcomes of surgical treatment were more favorable compared to conservative treatment (9). Conservative treatment of lumbar spinal stenosis comprises activity modification, physiotherapy, non-steroidal anti-inflammatory medications, lumbar bracing, and epidural infiltration. These treatment efforts are usually helpful in alleviating symptoms of neurogenic claudicarion; however, it is generally accepted that surgery is indicated if conservative management fails (10).

Decrompression is fundamental to the successful surgical treatment of a stenotic segment, and is accomplished by a thorough removal of all structures contributing to the neurologic compression (11). The type of decompression performed will depend on the anatomic site of stenosis and the patient's symptoms. Wide decompressive laminectomy combined with medial facetectomy and foraminotomy is the standard treatment.

Limiting the resection to the causative structures would prevent further damage and postoperative instability. A growing tendency toward less invasive decompressive surgery has emerged, sparing anatomical structures and decreasing the risk for postoperative iatrogenic instability (4). The interspinous process spacer offers patients with spinal stenosis a less invasive alternative to laminectomy (12). The success rate obtained with these devices is similar to that generally reported for decompressive surgery, which may prove highly indicated in the surgical treatment of lumbar stenosis, especially in the elderly. Kondrashov et al. (13) compared 18 patients who received interspinous implants to 12 patients who underwent laminectomy without fusion. Of the 18 interspinous patients, 12 were treated at one level and 6 at 2 levels. This compares to 3 of the 12 laminectomy patients who were treated at one level and 9 who were treated at 2 levels. They concluded that 78% of the interspinous group, versus only 33% of the laminectomy group, had successful outcomes at 4 years of follow-up. However, the preoperative average Oswestry Disability Index (ODI) scores in the interspinous group were 25% greater (45 vs. 36).

Interspinous process spacers are a relatively new technology, and the indications and design of these devices are likely to evolve. Deyo et al. (14) published a retrospective analysis comparing the complications, costs, and revision surgery rates of interspinous spacers and laminectomy or fusion surgery in 99,084 patients. They found a reoperation rate for spacer (16.8% at 2 years) that was substantially higher than reoperation rates observed for patients having decompression surgery (7.8% at 2 years). They suggested that interspinous implants might be a useful option for patients at particularly high risk from surgery. However, for patients of average risk, and with substantial expected longevity, the higher reoperation rate with spacers might make the case for conventional decompression surgery.

The extent of surgery to perform on elderly osteoporotic patients suffering from lumbar stenosis with instability must be determined by a combination of variety of clinical factors (age, physiological status, or medical comorbidities), and anatomical findings. In the presence of preoperative instability (4 mm of translation or >10º of angular motion between adjacent endplates on lateral flexion and extension radiographs, spondylolistesis, or scoliosis), or when laminectomy is accompanied by greater than 50% resection of both facets or complete facetectomy of one side, fusion is generally recommended. (14-18). A literature review shows conflicting results regarding the outcome of lumbar spine decompression and fusion surgery for spinal stenosis in the elderly. Ragab et al. (16) reported the results of 118 patients older than 70 years of age who underwent lumbar decompressive surgery. Among the 45 patients who had posterolateral fusion, only 3 had pedicle screw instrumentation. Of the 118 patients, 109 reported satisfaction with the operation, and found that in terms of morbidity, the results were comparable with those of a younger population.

Instrumented spinal fusion in elderly patients has been problematic concerning the safety and efficacy of pedicle screws. Carreon et al. (17) retrospectively reviewed 98 patients ages 65 or older that underwent decompression and instrumented fusion. They reported at least one major complication in 21% of patients, and at least one minor complication in 70%. They found that older age and an increased number of levels fused were found to be risk factors for the occurrence of major complications. Cassinelly et al. (18) studied 166 patients older than 65 years, including 18 patients older than 80, who were treated for stenosis with decompression and fusion with (n=75) or without instrumentation (n=91). They reported a similar rate of minor complications in both groups (30%), no deaths, and only one complication attributable to the use of instrumentation. Advanced age, the presence of medical comorbidities, or the use of instrumentation did not increase the rate of major or minor complications.

However, in elderly patients, because of their poor bone quality, mechanical failures due to screw loosening represent a major concern. Chang et al. (19) published the results of a retrospective study including 41 patients with osteoporosis that underwent spinal decompression and instrumentation with PMMA augmentation of the pedicle screw. There was neither symptomatic cement leakage nor significant screw migration after 2 years of follow-up.

Degenerative lumbar spondylolisthesis

Degenerative spondylolisthesis is the forward displacement of one lumbar vertebra in relation to the caudal vertebra with an intact neural arch. Slippage is more frequent in women, and most commonly occurs at the L4-L5 level. Degenerative spondylolisthesis is thought to be the result of chronic intersegmental instability with disk degeneration. This process results in loss of ligamentous support due to ligamentous laxity with compensatory hypertrophy of the facet joints and in thickening of the ligamentum flavum. It rarely exceeds

30% of vertebral width and it is generally asymptomatic, but may result in a compromise of the spinal canal and worsening of preexisting spinal stenosis at the level of the slip, but also can cause back pain and radiculopathy (5,10,20).
Diagnosis can be established by obtaining lateral radiographs of the lumbar spine and lumbosacral junction with the patient standing in order to assess the displacement. CT scanning offers the best visualization of bony morphology. The MRI will also determine the condition of the intervertebral disc at the level of the spondylolisthesis, and exclude canal or foraminal stenosis resulting in neural compression (21). Grading can be performed according to the Meyerding classification (22), with Grade I, II, III, and IV referring to 25%, 50%, 75%, and 100% displacement, respectively (Figure 1).
The majority of patients with degenerative spondylolisthesis will respond well to non-operative treatment, including NSAIDs, epidural injections, and lumbar flexibility and strengthening exercises. Patients with severe or persistent symptoms that interfere significantly with quality of life, or those with neurological deficit, may benefit from the surgical removal of bony and soft-tissue pressure on their neural elements.
There is no universal agreement regarding the optimal surgical approach for the treatment of this disorder: current controversies include the need for an additional fusion (either posterolateral or interbody fusion) with or without instrumentation, compared with decompression only. Lombardi et al. (23) reported on 3 groups of patients who were treated surgically for degenerative spondylolisthesis: group 1 was treated with wide decompression without fusion, group 2 was treated with decompression with fusion, and group 3 was treated with decompression with careful attention to preserve the pars interarticularis and facet joints. Group 1 produced the worst results, with only 33% revealing good to excellent results. Group 2 reported the best results, with 90% having good to excellent results. Group 3 did not fare as well as group 2, presumably due to a suboptimal decompression of the nerve rots in an attempt to preserve the facet joints and pars interarticularis.
Patients with a relatively stable listhesis could be safely treated by means of laminectomy without fusion. Presently, the consensus in the literature is that decompression with fusion is superior to decompression alone in terms of better functional outcome due to the lessening of symptomatic instability.

When fusion is performed, many authors recommend including instrumentation to improve fusion rates, reduce postoperative activity limitations, and improve patient outcomes. Fischgrund et al. (24) published a randomized prospective study comparing the results of decompressive lumbar laminectomy and posterolateral fusion with or without instrumentation, and were evaluated for a mean of 2 years after surgery. Transpedicular instrumentation significantly improved the fusion rates (82% of the instrumented cases versus 45% of the non-instrumented cases). However, clinical outcome assessed in terms of relief of pain and increase in activity showed no improvement with the addition of instrumentation. The findings of these authors are similar to the findings in previous studies in which the rate of radiographic union did not correlate with the clinical outcome. The question of which group of patients may significantly benefit from the addition of instrumentation remains unanswered.

Degenerative scoliosis

Scoliosis in adults can be primary degenerative scoliosis due to an asymmetric degenerative disc and facet joint osteoarthritis leading to a rotatory disorganization and destabilization of the spine; idiopathic adolescent scoliosis which progresses in adult life; a secondary adult curve to an oblique pelvis, leg length discrepancy, hip pathology, or asymmetrical anomalies at the lumbosacral junction; or be caused by osteoporosis combined with vertebral fractures and asymmetric arthritic disease. Nevertheless, once the curve has significantly progressed, sometimes it is difficult to know the exact primary cause of the curve (25,26).

Degenerative adult scoliosis induces more asymmetric degeneration and loading, creating a vicious circle that enhances curve progression. The destruction of discs, facet joints, and joint capsules ends in a 3-dimensional translational or rotational dislocation. The biological reaction to an unstable spine is the formation of facet joints and vertebral endplate osteophytes, and hypertrophy and calcification of the ligamentum flavum, all leading to an increasing narrowing of the spinal canal, thus creating central and recessal spinal stenosis (25,27).

Patients suffering from adult degenerative scoliosis may present constant and non-specific back pain usually present only when the patient is upright, and alleviating when the patient lying down flat or on their side, when the axial load is taken off the spine. Other important symptoms can be radicular pain, neurogenic claudication, and neurological deficit, including cauda equina syndrome with bladder and rectal sphincter involvement.

Severe rotation of the apical vertebra, a Cobb angle of 30º or more, lateral vertebra translation of more than 6 mm, or a position of L5 above the intercrestal line have all been discussed as features that are predictive of curve progression in patients with lumbar degenerative scoliosis (5,28,29). Osteoporosis is another major concern in the treatment of adult degenerative scoliosis. Degenerative curves become progressive due to the asymmetric load on weakened vertebrae, which get more wedged and deformed. With the progression of the curve, the patient may become more symptomatic (26).

Non-surgical treatment options consist basically of non-steroid anti-inflammatory medication, muscle relaxants, muscle exercises, and occasionally gentle traction, avoiding manipulations and physical activation that may increase the pain. Epidural, selective nerve root blocks, and facet joint blocks may help to control the pain temporarily. Sometimes a well-fitted brace to support the painful spine area may be necessary.

There are conflicting reports regarding the need for spinal surgery in this patient population. The indication for surgery and the type of surgery to be performed involve complex decision-making. Certainly, surgery is only an option when the non-surgical measures have no effect or do not promise any relevant long-term help. The surgical decision is also influenced by the patient’s general health, age, condition of bone quality, and expectations.

Available surgical options for adult degenerative scoliosis can be divided into posterior, anterior, or combined procedures. In cases with central or lateral stenosis and symptomatology limited to the legs without relevant back pain, a simple and limited decompression can be performed. However, if significant sagittal plane imbalance or lateral listhesis of 5 mm or more is present or wide and multilevel decompression is needed, decompression should be accompanied by instrumented stabilization to avoid the risk of postoperative curve progression (5,28,29) (Figure 2).

In some complex but favorable cases, vertebral osteotomies or sequential segmental correction and instrumentation may be considered. In patients requiring extended constructs for correction and stabilization, special attention must be given to spinal balance and local shearing among implants, especially in the presence of osteoporosis. In such patients, significant loads can be placed on mechanically compromised points of fixation and can lead to implant or adjacent segment failure (5).

The results of operative correction for adult spinal deformity have improved significantly over the past decade. Correction of curvature varies from 30 to 60% and is very dependent on the nature of the preoperative curve, its flexibility, and the technique used for correction. Despite these relatively modest gains, patient satisfaction is generally high and can reach up to 90%. If coronal and sagittal balance is achieved and maintained with a solid fusion, the outcomes are generally excellent. However, adult patients have an increased risk of experiencing surgical complications compared to adolescents. Pain is seldom totally alleviated, with residual pain in 5 to 15% of operated cases. Major complications include pseudarthrosis (5 to 27%), neurologic injury (1 to 5%), infection (0.5 to 5%), and thromboembolism (1 to 20%). Mortality remains low but not insignificant at less than 1% (5,26,30,31).

Osteoporotic vertebral compression fractures. Degenerative sagittal imbalance

Osteoporosis and associated fractures are a primary cause of mortality and morbidity in geriatric patients. It has been reported that the lifetime risk of osteoporotic facture is 30-50% in women and 15-30% in men (32). And low bone mass with an increased risk of subsequent fracture was reported to be one of the most prevalent community health problems affecting up to half of the elderly population in most Western countries (33).

Vertebral fractures are the most common pathological disorder resulting from osteoporotic disease, and an indicator of excess morbidity and mortality. In comparison to an age- and sex-matched control population at risk, patients diagnosed with vertebral fractures had significantly increased morbidity and mortality rates. Direct effects of vertebral fracture include chronic back pain, reduced range of motion, slower gait, and impaired pulmonary function (34).

It has been reported that the impairment in functional health status increases from 17 to 44% in the years after sustaining a vertebral fracture, and the mortality rate rises from 62 to 95 per 1000 person-years (35). Early detection and appropriate therapy for patients suffering vertebral fracture may decrease the deterioration in their physical function (36).

Vertebral compression fractures put patients with osteoporosis at much greater risk for developing local and global changes in spinal sagittal balance due to kyphotic deformities, and spinal stenosis secondary to imbalance and degenerative changes (37). Furthermore, symptomatic neurocompression caused by osteoporotic fractures can occur, and range from acute paraplegia, usually after an acute crush fracture, to delayed onset of insidious paralysis that gradually deteriorates to severe paraplegia (38). The latter is usually associated with delayed vertebral collapse and progressive kyphotic deformity.

Percutaneous spinal cement augmentation procedures are minimally invasive techniques for the treatment of osteoporotic vertebral fractures that do not respond to conservative treatments. Bone cement used for vertebroplasty and balloon kyphoplasty immediately stabilizes the fractured vertebral body, enhancing loading capacity and relieving pain (Figure 3). Many studies have reported satisfactory reductions in clinical symptoms caused by vertebral compression fracture on a short- and long-term basis after vertebroplasty and balloon kyphoplasty (39-42).

Hulme et al. (43) 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) and improvement in physical function (ODI fell from 60% preoperative to 32% postoperative).

Extravertebral cement leakage is the most frequently reported complication and is the major risk after vertebroplasty and balloon kyphoplasty. It is generally clinically asymptomatic; however, cases of major complications and death have been reported. Complications due to cement extravasations outside the vertebral body include pulmonary embolism, cement into the vena cava, heart and kidneys, spinal cord compression, and foraminal leaks producing nerve root compression requiring surgery for decompression (39-42). Another important question is the risk of fractures in adjacent-level vertebrae. A significant increase in the incidence of new painful fractures of adjacent vertebral bodies in patients with bone cement leakage has been recently reported (44).

Multiple compression fractures lead to a progressive kyphosis, loss of stature and paraspinal muscle shortening. In order to stand more erect, prolonged active contraction is necessary to maintain posture. This leads to complaints of back pain. This generalized backache may cause patients to limit their activity and alter their quality of life (45). Kyphosis correction achieved via vertebroplasty and kyphoplasty is limited and does not significantly contribute to overall sagittal alignment. 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 (Figure 4). Kim et al. (46) evaluated 32 patients with osteoporotic spinal deformities, with 94% of patients reporting subjective improvement, a 54% decrement in ODI, 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 3 patients requiring additional surgery to treat the complications.

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. (47)

Osteoporosis and spinal surgery complications

A number of previous studies have reported perioperative and postoperative complication rates when operating on patients with adult spinal deformity and poor bone quality of up to or more than 40%. However, there is little documentation of the specific types and frequencies of the associated complications.

Carreon et al. (17) published the results of a study examining the rate of perioperative medical complications in 98 elderly patients who underwent posterior decompression and lumbar arthrodesis with instrumentation to treat degenerative disease of the spine. The average age was 72 years (65 to 84 years). Perioperative complications occurred in 78 patients (79%). Twenty-one patients (22%) had at least one major complication including 2 deaths both from postoperative wound sepsis, and 69 had at least one minor complication (70%). The most common major complication was wound infection (10%), and the most common minor complication was urinary-tract infection (34%). The complication rate increased with older age, increased blood loss, longer operative time, and the number of levels of the arthrodesis. The presence, type, or number of preoperative medical conditions was not related to the prevalence of complications. This finding is similar to that of Benz et al. (48), who reported that the presence of associated medical diseases did not affect the frequency of postoperative complications. However, other studies showed that the prevalence of postoperative morbidity increased as the number of premorbid diseases increased (49-51).

De Wald and Stanley (52) revised 47 procedures in 38 patients to investigate the occurrence of instrumentation-related complications in multilevel fusion surgery for adult spinal deformity patients over the age of 65. The average follow-up period was 30 months. They found that spinal deformity correction in patients with poor bone quality had early (<3 months) complications including pedicle fractures and adjacent vertebral body compression fractures above and below constructs with an overall rate of 13%. They found late complications (>3 months) to include pseudoarthrosis with rod breakage (11%), screw loosening with last instrumented level (7%), acute disc herniation above the last instrumented level (4%) (Figure 5), pelvic fixation prominence (11%), and progressive junctional kyphosis at the cephalad portion of the construct (26%). One major complication, which normally leads to reintervention, is junctional kyphosis. Kim et al. (51) investigated the risk factors for sagittal thoracic decompensation in long lumbar spinal fusions in adults: patients with a sagittal imbalance of more than 5 cm and a 10-degree smaller lumbar lordosis than thoracic kyphosis at 8 weeks postoperative, and those greater than 55 years and with associated comorbidities, were considered to be at exceptional risk. The restoration of a balanced sagittal profile is considered to be the most important means of preventing junctional decompensation (53).

Not all patients with proximal junctional kyphosis (PJK) are symptomatic. Glattes et al. (54) reviewed the X-rays and clinical outcomes of 81 consecutive adult deformity patients to determine the incidence of PJK and its effect on patient outcomes. Average follow-up was 5.3 years. Incidence of PJK was 26%, but SRS-24 scores were not significantly affected. No patient, radiographic, or instrumentation variables were identified as risk factors for developing PJK. However, if the resulting loss of correction and progressive imbalance is caused by an adjacent vertebral body compression fracture, or fracture-subluxation, this may in time lead to muscle pain or further fracture, requiring an extension of the spinal fusion (Figure 6).

In cases of long fusions, the use of a rod that has a short taper to a smaller diameter so called transition rod, at the top end (55), and the addition of prophylactic vertebroplasty at segments immediately cranial and caudal to instrumentation have been advocated with the purpose of avoiding junctional segment fractures. Aydogan et al. (56) used prophylactic vertebroplasty augmentation in segments proximal and distal to multilevel instrumentation to prevent junctional segment fractures. The average age of the patients was 66 (59 to 78) years. All patients had the T-score value of less than -2.5. There were no proximal or distal junctional segment fractures observed during the follow-up course. They suggested that these additional vertebroplasties could serve as a possible means of avoiding junctional fractures. This opinion requires investigation before it can be confirmed, since additional vertebroplasty augmentation has been recently associated with further and more severe spinal fractures (57).

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Figure legends

Figure 1: **A**, lateral radiograph of a 78-year-old woman with neurogenic claudication. A Grade I L4 degenerative spondylolisthesis is present. Sagittal (**B**) and transverse MRI cuts demonstrate central neural and foraminal stenosis at L4-L5 (**C**) with normal canal width cranial to the stenosis (**D**). Lateral radiograph (**E**) obtained after laminectomy and L4-L5 instrumented arthrodesis with PMMA-augmented fenestrated pedicle screws.

Figure 2: **A**, coronal preoperative CT reconstruction of a 73-year-old woman who had severe degenerative adult scoliosis of the thoracolumbar spine. Postoperative posteroanterior (**B**) radiograph demonstrating correction obtained following a posterior-only approach with the use of a dual rod construct and PMMA-augmented fenestrated pedicle screws. Pelvic fixation was used because of the long thoracolumbar fusion and the need to fuse across the L5-S1 disc space.

Figure 3: Intraoperative fluoroscopy AP and lateral views of an 83-year-old woman with osteoporotic compression fractures on L1 and T10. Bone cement used for vertebroplasty and balloon kyphoplasty immediately stabilizes the fractured vertebral body, enhancing loading capacity and relieving pain.

Figure 4: **A**-**B**, posteroanterior and lateral radiographs of a 77-year-old woman with Parkinson disease, progressive sagittal and coronal imbalance and neurogenic claudication. Note L5 vertebroplasty. **C**-**D**, sagittal CT and MRI demonstrating a L3 osteoporotic compression fracture severely affecting the patient's global sagittal alignment. **E**-**F**, postoperative posteroanterior and lateral radiographs demonstrating correction obtained following posterior-only approach with an L3 pedicle substraction osteotomy, a dual rod construct with thoracic spine sublaminar wires and proximal and distal PMMA-augmented fenestrated pedicle screws, L5-S1 interbody fusion and pelvic fixation.

Figure 5: Sagittal T2-weighted MRI image demonstrating L2-L3 acute disc herniation above the instrumentation.

Figure 6: **A**, postoperative lateral radiograph of a 71-year-old woman who had laminectomy and L4-L1 fusion with PMMA-augmented fenestrated pedicle screws. **B**, early follow-up lateral radiograph demonstrating loss of correction and progressive imbalance caused by failure of the instrumentation at the

upper-instrumented vertebra with vertebral body compression fracture. **C**, the fusion was extended to T6 using bilateral pedicular screws and sublaminar wires. **D**, failure of instrumentation occurred again at the upper-instrumented vertebra. **E**, fusion was re-extended to T4 with thoracic spine sublaminar wires. Satisfactory profile in both frontal and sagittal planes were obtained.

Table1: Summary of reports of surgical treatment for degenerative lumbar disease using pedicle screws augmented with PMMA.