Update on the evidence for adjacent segment degeneration and disease

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Abstract

BACKGROUND CONTEXT: The evidence surrounding the topic of adjacent segment degeneration and disease has increased dramatically with an abundant amount of literature discussing the incidence of and techniques to avoid it. However, this evidence is often confusing to discern because of various definitions of both adjacent segment degeneration and disease.

PURPOSE: To organize and review the recent evidence for adjacent segment degeneration and disease.

RESULTS: Although multifactorial, three distinct causes of adjacent segment disease in both the lumbar and cervical spine have been discussed: the natural history of the adjacent disc; biomechanical stress on the adjacent level caused by the fusion; and disruption of the anatomy at the adjacent level with the initial surgery. The incidence of adjacent segment degeneration in the lumbar spine has been widely reported in the literature from 0% to 100%; conversely, the reported incidence in the cervical spine is less variable. Similarly, strategies at avoiding adjacent segment disease in the lumbar spine include arthroplasty, dynamic fixation, and percutaneous fixation, whereas in the cervical spine the focus has remained on arthroplasty.

CONCLUSIONS: Adjacent segment disease and degeneration remain a multifactorial problem with several techniques being developed recently to minimize them. In the future, it is likely that the popularity of these techniques will be dependent on the long-term results, which are currently unavailable. Published by Elsevier Inc.

Keywords: Adjacent segment; Arthroplasty; Arthrodesis

Introduction

The indications for arthrodesis of the lumbar and cervical spine have continued to expand with more fusion procedures being performed every year [1]. Only recently have surgeons become concerned with adjacent segment degeneration and disease, leading to several reports on the incidence of this relatively common problem [2–10]. Adjacent segment degeneration represents the radiographic changes of the intervertebral discs adjacent to the surgically treated levels, whereas adjacent segment disease is defined as the pathologic process associated with disc degeneration leading to clinical symptoms, such as radiculopathy, stenosis, and instability [11]. Furthermore, avoidance of adjacent segment disease has been a rationale for the development of total disc arthroplasty [12], and with the recent popularity of this new technology, the study of the adjacent segment disease has increased exponentially. Although the same terms are used for both the cervical and lumbar spine, the multifactorial process that leads to its development differs in these two regions.

One very significant question that remains to be answered is the extent to which the adjacent segment degeneration adjacent to an arthrodesis represents age-appropriate degeneration occurring because of natural history alone.
The objectives of this review were to discuss the recent literature on the incidence of and potential solutions for the adjacent segment degeneration and disease in the lumbar and cervical spine.

Lumbar spine

Incidence

The unique anatomy and biomechanics of the lumbar spine cause the region to be more susceptible to degenerative changes and, consequently, surgical intervention [14] (Fig. 1, Table 1). Although adjacent segment degeneration/disease can be associated with decompressive procedures, most of the discussion about the adjacent segment has focused on arthrodesis [15–18]. The development of adjacent segment disease is undoubtedly multifactorial, with several studies documenting the incidence rate [5,15,17,19,20]. In a systematic review, by Harrop et al. [11], which compared arthrodesis to arthroplasty, the incidences of adjacent segment degeneration and disease associated with arthrodesis were 34% and 14%, respectively. They reported the incidence of adjacent segment disease to be significantly less with total disc arthroplasty; however, the groups were different because the arthroplasty patients were younger and, therefore, less susceptible to degeneration [11]. In addition, the arthroplasty patient data were collected as a part of industry-funded Investigational Device Exemption studies, which, although rigorous, could be susceptible to surgeon and patient bias. Ultimately, several variables have been identified as potentially contributing to adjacent segment disease, including preexisting disease/natural history, increased adjacent segment mobility, and disruption of adjacent segment anatomy [5,16,21].

To understand if adjacent segment disease is related to the surgical intervention or simply the natural progression of degeneration, the ideal study would evaluate the adjacent level in patients treated nonoperatively and compare the incidence of adjacent level disease/degeneration to a similar group treated operatively. Unfortunately, this does not exist.
Table 1
Summary of lumbar adjacent segment disease studies

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Design</th>
<th>Study group</th>
<th>Sample size</th>
<th>Follow-up (mo)</th>
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<th>Adjacent degeneration</th>
<th>Adjacent disease</th>
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<tr>
<td>Guyer et al. [39]</td>
<td>2009</td>
<td>RCT</td>
<td>Lumbar fusion versus CHARITE</td>
<td>133</td>
<td>60</td>
<td>44</td>
<td>N/A</td>
<td>5.5% CHARITE</td>
<td>No difference in the clinical outcome between groups</td>
</tr>
<tr>
<td>Djurasovic et al. [31]</td>
<td>2008</td>
<td>Case control</td>
<td>Lumbar fusion</td>
<td>101</td>
<td>58</td>
<td>54</td>
<td>N/A</td>
<td>18.3% ALIF</td>
<td>Loss of lordosis is a risk for ASD</td>
</tr>
<tr>
<td>Min et al. [33]</td>
<td>2007</td>
<td>Case control</td>
<td>ALIF versus PLIF</td>
<td>48</td>
<td>44.6</td>
<td>53</td>
<td>44% ALIF</td>
<td>82.6% PLIF</td>
<td>ALIF causes less ASD than PLIF</td>
</tr>
<tr>
<td>Sears et al. [10]</td>
<td>2011</td>
<td>Case series</td>
<td>PLIF</td>
<td>912</td>
<td>63</td>
<td>63</td>
<td>N/A</td>
<td>27.3%</td>
<td>Rate highest in multilevel fusions</td>
</tr>
<tr>
<td>Lee et al. [46]</td>
<td>2010</td>
<td>Case series</td>
<td>Two-level ALIF w/PPSF</td>
<td>24</td>
<td>36</td>
<td>56.3</td>
<td>33%</td>
<td>N/A</td>
<td>Clinical symptoms unrelated to ASD</td>
</tr>
<tr>
<td>Bae et al. [45]</td>
<td>2010</td>
<td>Case series</td>
<td>ALIF, TLIF, PPSF</td>
<td>103</td>
<td>59</td>
<td>48.5</td>
<td>8.7%</td>
<td>16% isthmic</td>
<td>Sagittal imbalance correlates with ASD</td>
</tr>
<tr>
<td>Kim et al. [8]</td>
<td>2010</td>
<td>Case series</td>
<td>Circumferential lumbar fusion</td>
<td>69</td>
<td>70</td>
<td>50</td>
<td>72.7% isthmic spondylolisthesis</td>
<td>24% degeneration</td>
<td>MRI is reliable for diagnosis</td>
</tr>
<tr>
<td>Cheh et al. [6]</td>
<td>2007</td>
<td>Case series</td>
<td>Pedicle screw lumbar fusion</td>
<td>188</td>
<td>88</td>
<td>55</td>
<td>42.6%</td>
<td>30.3%</td>
<td>Age and length of fusion are risk factors</td>
</tr>
<tr>
<td>Wai et al. [34]</td>
<td>2006</td>
<td>Case series</td>
<td>ALIF</td>
<td>39</td>
<td>240</td>
<td>58.3</td>
<td>74.3% on MRI</td>
<td>N/A</td>
<td>No correlation between MRI and clinical symptoms</td>
</tr>
<tr>
<td>Aiki et al. [32]</td>
<td>2005</td>
<td>Case series</td>
<td>Posterolateral fusion</td>
<td>117</td>
<td>84</td>
<td>51</td>
<td>N/A</td>
<td>7.7% reoperation</td>
<td>Multisegment fusion and coronal/sagittal imbalance</td>
</tr>
<tr>
<td>Ghiselli et al. [17]</td>
<td>2004</td>
<td>Case series</td>
<td>Posterior lumbar fusion</td>
<td>215</td>
<td>80.4</td>
<td>50</td>
<td>N/A</td>
<td>27.4% reoperation</td>
<td>Highest reoperation rate</td>
</tr>
<tr>
<td>Okuda et al. [15]</td>
<td>2004</td>
<td>Case series</td>
<td>PLIF</td>
<td>87</td>
<td>43</td>
<td>64</td>
<td>29%</td>
<td>4% per year</td>
<td>No correlation preoperatively</td>
</tr>
<tr>
<td>Ishihara et al. [3]</td>
<td>2001</td>
<td>Case series</td>
<td>ALIF</td>
<td>23</td>
<td>134</td>
<td>51</td>
<td>52% cephalad level (73% MRI)</td>
<td>N/A</td>
<td>No correlation between radiographic findings and clinical results</td>
</tr>
<tr>
<td>Kumar et al. [19]</td>
<td>2001</td>
<td>Case series</td>
<td>PLIF, PLIF</td>
<td>83</td>
<td>60</td>
<td>56.6</td>
<td>42.1%</td>
<td>16.8%</td>
<td>Radiographic changes do not correlate with clinical outcome</td>
</tr>
</tbody>
</table>

RCT, randomized control trial; ALIF, anterior lumbar interbody fusion; ASD, adjacent segment disease; PLIF, posterior lumbar interbody fusion; PPSF, percutaneous pedicle screw fixation; MRI, magnetic resonance imaging.

Adjacent segment degeneration—radiographic degeneration; Adjacent segment disease—clinically significant degeneration.
in the current literature, and the true incidence of postoperative adjacent level disease related to the natural progression of disc degeneration remains unclear. Although the ideal "natural history" study does not exist, several have reported the existence of disc degeneration in asymptomatic individuals [22–24]. In a landmark study by Boden et al. [24], the prevalence of abnormal findings on MRIs of asymptomatic patients was 57% in patients older than 60 years. The study is limited by its small sample size, but it does highlight the importance of patient age on the prevalence of radiographic pathology and was successful in bringing to light the impressively high rate of degenerative changes seen on the MRI at asymptomatic levels. Following up on the results of this study, Borenstein et al. [25] reexamined the patients with abnormal findings in the Boden study and found that the degenerative changes observed on the original MRI were not predictive of the development of future low back pain. In 2002, Elfering et al. [26] prospectively followed asymptomatic patients with MRI finding that 41% of patients had a progression of degenerative changes over a 5-year-period but that the radiographic findings were only weakly correlated to the clinical symptoms. They concluded that patient activity level and occupation were predictive of degeneration progression on MRI [26]. The results of these studies have been reinforced by subsequent studies, which have continued to echo the disconnection between radiographic pathology and clinical symptoms [22,23]. Clearly, radiographic degeneration is a common finding in nonsurgically treated patients, and this supports the argument for the role of natural history in the development of adjacent segment disease.

A major challenge that remains is identifying what radiographic pathology is clinically significant. New MRI technology (T2 mapping, T1 rho, and so on) is developing, which provides a more detailed view of the intervertebral disc [27,28]. The techniques are making recognition of early degeneration possible and some evidence exists to suggest that these detailed MRI findings may coincide with symptoms [27]. However, as these techniques evolve, care must be taken to ensure that physical complaints correlate to the radiographic findings, and, therefore, when evaluating an MRI, one has to be careful not to overinterpret a potentially asymptomatic level.

Another major factor implicated in the cause of adjacent segment disease/degeneration is altered biomechanics resulting in increased mobility at adjacent levels. The adjacent level biomechanical changes associated with fusion have been well documented by several studies and include an increased range of motion (ROM) and increased intradiscal pressure [16,21,29,30]. The literature clearly supports changes in the adjacent level biomechanics, but it remains difficult to demonstrate a causal relationship with degeneration. One potential source for the biomechanical changes is altered sagittal alignment after arthrodesis, and this has been implicated to increase the rate of adjacent segment disease [19,31,32]. In 2008, Djurasovic et al. [31] compared two matched cohorts and found that patients with postoperative loss of lordosis had a significant increase in adjacent segment degeneration. Stand-alone anterior lumbar interbody fusions (ALIFs) are the best example, clinically, of an isolated change in the biomechanical profile because the exposure and procedure generally do not disrupt the anatomy at the adjacent level. Comparatively, open posterior procedures involving instrumentation or decompression expose and occasionally disrupt the adjacent level ligamentous structures, potentially contributing to adjacent level degeneration/disease [5,33]. Therefore, to determine if there is a relationship between the altered biomechanics of fusion and adjacent level degeneration, we begin our discussion with the literature on ALIFs. In a study of patients with normal discograms preoperatively, Wai et al. [34] evaluated patients with an MRI over 20 years after an ALIF. They found that only 6% of patients required surgery at the adjacent level and that there was a similar incidence of adjacent level degeneration compared with other nonadjacent levels (23.1% and 17.9%, respectively). The study concluded that the adjacent level disease was more likely related to the natural history of the disc than the altered adjacent level biomechanics [34]. Conversely, Ishihara et al. [3] found the incidence of adjacent level degeneration after ALIF for isthmic spondylolisthesis to be 52% in the cephalad adjacent level and 70% in the caudal adjacent level. They attributed this high incidence to the change in mobility and disc pressure but were unable to correlate it with clinical symptoms (not adjacent segment disease) [3]. However, there was no preoperative assessment of the adjacent level, a potential confounding variable. Ultimately, the incidence of adjacent level degeneration after ALIF is likely somewhere in the middle of these two studies, but the relative increase specifically secondary to the biomechanical changes remains unknown.

In addition to the altered biomechanical profile because of fusion, disruption of the posterior elements also changes the normal anatomy and can potentially aggravate the adjacent level [33,35]. The difference in adjacent level degeneration/disease between anterior and posterior fusions could provide insight into the importance of preservation of the adjacent level posterior elements; however, there is currently little available literature to support this [33]. Min et al. [33] recently published a study comparing anterior versus posterior interbody fusions for spondylolisthesis and found the incidence of adjacent segment degeneration to be 44% with ALIF and 82.6% with posterior lumbar interbody fusion. In the review by Harrop et al. [11], the incidence of adjacent level degeneration with a posterior procedure was between 8% and 100%, with the incidence of adjacent level disease between 0% and 27.5%. In this particular study, the reported incidence was equally variable among anterior procedures [11]. Every surgeon recognizes the importance of the adjacent level facets with posterior procedures and the posterior elements contribute to postoperative adjacent level degeneration/
disease, but this problem remains multifactorial and difficult to discern.

**Avoidance strategies**

With the recognition of the association between adjacent segment disease and fusion, surgeons and implant manufacturers began developing methods to avoid this complication [36–38]. Attempts at altering the natural history of disc degeneration are still not available clinically but seem very appealing at an adjacent level. If a patient underwent surgery at one level with an early evidence of degeneration at an adjacent level, it would be of great value to have the ability to alter the natural history of the adjacent level at the time of the index procedure.

Although disease-altering technology is not currently available, several implants have been marketed to avoid adjacent level degeneration [39,40]. Total disk replacement (TDR) was founded on the biomechanical profile that fusion causes adjacent segment degeneration [2]. Advocates of TDR support its use based on the equivalent clinical results to ALIF, with the potential to avoid the long-term complication of an adjacent level disease [11,39]. Presently, only 5-year data exist on the randomized controlled trials in the United States. Guyer et al. [39] found there was no significant difference in the adjacent level ROM between the ALIF and TDR groups, which is concerning, considering a major goal of TDR includes avoiding the adverse kinematics on the adjacent level. Furthermore, at the 2-year follow-up, 40% of patients who underwent TDR had 5° or less of motion across the TDR [41], and this may help explain why the adjacent level ROM was not changed. Overall, the rate of adjacent segment disease was found to be higher in the ALIF group (18.3% vs. 5.5%), although the statistical significance of the differences was not reported [39]. The only evidence to support a decreased incidence of adjacent segment disease with TDR is a weak Class 3 evidence, which admittedly does not have matched patient age cohorts [11]. Ultimately, when long-term follow-up is available on the Food and Drug Administration Investigational Device Exemption studies, we may have an answer to whether TDR decreases adjacent level disease.

Similar to TDR, dynamic fixation options have been developed to avoid adjacent level disease, but long-term results are also unavailable. Morishita et al. [42] recently published their results comparing dynamic fixation with circumferential fixation at L4–L5 and found a change in the kinematics and an increased rate of degeneration with rigid fixation. Although they found the results encouraging, the results from other studies have not been as positive. Schaeren et al. [43] found the incidence of adjacent segment degeneration to be 47% at 4 years and Schnake et al. [44] found it to be 29% at 2 years. Again, this likely argues toward a multifactorial process with the biomechanical changes after arthrodesis being only partially contributory.

Another technical strategy for avoiding adjacent segment degeneration is the use of percutaneous posterior instrumentation when indicated to avoid disruption to the posterior adjacent segment anatomy [45,46]. In a study of two-level ALIFs followed by a percutaneous posterior instrumentation, Lee et al. [46] found the incidence of adjacent segment disease to be 33%. An additional study published from the same institution, by Bae et al. [45], found the incidences of adjacent segment degeneration and disease with a one-level fusion using percutaneous posterior fixation to be 10.6% and 1.9%, respectively. Although they admit the improvement seen with anterior instrumentation could be related to the lordosis obtained by the ALIF, they attribute the relatively low incidence of adjacent segment disease to the lack of soft tissue disruption posteriorly [45].

The currently available strategies aimed at avoiding adjacent segment disease focus on two potential causes for the problem: changes in the biomechanical profile of the implanted devices and avoidance of adjacent level soft tissue disruption [39,45,47]. The early results for these approaches, which include the technologies of arthroplasty, dynamic fixation, and percutaneous fixation, in regards to their ability to avoid adjacent segment disease have been mixed [39,46]. Longer-term data are still needed to determine whether these approaches will minimize the incidence of adjacent segment degeneration and disease.

### Cervical spine

**Incidence**

Similar to the lumbar spine, the etiology of adjacent segment disease in the cervical spine is multifactorial in nature, with numerous studies documenting the incidence of adjacent segment disease (Table 2) [2,9,13,48]. As in the lumbar spine, the likely causes of adjacent segment disease include preexisting disease/natural history, increased adjacent segment mobility, and disruption of adjacent segment anatomy [49–53]. In a study published by the senior author, the annual incidence of adjacent segment degeneration after anterior cervical arthrodesis was found to be approximately 3% per year and 25.6% at 10 years [2]. This study included cervical noninstrumented arthrodesis patients who had undergone single and multilevel anterior cervical discectomy and fusions (ACDFs) and corpectomies. Age, segmental motion, and preexisting disease were found to be the risk factors for the development of adjacent segment disease. In contradistinction to the authors’ original hypothesis, the incidence of adjacent segment disease was less in patients with multiple level fusions. This particular finding conflicts with the commonly held belief that adjacent segment disease is related to an increased biomechanical stress at the adjacent level, as it is known that a one-level fusion places less stress on the adjacent level than a two-
<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Design</th>
<th>Study group</th>
<th>Sample size</th>
<th>Follow-up (mo)</th>
<th>Age (y)</th>
<th>Adjacent degeneration</th>
<th>Adjacent disease</th>
<th>Conclusions</th>
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<tr>
<td>Burkus [60]</td>
<td>2010</td>
<td>RCT</td>
<td>ACDF versus Prestige</td>
<td>Prestige, 276; ACDF, 265</td>
<td>60</td>
<td>43</td>
<td>N/A</td>
<td>8% Prestige reoperation</td>
<td>13% ACDF reoperation</td>
</tr>
<tr>
<td>Maldonado et al. [66]</td>
<td>2011</td>
<td>Prospective cohort</td>
<td>ACDF versus T-CDR</td>
<td>190</td>
<td>36</td>
<td>47</td>
<td>10.5% ACDF, 8.8% T-CDR</td>
<td>N/A</td>
<td>No difference in symptomatic ASD in ACDF versus T-CDR</td>
</tr>
<tr>
<td>Matsumoto et al. [48]</td>
<td>2010</td>
<td>Prospective cohort</td>
<td>ACDF versus healthy control</td>
<td>265</td>
<td>120</td>
<td>47 (ACDF)</td>
<td>N/A</td>
<td>Degenerative MRI findings higher in ACDF group. No correlation with symptoms</td>
<td></td>
</tr>
<tr>
<td>Kim et al. [64]</td>
<td>2009</td>
<td>Prospective cohort</td>
<td>ACDF versus Bryan disc</td>
<td>Bryan, 51; ACDF, 54</td>
<td>20</td>
<td>19</td>
<td>Bryan, 43.5; ACDF, 46.4</td>
<td>N/A</td>
<td>Radiographic ASD 3.5 more common with ACDF. Does not correlate clinically</td>
</tr>
<tr>
<td>Garrido et al. [57]</td>
<td>2011</td>
<td>Case control</td>
<td>ACDF versus Bryan disc</td>
<td>Bryan, 21; ACDF, 25</td>
<td>24</td>
<td>48</td>
<td>N/A</td>
<td>2 y—64% (ACDF), 25% (Bryan); 4 y—84% (ACDF), 52% (Bryan)</td>
<td>Significantly higher adjacent segment ossification in ACDF</td>
</tr>
<tr>
<td>Jawahar et al. [65]</td>
<td>2010</td>
<td>Case control</td>
<td>ACDF versus C-TDR</td>
<td>C-TDR, 113; ACDF, 57</td>
<td>38</td>
<td>44.5</td>
<td>16.8% C-TDR, 14% ACDF</td>
<td>16.8% C-TDR, 14% ACDF</td>
<td>No difference in symptomatic ASD</td>
</tr>
<tr>
<td>Song et al. [13]</td>
<td>2011</td>
<td>Case control</td>
<td>ACDF</td>
<td>87</td>
<td>84.8</td>
<td>54.4</td>
<td>16% adjacent level, 5% nonadjacent level</td>
<td>2% adjacent level, 0.7% nonadjacent level</td>
<td>No significant difference in symptoms in adjacent and nonadjacent levels</td>
</tr>
<tr>
<td>Robertson et al. [58]</td>
<td>2005</td>
<td>Case control</td>
<td>ACDF versus Bryan disc</td>
<td>Bryan, 103; ACDF, 202</td>
<td>24</td>
<td>Bryan, 55.9; ACDF, 44.5</td>
<td>13% Bryan, 54% ACDF</td>
<td>4% Bryan, 57% ACDF</td>
<td>Motion preservation decreases ASD &lt;5 mm from plate to disc increases the risk for adjacent ossification</td>
</tr>
<tr>
<td>Park et al. [59]</td>
<td>2005</td>
<td>Case series</td>
<td>ACDF with plate</td>
<td>118</td>
<td>25.7</td>
<td>51.8</td>
<td>59% of cephalad discs, 29% of caudal discs</td>
<td>N/A</td>
<td>Adjacent levels (both cephalad and caudal) most affected by corpectomy</td>
</tr>
<tr>
<td>Kulkarni et al. [4]</td>
<td>2004</td>
<td>Case series</td>
<td>Cervical corpectomy</td>
<td>44</td>
<td>17.5</td>
<td>46</td>
<td>75%</td>
<td>N/A</td>
<td>Adjacent levels (both cephalad and caudal) most affected by corpectomy</td>
</tr>
<tr>
<td>Hillibrand et al. [2]</td>
<td>1999</td>
<td>Case series</td>
<td>ACDF</td>
<td>374</td>
<td>120</td>
<td>51</td>
<td>N/A</td>
<td>14.2% prevalence, 19.2% at 10 y</td>
<td>2.9% per yr, 25.6% at 10 y</td>
</tr>
</tbody>
</table>

RCT, randomized control trial; ACDF, anterior cervical discectomy and fusion; ASD, adjacent segment disease; T-CDR, total cervical disc replacement.
Adjacent segment degeneration—radiographic degeneration; Adjacent segment disease—clinically significant degeneration.
three-level procedure [2,54]. The authors surmised that the preexisting adjacent level disease in the single-level cases contributed to the higher incidence of postoperative disease within this cohort. Overall, the study concluded that the development of symptomatic adjacent pathology is related to the natural history of the disease process and not the surgical technique or operative management [2]. A major drawback of the study and conclusion is that the annual incidence of degeneration in patients treated nonoperatively may have been similar to what was observed in the arthrodesis patients, and unfortunately, there is no nonoperative group for comparison. In 2010, Matsumoto et al. [48] compared ACDF patients to healthy control patients and found that ACDF increased the incidence of adjacent level degeneration on MRI at the 10-year follow-up [48]. The critique of this article is that the two groups do not represent matched cohorts. Patients who undergo ACDF for disc degeneration have already proven their discs are susceptible to degeneration and there are potentially genetic and environmental factors increasing their incidence of disc degeneration. The authors recognized this as a limitation and admit that a study such as this would be difficult given the challenge of appropriately matching the two cohorts [48]. Klippel-Feil syndrome, a genetic disorder that manifests itself in the cervical spine by way of congenital spinal fusions provides an interesting insight into the argument for an altered biomechanical state as the cause of adjacent segment disease. Patients with this condition frequently develop cervical spine symptoms at levels adjacent to their congenital fusions. The degeneration is believed to be a result of a biomechanical change from the congenital fusions that, in turn, causes pathology in other areas of the cervical spine [55,56]. To date, multiple studies have documented the high incidence of adjacent disease in ACDF patients indicating that this patient group, whether from altered biomechanics or natural progression, is at relatively high risk of adjacent segment disease [13,57–59].

In addition to the change in the kinematics seen at the adjacent level, soft tissue disruption is also considered a potential cause of adjacent level disease, although this is much more difficult to experimentally elucidate. In a study evaluating incorrect needle localization intraoperatively (needle placed at an adjacent level that was not included in the fusion), there was a threefold increase in the adjacent level degeneration at almost 2-year follow-up [52]. The authors attributed the increased adjacent segment degeneration to both the dissection over the adjacent level and the puncture of the annulus [52]. Additionally, adjacent level ossification has been associated with plate placement within 5 mm of the adjacent level [59]. The association between adjacent level ossification, degeneration, and ultimately disease has not been proven, but the placement of the plate closer to the adjacent level would potentially disrupt the adjacent level anatomy, such as the anterior longitudinal ligament. Both of these studies highlight the importance of avoiding the soft tissue anatomy at the adjacent level.

The natural history of the cervical disc degeneration and the incidence of symptomatic cervical disease in surgically treated patients vary depending on the study. Clearly, patients who have undergone cervical fusions are at an increased risk of developing adjacent segment disease. What remains unknown is how much of this is related to the surgical procedure and ultimately arthrodesis and how much is related to the natural history of their disease. Currently, the 3% per year rate published by the senior author is the most widely referenced number regarding the development of adjacent segment disease [2]. This commonly referenced incidence rate is in sharp contrast to the rate in the lumbar spine, which has a much greater variability within the literature [11,17].

Avoidance strategies

Cervical disc replacement (CDR) has become increasingly popular and has gained merit over the past 10 years with a primary goal to preserve motion and avoid adjacent segment problems (Fig. 2). Short-term clinical outcomes for CDR have been positive and comparable with ACDF [12,60,61]. Similar to lumbar TDR, the proponents of CDR argue that it avoids the biomechanical changes at the adjacent level seen with arthrodesis [54,57]. In vitro studies have demonstrated a difference in motion at the adjacent level between ACDF and CDR, although clinical studies have been less decisive [49–51,54,62]. Furthermore, there have been no in vitro studies evaluating the adjacent segment across the occipitocervical or atlantoaxial joints. In a study by Dmitriev et al. [62], CDR was found to maintain adjacent level intradiscal pressures at preoperative levels compared with arthrodesis. Subsequent biomechanical studies have shown similar positive results, including Cunningham et al. [54], who demonstrated improved adjacent level biomechanics after one- and two-level CDR in comparison with ACDF. Although there is abundant in vitro biomechanical literature to support the improvement in adjacent level kinematics after CDR, the in vivo data are less uniform. In a recent study by Kelly et al. [51], reviewing 199 patients at 24 months after surgery, it was found that there was no association between the adjacent level ROM and the treatment modality (ACDF vs. CDR). Conversely, Park et al. [63], in a study of 272 disc replacements compared with 182 ACDF patients, found the adjacent level ROM to be increased with ACDF.

Disc replacement’s ability to preserve adjacent level ROM and the biomechanical profile provide encouraging data; however, the most clinically significant studies report follow-up on adjacent level disease. Kim et al. [64] published a study demonstrating an incidence of 17.6% adjacent segment radiographic changes after CDR at only 12 to 40 months postoperatively, which seems alarmingly high except when compared with their ACDF group, which was 40.7%. On the other hand, Jawahar et al. [65] recently demonstrated that the incidence of adjacent segment
degeneration at 37 months was not significantly different after CDR (16%) compared with ACDF (18%). Similarly, the 5-year results of one Food and Drug Administration study published this past year did not show any significant difference (although a small trend) in the rate of adjacent level surgery, 8 of 144 in the CDR group compared with 13 of 127 in the ACDF group [60]. The results of the randomized controlled data provide arguments for and against the use of CDR to prevent adjacent segments disease; however, drawing generalized conclusions from these data should be done so with caution. Patient demographics vary among the studies in terms of age, amount preoperative disease, and function. Additionally, follow-up duration, drop-out rate, and randomization were not the same across the individual studies [51,60,63–65]. Because of these facts, making direct comparison of the individual study results is difficult. Furthermore, in these particular studies [51,60,63–65], ACDF was performed with the addition of an anterior plate. The use of a plate has been independently associated with adjacent segment ossification if placed improperly [59] and, therefore, this may confound the rate of radiographic adjacent segment degeneration in the ACDF cohorts. Ultimately, although these studies do provide the highest level of currently available evidence, conclusive statements about the impact of motion preservation on adjacent segment disease will likely depend on the long-term follow-up data within the individual study groups.

**Conclusion**

The study of adjacent segment degeneration and disease is challenging because patients must be followed for decades to determine whether an intervention made a difference in the final outcome. Given that spine surgery is an ever changing profession, current techniques and implants are not the same as they were 10 years ago and they will be different when we assess our current patients 10 years from now. With rapidly evolving technology, studying adjacent segment disease becomes more difficult. However, if we focus on the known causes of the problem, our avoidance strategies can be adjusted accordingly.
Presently, the incidence, etiology, and the approach to avoid adjacent segment disease appear to be more homogenous in the cervical spine [2,11]. Reports on the incidence of lumbar spine adjacent segment degeneration are widespread and related to the variety of techniques that address lumbar spine pathology. Similarly, attempts at avoiding lumbar adjacent segment disease have included arthroplasty, dynamic fixation, and percutaneous instrumentation [39,42,45], whereas in the cervical spine the focus has remained with arthroplasty [48,60,66]. In the future, long-term results will be required to justify continued utilization.

References


