Fusion has become the standard of care for numerous pathologic conditions of the spine over the past 50 years. Instrumented thoracolumbar fusion for adolescent and adult spinal deformity has enjoyed great success in arresting the progression of and correcting scoliotic deformity. In the cervical spine, decompression and fusion have provided a greater than 90% likelihood of relieving radicular symptoms and stabilizing or improving myelopathy. Decompression and posterolateral fusion of the lumbar spine have been shown to be the superior form of surgical management for degenerative spondylolisthesis in prospective randomized studies. Given the high clinical success recognized in using fusion for deformity and stenosis of the cervical and lumbar spine, the long-term sequelae of these procedures has been considered of secondary importance. However, as spinal fusion is being performed on younger patients and as the rates of cervical and lumbar spine surgery have increased over the past two decades, concern regarding the effect on adjacent motion segments has been increasing. Furthermore, as indications for fusion have expanded to include mechanical back and neck pain with more variable success rates, concern for adjacent segment degeneration has been amplified.

Adjacent level degeneration, following cervical, lumbar, and lumbosacral fusions, has been well documented in recent literature, yet there remains considerable controversy as to when adjacent level radiographic degeneration becomes clinically relevant. It has also become evident that maintenance of sagittal alignment of the spine has important clinical implications when treating and preventing adjacent segment degeneration and flat back syndrome. Numerous studies have demonstrated in properly selected patients that decompression and fusion can yield marked improvement with respect to pain and outlook for various conditions of the spine. However, there are also numerous articles that suggest otherwise, with the results of spinal fusion described as unpredictable, if not unsatisfactory, and often precipitating further surgical intervention.

It is important, therefore, to understand the long-term consequences of cervical, lumbar, and lumbosacral fusions, and their impact on adjacent segment degeneration.

**Cervical Spine**

**Clinical Evidence of Adjacent Segment Disease**

Radiographic evidence of adjacent level degeneration in the cervical spine has been documented. Katsuura and colleagues noted degenerative changes evident on radiological examination in levels adjacent to a fused segment in 21 of 42 (50%) patients, following anterior cervical interbody fusion, at 9.8 years average follow-up. Goffin and associates reported on 181 patients treated by anterior cervical interbody fusion, with an average follow-up of greater than 8 years. Patients were clinically and radiologically examined by independent investigators who reported mild radiologic deterioration at adjacent levels in 92% of cases studied and moderate to severe changes in 43% of cases. The severity of radiographic changes was associated with the time interval since surgery. However, radiographic adjacent segment degeneration was not correlated with clinical symptoms.

Herkowitz and coworkers studied 44 patients with cervical radiculopathy randomized to anterior discectomy and...
Yue and associates evaluated clinical and radiologic outcomes at an average of 7.2 years following anterior cervical discectomy and fusion. In this series, 12 of 71 patients (16.9%) required second procedures for symptomatic adjacent level disease at an average of 41.8 months following the index procedure. In a similar study, Ishihara and coworkers determined an incidence of symptomatic adjacent segment disease of 19% of 112 patients studied. Symptoms developed at an average of 6.5 years following the index procedure. Of those patients who developed symptomatic adjacent level disease, 37% failed nonoperative treatment and required additional operations. Keplán-Meier survival analysis determined a disease-free survival of 89% at 5 years, 84% at 10 years, and 67% at 17 years. Disc protrusion at the adjacent level demonstrated on preoperative myelography or magnetic resonance imaging (MRI), was associated with development of adjacent level disease. Based on these studies, the incidence of radiographic adjacent segment degeneration in the cervical spine is estimated to be between 5% and 9% per year. However, symptomatic adjacent segment disease appears to occur at a rate of 2% to 3% per year following anterior cervical discectomy and fusion.

**Biomechanics**

The subaxial cervical spine, where most fusion procedures are performed, is bordered by a highly mobile upper cervical region that provides nearly half of all cervical motion. Numerous biomechanical studies examining the effects of arthrodesis on adjacent levels have been reported although none have utilized a model which includes the upper cervical region. Eck and colleagues performed a biomechanical study using cadaveric cervical spine specimens. The investigators demonstrated significant increases in intradiscal pressure and segmental motion adjacent to a fused segment during normal ranges of motion. They surmised that these changes could partially explain the mechanism of early disc degeneration within the cervical spine. Further studies have substantiated these observations, demonstrating increased stress responses in adjacent levels. Lopez-Espina and associates noted a 96% increase in stresses at the nucleus, annulus, and endplate of levels adjacent to fused cervical motion segments, utilizing finite element analysis in a cadaveric model. Increased adjacent level stresses were noted following two-level fusions when compared to single-level. Whether increased stress at motion segments adjacent to arthrodeses is above a clinically relevant threshold is unknown.

**Lumbar Spine**

**Clinical Evidence of Adjacent Segment Disease**

There is substantial reporting in the literature regarding the development of adjacent level disease following lumbar fusion. Many investigators have reported their clinical series and demonstrated conflicting results. Lehmann and coworkers, did a retrospective study of 62 patients at a mean of 33 years following lumbar fusion, and they noted segmental instability above the fusion in 45% of patients in whom follow-up radiographs were available. Fifty-seven percent of patients reported episodes of back pain in the previous year and 53% required pain medication. However, radiographic deterioration of the adjacent segment did not correlate with symptoms.

In an attempt to determine the etiology of adjacent level degeneration, some investigators have sought to delineate those distinguishing risk factors that are inherent either within the patients or the surgery. Etebar and Cahill performed a retrospective analysis on 125 consecutive patients who had undergone lumbar fusion with rigid instrumentation for degenerative instability at an average of four-years follow-up. A total of 18 of 125 patients (14%) developed symptomatic adjacent segment degeneration at a previously asymptomatic level, 15 of whom were postmenopausal females (83%). The investigators concluded that the risk of adjacent segment degeneration is higher for patients with rigid instrumentation performed to treat degenerative instability, and that this risk appears to be particularly high in postmenopausal females.

In a study evaluating the long-term clinical and radiologic results of anterior lumbar interbody fusion (ALIF) for ischemic spondylolisthesis, Ishihara and colleagues included 23 patients who were followed for more than 10 years (average, 13.3 years). Radiographs demonstrated new adjacent disc degeneration in 52% in the upper adjacent level and in 70%
of cases in the lower adjacent level at final follow-up; rates of 4% and 5% per year occurred, respectively.\textsuperscript{31} Magnetic resonance images of 11 patients at final follow-up demonstrated 73% prevalence of intervertebral disc degeneration in the upper adjacent levels and 100% in the lower adjacent level. Penta and associates performed a radiologic study to evaluate the relationship between adjacent level disease and fusion length.\textsuperscript{32} Using plain films and MRI at the ten-year follow-up, the investigators studied 52 patients who, preoperatively, demonstrated a normal disc above the intended level of fusion. The study found that 32% of these 52 patients had degenerative changes and that this percentage was not influenced by the length of the fusion.

In a recent retrospective study of 215 patients who underwent posterior lumbar arthrodesis, with an average follow-up of 6.7 years, Ghiselli and coworkers identified 59 (27.4%) patients who required additional decompression or fusion at the adjacent level. Kaplan-Meier survival analysis predicted a disease-free survival rate of 83.5% at five years and 63.9% at ten years following the index procedure. No significant correlation was found between preoperative arthritic grade and the need for additional surgery.\textsuperscript{33}

One theory ascribes these adjacent segment degenerative changes to the natural history of the degenerative disease process. The aforementioned study by Penta and colleagues reported that degenerative changes following spinal fusion were not related to the length of fusion. From this, they hypothesized that degeneration following lumbar interbody fusion is determined more by the degenerative disease process than by the fusion itself.\textsuperscript{32} The opposing biomechanical theory attributes early degenerative changes to the relative hypermobility of the adjacent motion segment and the increased stresses placed on the adjacent discs, endplates, and facets.\textsuperscript{34,35}

**Biomechanics**

There are numerous biomechanical studies that have investigated the effects of lumbar spine fusions on adjacent levels. Most of these studies test the hypothesis that fusion of one level will cause an associated transference of load to its adjacent level. Using roentgen stereophotogrammetric analysis, Axelsson and associates demonstrated that fusion of the lumbosacral spine altered the kinematics of the adjacent segments, redistributing mobility toward the juxtafused segments.\textsuperscript{36} Alteration in the biomechanics of the adjacent motion segment was evaluated by Weinhoiffer and associates in an in vitro study that demonstrated intradiscal pressures increased within adjacent levels as flexion motion increased. An increase in pressure was shown to directly correlate with the number of levels fused.\textsuperscript{37}

It has been theorized that an increase in intradiscal pressure predisposes a motion segment to disc deterioration and spondylotic degeneration. In a lumbar cadaveric experiment, Chow and coworkers confirmed hypermobility and an increase in intradiscal pressures of adjacent segments following fusion, but they questioned whether or not the neighboring unfused segments were loaded beyond their physiological limits.\textsuperscript{3} In a radiologic study evaluating this transference of stress, Frymoyer and colleagues noted a compensatory increase in the range of lumbar motion in adjacent levels following lumbar fusions using flexion-extension radiographs.\textsuperscript{16}

**Correlation Between Radiographic Degeneration and Clinical Disease**

The clinical correlation of radiologic adjacent level degeneration remains a topic of controversy. The clinical relevance of radiographic degenerative changes and the corroborating biomechanical evidence attempting to demonstrate causality is unclear. Further clouding the issue is the presence of degenerative changes in completely asymptomatic patients.\textsuperscript{38} Boden and associates' classic article noted abnormal findings on approximately 57% of lumbar magnetic resonance scans in asymptomatic patients aged 60 years or older.

Surprisingly, there was degeneration or disc bulging involving at least one lumbar level in 35% of subjects between 20 and 39 years of age, and in all but one of the 60- to 80-year-old asymptomatic subjects.\textsuperscript{39} In a similar study, Boden and coworkers performed cervical MRI scans on 63 asymptomatic individuals and found disc degeneration or narrowing at one or more levels in 25% of subjects less than 40 years of age and in nearly 60% of those older than forty.\textsuperscript{40}

The following studies fail to reveal a high degree of clinical correlation with postoperative radiologic adjacent segment deterioration. Guigui and colleagues reported on 102 patients who underwent posterolateral single-level lumbar fusion. Degenerative changes were present radiographically in at least 49% of patients at an average of 8.9 years follow-up. However, only eight of these patients with radiographic changes had symptoms warranting further surgical management.\textsuperscript{41} In the study of Ishihara and associates, who evaluated anterior lumbar interbody fusion for isthmic spondylolisthesis, degenerative changes were reported in up to 70% of adjacent levels. However, no evidence of clinical deterioration was found throughout their ten-year follow-up. In cases of nonunion, they found that JOA (Japanese Orthopaedic Association) scores gradually worsened with time, but overall results did not differ from those patients who did achieve union.\textsuperscript{42}

Kumar and coworkers performed a long-term study with minimum 30-year follow-up, comparing a cohort of 28 patients treated with a posterior mid-line fusion for degenerative disc disease to 28 patients treated for degenerative disc disease without fusion. The incidence of radiographic deterioration at levels adjacent to the fused segment was twice as high in the fusion group as in the nonfusion group. However, no statistically significant difference was found between the two groups in clinical outcome measures and functional testing.\textsuperscript{43}
There are few articles that specifically detail the clinical outcomes of symptomatic adjacent segment breakdown. Lee documented 18 patients in whom new symptoms developed that were associated with the segment adjacent to a fusion after an average symptom-free interval of 8.5 years (range: 1-38 years). The most common pathologic condition at the adjacent segment was hypertrophic degenerative arthritis of the facet joints. Schlegel and associates analyzed 58 new patients who developed spinal stenosis, disc herniation, or instability at a segment adjacent to a previously asymptomatic fusion performed an average of 13.1 years earlier. Interestingly, 58% of segments immediately next to the adjacent segment deteriorated at the same time as the adjacent segment. The study noted that sagittal and coronal imbalance appeared to play a role in adjacent segment breakdown although statistical significance was not evident.

**Deformity and Adjacent Segment Disease**

Recent literature has highlighted the importance of sagittal alignment and its relation to the development of adjacent level degeneration. In Katsuura’s aforementioned study evaluating anterior cervical fusion, a total of 43% of patients with adjacent level degeneration had malalignment of the cervical spine at the time of diagnosis. Degenerative change in adjacent intervertebral levels was observed in 77% of segments fused in kyphosis. Kumar and coworkers performed a similar study analyzing the relationship between lumbar sagittal imbalance and the development of adjacent segment degeneration. Thirty-one of 83 patients (38%) who had undergone lumbar fusion for degenerative disc disease had radiographic evidence of adjacent level degeneration above the level of the fusion at an average of 5.2 years following the index procedure. Of these 31 patients, 14 (45%) required a second surgical intervention. The lowest incidence of adjacent level degeneration was seen in patients with a normal C7 sagittal plumb line and normal sacral inclination (8%). In those with sagittal imbalance, vertical sacral inclination, or both, the incidence of adjacent segment disc degeneration was approximately 50%.

Biomechanical studies have demonstrated the importance of sagittal alignment on adjacent motion segments. Oda and colleagues compared the effects of a kyphotic posterolateral fusion to a sagittally balanced in situ fusion in the lumbar spine of sheep. The kyphotic posterolateral fusion significantly influenced supra-adjacent motion segment biomechanics, by inducing more stiffness in the posterior ligamentous complex and increasing lamina strain under flexion-extension loading. Results of histologic analysis showed significant degenerative changes of the more cephalad L2-L3 facet joints in the kyphotic group. The investigators inferred that, in the group fused in kyphosis, compensatory hyperlordosis at the cranial adjacent level led to lordotic contracture of the posterior ligaments. Significant degenerative changes were noted in the infra-adjacent facet joints in the kyphotic group as well. These results indicate that a kyphotic deformity may lead to adjacent level facet joint contracture and facet arthritis and may be the pain generator in such cases.

Akamura and coworkers performed a biomechanical study in which they tested the effect on adjacent motion segments of fusing a lumbar segment in various sagittal positions. An in vitro biomechanical study of L4–L5 lumbar fixation in three different sagittal alignments was performed, and the total flexion-extension motions at the adjacent levels (L3–L4 and L5–S1) were measured. The three different fixation alignments were in situ fixation, hyperlordotic fixation, and hypolordotic fixation. Hypolordotic alignment at L4–L5 caused the greatest increase of sagittal motion at the adjacent L3–L4 level, and the differences were statistically significant in comparison with in-situ fixation, and hyperlordotic fixation. This study corroborates the importance of fusing the lumbar spine in situ or in hyperlordosis to prevent compensatory increased adjacent segment motion, which may predispose to early degeneration.

In a radiologic analysis of posture before and after lumbosacral fusion, done in order to evaluate the influence of sagittal alignment on the occurrence and pattern of postsurgical pain, Lazennac and colleagues demonstrated that postfusion pain correlated with a more vertical sacrum and pelvic retroversion. Appropriate alignment of the fused

![Figure 1](image-url) Figure 1 This 64-year-old male was treated, in 1996, with posterior decompression and instrumented fusion at L4-5 for degenerative spondylolisthesis with stenosis.
segments is of paramount importance to minimize muscle fatigue during maintenance of erect posture. Anatomic coronal and sagittal balance appears to reduce posterior strain and associated degenerative changes.

Edwards and associates performed a retrospective clinical and radiographic analysis of long adult deformity fusions, terminating at L5 at a mean follow-up of 5.6 years. The investigators found that L5-S1 degenerative changes developed in 19 of 31 patients (61%) who were previously assessed as having healthy L5-S1 discs prior to surgery. Infra-adjacent disc degeneration was associated with positive sagittal balance and a need for revision surgery.

The Impact of Motion-Sparing Technology on Adjacent Level Disease

Concern for the development of adjacent level disease following arthrodesis has generated interest in the development of motion-sparing alternatives to fusion. Short-term experience with total disc arthroplasty from clinical trials in the United States has been encouraging, but there is little long-term data available regarding the impact of total disc arthroplasty on adjacent segment disease. Robertson and coworkers compared the prevalence of adjacent degeneration at two-year follow-up in recipients of the Bryan cervical disc replacement to those who underwent single-level cervical discectomy and fusion. Fusion was found to be significantly more associated with increased radiologic (odds ratio: 2.44) and clinical (odds ratio: 35.8) adjacent level disease. The investigators concluded that motion-sparing procedures in the cervical spine may be protective of adjacent levels when compared to fusion.

Clinical experience with arthroplasty has been more extensive in Europe. Zeegers and colleagues reported a series of 50 patients who underwent lumbar disc arthroplasty with the Charité III implant. Eleven patients (22%) required additional surgery at the adjacent level within two years following the index procedure. Four patients underwent discectomy and seven required prosthetic replacement for symptomatic adjacent segment disease. Huang and associates noted a decreased prevalence of radiographic adjacent level disease at 8.7 years following total disc replacement in patients who achieved greater than five degrees of motion at

Figure 2 Nine years later, the patient returned with new symptoms of claudication and low back pain. Lateral radiograph. A, demonstrates new spondylolisthesis and anterior osteophyte formation at L3-4. B and C, Myelogram and postmyelogram CT demonstrate new lateral recess stenosis at the supra-adjacent L3-4 level.
This data would suggest that physiologic motion may be protective in the development of adjacent level degeneration. However, the question as to whether motion preservation reduces adjacent level disease will remain unanswered until more long-term data from randomized controlled trials of total disc replacement versus fusion become available.

**Treatment**

Prevention of adjacent level degenerative disease is a complicated and controversial topic. There are no established guidelines for the treatment of degenerative disc disease. The argument for including a degenerative disc above a segment requiring fusion is the prevention of adjacent level degeneration and postfusion pain. On the other hand, the clinical relevance of degenerated lumbar discs is not well established, and an increase in fusion length has been shown to predispose patients to greater perioperative morbidity. Many authors have argued against the inclusion of a degenerative adjacent segment in a fusion, based solely on radiographic findings with a paucity of supportive clinical evidence. In a five-year retrospective study, Miyakoshi and coworkers found no significant difference in clinical results between their patients with or without preoperative L5-S1 disc space narrowing who underwent one-level posterior fusion at L4-5. Similarly, Throckmorton and colleagues, in a retrospective review of 25 consecutive patients who underwent lumbar fusion for degenerative instability, found no adverse impact on clinical outcomes when the fusion ended adjacent to a degenerative motion segment.

Many would agree that there may be instances when prophylactic adjacent segment fusion may be beneficial, such as in those patients with sagittal malalignment, instability, or overwhelming axial pain, confirmed by positive provocative discography. Elimination of painful disc disease with restoration of sagittal alignment seems to play an important role in averting adjacent level degeneration, as well as being vital to a successful surgical outcome.

In the previously cited study by Hilibrand and associates that evaluated adjacent level degeneration following cervical spinal fusion, it was demonstrated that the risk of new disease at an adjacent level was significantly lower following a multilevel arthrodesis than it was following a single-level arthrodesis. The study concluded that all degenerated segments causing radiculopathy or myelopathy should be included in an anterior cervical arthrodesis. It was their belief that further degeneration is likely secondary to progression of the disease process rather than the result of the fusion itself.

**Conclusion**

The development of adjacent level degeneration following cervical, lumbar, and lumbosacral fusions is most likely related to several postoperative mechanical factors as well as the normal aging process of the spine. The literature seems to support a multivariate etiology of this phenomenon. In order to consider further operative intervention, radiographic findings of adjacent segment disease must be strongly correlated with clinical findings (Figs. 1 to 3).

The incidence of radiographic adjacent segment disease following fusion has been reported to be as high as 50% in the cervical spine and 70% in the lumbar spine at ten years. However, the incidence of clinically relevant symptomatic adjacent segment disease is quite lower, estimated at 25% in the cervical spine and 36% in the lumbar spine at 10 years. Sagittal malalignment appears to have a strong influence on the development of adjacent segment disease. In patients with symptomatic adjacent level degeneration, fusion in addition to decompression of the adjacent segment is often warranted. More long-term data is needed to determine the influence of motion sparing alternatives on the development of adjacent segment degeneration.

**References**

2. Robinson RA, Smith GW. Anterolateral cervical disc removal.