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Review article

Degenerative disease supra- and infra-jacent to fused lumbar and lumbo-sacral levels

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ABSTRACT

Disc degeneration is a normal age-related process. Accelerated degeneration of discs adjacent to fused spinal levels has been observed in numerous case-series studies. The available data document this phenomenon and provide information on its time to occurrence but show huge variations in incidence rates (5% to 70%). The supra-jacent disc is involved more often than the infra-jacent disc. Studies have clarified the underlying biomechanical rationale by showing increased loading of the adjacent discs. Risk factors have been the focus of the most recent studies. They include the number of fused levels, sagittal alignment, level of fusion, stiffness of the construct, and integrity of the posterior structures. Nevertheless, the many published studies have produced somewhat conflicting results. Various radiological criteria have been used to define degeneration of the adjacent disc. Although most patients have no symptoms, adverse effects on the spine and/or nerve roots may occur and, in some cases, require revision surgery. We draw attention to the many sources of bias in the published studies, of which we provide a critical and pragmatic discussion in the light of our personal experience.

1. Introduction

Disc degeneration results in loss of the mechanical and biological properties of the inter-vertebral disc. Age-related disc degeneration is normal. However, disc degeneration is abnormal when it occurs prematurely. The disc may be affected either directly, by an infection or injury, or indirectly, by a mechanical process related to environmental factors that impair disc function. This last mechanism explains the disc disease that occurs adjacent to a fused intervertebral level or segment, known as adjacent segment degeneration (ASD). The relationships between the disc and the facet joints explain that the degenerative process affects the entire mobile segment of the spine and not only the disk. Involvement of the disc is the most obvious and the best-documented abnormality. However, involvement of the facet joints (hypertrophy/stenosis) can cause concomitant clinical neurological manifestations.

That disc degeneration is multifactorial and has been firmly established. Whether disc degeneration can occur specifically as a result of intervertebral fusion was controversial initially, as shown by studies published in the 1980s. However, the association between fusion and disc degeneration was widely reported and discussed as early as the 1990s [1]. Subsequently, this association was established by well-designed controlled studies providing a high level of evidence [2–4].

An overall view of spinal anatomy and geometry is needed to understand the accelerated degenerative process. The spine can be seen as a composite semi-rigid system composed of a continuous alternation of stiff structures – the vertebrae – and of yielding structures – the intervertebral discs. The surgical fusion of two or more consecutive vertebrae disrupts this regular alternation. It makes intuitive sense that induced rigidity of a spinal segment modifies spinal kinematics (and in some cases overall alignment) and significantly affects load distribution. This overall biomechanical view should not eclipse the biological factors involved in ASD; nevertheless, various mechanical parameters related to the patient and surgical technique can explain the severity, rapidity, and type of the degenerative process. Thus, relevant factors may include body weight; physical activity; number of fused vertebrae; fixed curvature angle created by the instrumentation; site of the fusion and, more specifically, inclusion of the lumbo-sacral and thoraco-lumbar junctions into the fused segment; gender; age at fusion; and time since fusion.

ASD is a topical issue, given the increased use and sophistication of inter-vertebral fusion, combined with the substantial number of patients having had spinal fusion in the past. The follow-up of these patients will become a public health issue. ASD may develop in the

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short or medium term, raising questions about spinal fusion techniques and adjustments (lordosis; length; rigid or flexible; anterior, posterior, or circumferential fusion).

ASD cannot fairly be described as an iatrogenic event. Instead, ASD is an expected remote consequence of a necessary surgical procedure done to treat an abnormality whose natural course without surgery would result in worse outcomes. Indeed, with or without surgery, any type of disc dysfunction eventually has adverse effects on the adjacent discs [5].

In addition, not all disc changes constitute disc disease. Although, the disc classified as normal can be contrasted to the degenerative disc, whether 'normal' should be equated to 'ideal' is open to question. We believe the 'normal for age' concept is useful when describing discs.

In this work, we review and update the issues raised by ASD, based on a critical interpretation of published data.

2. Epidemiology

2.1. *Prevalence of adjacent segment degeneration (ASD)*

Methodological differences have led to considerable variability in the results of epidemiological studies (Table 1). Limitations to meta-analyses include variability in the diagnostic criteria, heterogeneity in patient populations and aetiologies, and differences in follow-up duration [33]. Survival analyses may be more relevant, as they consider exposure duration. In a study by Ha et al. [12], Kaplan-Meier survival without ASD was 72% after 1 year, 63% after 2 years, and 52% after 4 years in patients who had spinal fusion for degenerative lumbar scoliosis.

2.2. *Does adjacent segment degeneration (ASD) predominantly affect the supra- or infra-jacent disc?*

In case-series studies that provide detailed information on the fused levels, the supra-jacent disc was predominantly involved. Cheh et al. [26] reported that the supra-jacent disc was affected in 88.8% of cases, the infra-jacent disc in 7.5%, and both in 3.7%. The study of 67 patients reported by Park et al. [17] is of particular interest, as all the fusions (whether involving one, two, or three levels) ended at L5. ASD occurred in the supra-jacent disc in 34% of patients, infra-jacent disc in 19%, and both in 6%. In a cohort of 3188 patients with a 10-year follow-up studied by Ahn et al. [34], among patients with ASD the supra-jacent disc was affected in 79.5% of cases, the infra-jacent disc in 18.8%, and both in 1.8%.

3. Pathophysiology

In vitro studies and numerical simulations consistently showed increased pressure within the adjacent disc(s) after lumbar segmental fusion [35–39]. Kim et al. [38] and Chen et al. [40] found larger pressure increases in the supra-jacent than in the infra-jacent disc, in keeping with the results of clinical studies.

Biomechanical studies can be designed to test a number of hypotheses. Senteler et al. [41] recently reported increased shear forces in the supra-jacent disc, with a specific effect of sagittal spine-pelvis alignment: the increase in shear force was greater when the difference between pelvic incidence and lumbar lordosis exceeded 15°. Akamaru et al. [42] found a similar influence of sagittal malalignment, with increased mobility at the supra-jacent disc after hypolordotic segmental fixation.

Other technical factors may influence the loads applied to the adjacent discs. Chosa et al. [43] and Goto et al. [44] reported that loads through the adjacent discs were increased 2-fold after interbody fusion compared to postero-lateral fusion (flexion/extension).

Recent studies consisted in numerical simulations of the effects of posterior implants made of polyetheretherketone (PEEK) versus titanium, with the goal of developing fixation devices characterised by a modulus of elasticity similar to that of bone [37,45].

Finally, Kim et al. [46] reported an influence of decompression with total facetectomy.

Clinical case-series studies have identified several risk factors. Most studies suggest that a larger number of fused levels increase the risk of ASD [21,28]. Yang et al. [9] found a higher proportion of patients with more than two grades of degeneration progression on the UCLA scale in adjacent discs after fusion of two or three levels compared to a single level. Liao et al. [47] studied patients with spinal fusion ending at L5. UCLA grade progression at L5-S1 was significantly greater after fusion of three or more levels than after fusion of one or two levels. Park et al. [17] reported similar findings.

In contrast, in a population of patients with degenerative lumbar scoliosis, Ha et al. [12] found no difference in survival without ASD between patients with fusion of three or more levels and those with fusion of one or two levels. Soh et al. [20] obtained similar findings in a study of patients with fusion of one to three levels.

That greater fused segment length is associated with higher loads through the discs at either end makes sense, since motion must be handled by a smaller number of free intervertebral levels. Nevertheless, the heterogeneity of published data supports a role for other factors, such as the fused level and sagittal alignment.

When extensive fusion is performed, inclusion of the junctions, i.e., L5-S1 and the thoraco-lumbar junction, may exert specific effects. Sears et al. [48] observed an increase in the risk of ASD with the number of fused levels. The risk was higher after fusion stopping at L5 (i.e., shorter fusion leaving L5-S1 intact), whereas stopping at L4 had no influence.

Cheh et al. [26] also found that the risk increased with the number of fused levels, as well as with fusion extending proximally to L1-L3, compared to L4 or L5. In contrast, fusion extending up to the lower thoracic levels (i.e., more extensive) was associated with a lower risk of ASD.

Despite the scarcity of supporting evidence, a combined influence of fusion length and sagittal alignment makes sense, as decreased tolerance of sagittal alignment would be expected after extensive fusion. In a study of 120 patients managed with circumferential fusion for spondylolisthesis then evaluated after a mean follow-up of 3 years, Wimmer et al. [49] found that anterior-posterior translation of the supra-jacent disc was more common after fusion of several levels than after fusion of a single level. The decision to fuse several levels was based on pre-oeprative discography of the adjacent levels. Unfortunately, sagittal alignment parameters were not described in detail (the report specifies only that slippage correction was partial in 50% of cases).

Intuitively, one would expect persistent sagittal malalignment to have deleterious effects. As indicated above, biomechanical studies showed that hypolordotic fusion increased the risk of ASD. Several studies evaluated sagittal alignment based on radiological data at last follow-up in patients with confirmed ASD.

Radiographs at last follow-up after fusion of a single level (L4-L5) compared by univariate analysis showed no difference in segmental or lumbar lordosis between patients with and without ASD in studies by Min et al. [11] and Chen et al. [8].

In contrast, using logistic regression, Bae et al. [16] found that segmental and lumbar lordosis correlated significantly with ASD.

Nevertheless, the curvatures on the immediate post-operative radiographs may be more relevant.

In patients with long fused segments, Kumar et al. [18] observed a lower frequency of ASD at last follow-up when the C7 plumb line was within 2.5 cm of the posterior-superior angle of S1 and sacral inclination was greater than 40° than when the C7 plumb line was abnormal and/or the sacrum was vertical.