**Disc Degeneration in Unfused Caudal Motion Segments Ten Years Following Surgery for Adolescent Idiopathic Scoliosis**

Baron S. Lonner MD, Yuan Ren PhD, Michelle M. Marks MA, Peter O. Newton MD, Randal R. Betz MD, Amer F. Samdani MD, Karen Chen, Harry Shufflebarger, Suken A. Shah, Daniel R. Lefton MD, Hussein Nasser MD, Colin T. Dabrowski BS

**Introduction**

Adolescent idiopathic scoliosis (AIS) is a lateral curvature of the spine occurring in 2-3% of the adolescent population1,2. Surgical correction of AIS is indicated for large and progressive curvatures. The standard operative procedure is a spinal arthrodesis either from a posterior, anterior, or combined approach and has been for nearly a century3-11.

The drawbacks of spinal fusion include loss of mobility and loss of growth within instrumented spinal segments, and the potential for degenerative disc disease and back pain caudal to the fusion. Factors previously associated with disc degeneration include a distal lumbar lowest instrumented vertebrae (LIV) as well as poor maintenance of sagittal alignment12-19. The assessment of caudal disc degeneration has required the utilization of magnetic resonance imaging to visualize the unfused motion segments20-22. The limitations of that methodology are the lack of routine preoperative MRI to serve as a pre-operative baseline of intervertebral disc health as well as the expense and impracticality of obtaining routine postoperative MRI studies in asymptomatic individuals. Therefore, the cohorts that have been studied have been relatively limited in size and/or are not current19-22.

Durability of surgical outcomes is essential for maintenance of quality of life as well as for family decision-making and for assessment of the value of an operative intervention from a medico-economic viewpoint. This is certainly the case for AIS in which otherwise healthy and relatively asymptomatic individuals are being offered largely prophylactic operations to ward off or delay the sequelae of untreated scoliosis. The health of remaining distal motion segments is one factor associated with the survivorship of the spinal arthrodesis associated with surgical correction. Therefore, we set out to study the incidence of disc degeneration in the caudal unfused segments below an arthrodesis in a large cohort of AIS patients with minimum 10-year follow-up following surgery using radiographic markers of disc degeneration (RMDD), a methodology that has not previously been utilized in this population. A related methodology was used to create a scoring system of disc degeneration in a cadaveric study by Benneker et al23. We hypothesized that the incidence of RMDD would increase over time, with increasing length of the fusion, distal LIV, and would vary by approach and anchor type. We also surmised that health-related quality of life outcomes as assessed by the SRS-22 would be negatively impacted by more severe disc degeneration caudal to the fusion.

**Materials and Methods**

Query of a multicenter AIS database registry of operatively managed patients who were prospectively enrolled was conducted. This registry was established in 1995 with over 4768 operative patients currently enrolled in the database. There are 15 participating sites (12 in the United States, 2 in Canada and 1 in the United Kingdom). Inclusion criteria for this study were AIS patients who underwent corrective surgery with a minimum of 10-year follow-up. Institutional Review Board approval was obtained for this study from all participating sites.

Demographic, clinical and radiographic data collected included age at surgery, gender, height, weight, major cobb angle and Lenke curve type. Operative parameters assessed included operative approach, total operative time, and level of lowest (LIV) instrumented vertebra and number of levels fused. SRS-22r quality of life (QOL) outcome scores were also evaluated. Radiographic images from all study sites were submitted to one centralized location where standard radiographic parameters were measured by a single experienced trained investigator using SpineView software version 2.4.

Five radiographic indicators of disc degeneration including osteophytes, schmorl’s nodes, intradiscal calcification, sclerosis and irregular endplate shape were evaluated and scored by a single independent radiologist, using a modification of a composite radiographic score described by Benneker at al. in which disc height was also considered23. This parameter was left out of our modified score due to the fact that disc wedging is expected with residual scoliosis and would likely confound our results. A composite radiographic score (CRS) was calculated using the sum of each of the disc degeneration indicators which is listed in Table 1. Evaluation was performed pre-operatively and at first erect examination between 4-6 weeks, 2, 5 and 10 years on PA and LAT X-rays. The final CRS was defined as the maximum score among the free segments caudal to LIV on either PA or lateral x-ray at each time point. The severity of CRS in relation to time point after surgery and various potential risk factors, including number of levels fused, LIV, LIV translation, residual lumbar curvature, wedging of the subjacent disc below the LIV, construct type and surgical approach were assessed using linear regression or Pearson’s Chi-2 test. A sub-group assessment was performed in Lenke 1c and 3c curves which were fused cephalad to L1 in the thoracic region to evaluate RMDD following selective thoracic fusion. Results from this sub-analysis were excluded from the main findings due to a limited sample size of 10 patients. CRS≥ 3 was chosen to indicate significant disc degeneration. Association of CRS with SRS-22 outcome was evaluated by linear regression. Statistical Package for the Social Sciences (SPSS) version 19.0 (IBM, Armonk, New York) was used for statistical analysis. *P* value *<* 0.05 was considered significant.

**Results:**

One hundred and ninety-three consecutive patients (86% females) with a mean age of 14.4 years at surgery were assessed. Of the 4768 patients in the registry, 1700 reached the ten-year postoperative time-point at the time of data collection; therefore, 11.4% follow-up of eligible are represented in this study. Age, gender, pre-operative radiographic measurements and operative parameters were similar between the studied group and the eligible patients who did not return for their 10-year follow-up. Surgical approach included 89 (46.1%) posterior fusion, 91 (47.2%) anterior fusions and 13 (6.7%) posterior fusion with anterior release. The mean number of levels fused was 7.9±2.8 levels. The main Cobb magnitude was corrected from 51.0±11.3° and maintained at 22.0±8.8° at 10 years post-operatively (Table 2).

Changes in CRS severity over the 10 years of follow-up are illustrated in Figure 1. CRS≥3 occurred in 1.6%, 0.54%, 3.7%, 6.8% and 7.3% of patients at the various time points, respectively. There was a significant trend toward an increase in CRS≥3 incidence for the study period (*r*2=0.83, *p*=0.0313). 74.6% of patients had a CRS of 0 pre-operatively and this dropped to 43.0% at 10 years. Contributors to maximum CRS at 10 years were Schmorl's nodes (7.3% of patients), osteophytes (40.4%), sclerosis (29%), and irregular endplate (8.3%) (Table 3).

The incidence of significant DD in relation to distance from the LIV is shown in Figure 2. Among patients who developed significant DD, 50% occurred at the 2nd disc caudal to the LIV (p=0.0030). No significant DD was observed beyond 5 discs caudal to the LIV. LIV of L4 compared to more cephalad LIV had the highest risk of developing significant DD (27.3%; *p*=0.0267) (Figure 3). Severity of DD was not associated with number of levels fused (*p*=0.2131). Surgical approach was not found to be a risk factor of developing severe disc degeneration (p=0.8245). Severe disc degeneration was developed in 2 of 14 patients (14.3%) with hook anchors at the LIV comparing with 12 of 179 (6.7%) with screw anchors, however this difference was not statistically significant (p=0.2922). Disc angulation below the LIV (p=0.8446; p=0.1080), LIV translation (p=0.3962; p= 0.1628) and residual lumbar curve (p=0.4290; p= 0.5720) at first erect and 2-year post-operation were not associated with developing DD. No significant association between 10-year CRS and SRS-22 domain and total scores was found.

**Discussion**

Intermediate and long-term outcome studies following operative treatment of AIS are essential to inform surgeon counseling and patient decision-making, to determine the value and durability of a largely prophylactic surgery, and to provide a milieu for the exploration of alternative surgical techniques such as non-fusion scoliosis correction24-28. We performed an analysis of disc degeneration (DD) caudal to the fusion in a large cohort of AIS patients ten years following surgery. This is the largest long-term follow-up study of its kind assessing contemporary surgical technique. One hundred ninety-three patients met the inclusion criteria and were assessed with a novel methodology of DD assessment. This, we believe, will serve as a benchmark for longer term follow-up of patients treated with current techniques.

We found significant DD occurring in 7.3% of our cohort. This occurred two discs caudal to the LIV in 50% of the cohort and was most common in patients with LIV of L4. We chose a composite score of ≥3 as indicating significant DD which we believe provides a relatively low threshold for determining radiographic significance so as not to underestimate this problem, especially given the lack of MRI corroboration. 40% of our cohort had no RMDD and most of the subjects had only mild RMDD. Fortunately, significant DD was not found to cause any significant impact on SRS outcomes. We did not find any correlation of residual lumbar curvature, LIV translation, and subjacent disc wedging with RMDD.

A number of prior studies provide context for our findings. Cochran and Nachemson reported on 95 patients following Harrington rod instrumentation operated from 1968 until 1975 with minimum 5 years and just under 10 years mean follow-up. Increased DD was associated with fusion to L4 or L5 and back pain also correlated with these distal fusion levels. There was no loss of function in the cohort overall compared to 85 normal controls12. In 2003, Danielsson and Nachemson published two papers on long-term outcomes following brace and surgical treatment of AIS. In the former paper, 127 brace-treated patients with mean 22 years follow-up had a residual curvature of 30 degrees. “Obvious disc degeneration” was noted in nearly 16% of patients versus none in non-scoliotic healthy controls29. In the operative cohort of 139 patients with minimum 20-year (mean 23 years) follow-up, treated with Harrington instrumentation, moderate to severe DD was reported on radiographic assessment in 45.5% of patients fused to L5 versus 16.4% fused to L4 or more cephalad. Back pain within the past one year was experienced in 77% of operative patients versus 58% of controls. 28% of patients fused to L4 or L5 had a slight decrease in back function compared to controls13. Green et al. reported on 20 patients with mean follow-up of 11.8 years, utilizing MRI assessment both pre- and post-operatively. New disc pathology was noted in 85% of subjects in unfused caudal segments with three individuals having evidence of severe DD. Only one patient had a degenerative disc adjacent to the fusion, the majority of DD occurred at L5/S1. Outcome scores were not affected by the DD in this cohort19. Larson et al. reported a mean 20 years (range 14-24 years) follow-up comparing selective thoracic fusions (STF) in 19 subjects to long fusions (LF) in 9 patients with Lenke 1c and 3C curves treated with all-hook constructs. STF patients had stable residual lumbar curves and L4 obliquity as well as global alignment parameters and there were no significant differences in outcomes except for higher SRS outcomes scores for LF in self-image and function domains30. In the Larson study, radiographic DD was scored with a non-validated measure and this included only the disc immediately caudal to the LIV. No differences were noted between the two groups. There are two widely quoted natural history studies by Weinstein, et al. involving untreated AIS patients out to 40 and 50 years, follow-up, respectively. In the first study, radiographic factors associated with curve progression and rates of curve progression into adulthood were described. RMDD was not evaluated.32  In the follow-up study, chronic back pain was reported in 61% of untreated patients with scoliosis versus 35% in normal controls. Eighty-seven percent of the scoliotic individuals were noted to have lumbar osteoarthritis, but there was no grading system used nor any description of how this was determined.33 Again, these landmark studies did not involve operatively treated individuals.

Our study differs from the above seminal long-term outcomes studies in a number of ways. Our 10-year follow-up involves patients treated with contemporary techniques with the majority (~93%) having distal pedicle screw anchors compared to predominantly segmental or Harrington hook constructs in the other studies. Furthermore, our subject numbers are substantially larger than what has been reported by the other investigators with operative cohorts ranging from 20 to 139 subjects12,13,29,30. We studied 193 patients. Furthermore, aside from the study by Green et al, in which preoperative and postoperative MRI was evaluated in 20 patients, the other studies relied on coarse assessment of DD on radiographs without a formal scoring system in addition to pain and functional outcomes questionnaires30. For example, in the Cochran study, disc spaces below the fusion were assessed for decreased disc space height, osteophytes, retrolisthesis, and facet arthropathy but no quantification of these findings was provided. The intervertebral discs in the remaining motion segments were noted to have a binary data point of clear disc degeneration or not12. In the Danielsson study, a minimum of 25% loss of disc height of the observed level was considered to indicate significant DD but there was no mention of how this was assessed nor was grading of the DD performed13,29. We have created a new DD grading system for the scoliotic spine based on a modification of a prior grading system that was validated with MRI and biochemical analysis in a cadaver study23. We modified this scoring system, removing disc space height as a parameter, due to the confounding factor of disc wedging as a result of scoliosis that would confuse the grading, potentially. We intend on doing a formal validation of this modified methodology with MRI imaging in the future in other accessible pediatric and adult cohorts in which the imaging is available.

A number of limitations to our study are acknowledged and may serve as a basis for future study and improvements in methodology. Our methodology for radiographic scoring of DD, although based on a previously validated methodology, should be further validated through correlation with MRI grading of DD in a scoliotic cohort. Furthermore, DD is only one component of the degenerative spinal cascade. We do not include assessment of facet arthropathy in our grading which would be difficult to do with radiographic imaging alone. Additionally, 10 years is a relatively short span of time in the operated adolescent. We intend on following these patients out to 20-years follow-up and beyond and to increasing the percentage of eligible patients out of the total operative cohort, to be assessed at a minimum of ten years. Although only 11% of eligible patients had the complete follow-up, demographic, radiographic, and operative parameters were similar between those who were included in this study and those who did not have a ten-year visit. We believe future investigations will be enhanced by obtaining a non-scoliotic control group for comparison of RMDD and quality of life outcomes. Finally, we have not taken into account, local and regional sagittal parameters including instrumented segment lumbar lordosis and relation to pelvic incidence and the impact of same on radiographic DD.

In this largest study of its kind in which contemporary surgical techniques for scoliosis correction were assessed at 10 years postoperatively using a novel radiographic scoring system of DD in unfused caudal motion segments, we have found an overall rate of significant DD of 7.3%. The greatest risk of DD occurs when fusions are extended to the L4 level and DD is most commonly found two levels caudal to the LIV. Finally, we believe the radiographic scoring system described and utilized for the first time in a scoliosis cohort can be applied to assess innovative corrective strategies such as fusionless tethering which holds the potential for less distal DD below the corrected spinal segments. Patients can be informed that the risk of significant DD below a fusion for AIS is minimal at 10 years following surgery and that limiting the distal extent of fusion is a valuable pursuit, even if residual lumbar curvature remains. Longer term follow-up will provide additional information that will inform families facing surgical decisions and will provide a basis for comparison of prophylactic surgery for asymptomatic adolescents versus delaying surgery until symptoms develop in the adult31.

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Table 1. radiographic indicators of disc degeneration used to calculate the composite radiographic score (CRS).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Score** | **Osteophytes** | **Schmorl's Nodes** | **Intradiscal Calcifications** | **Sclerosis** | **Endplate Shape** |
| **0** | Margins rounded | Not Present | No calcification | None | Continuous |
| **1** | Margins Pointed | Present | Rim calcification | Moderate | Irregular |
| **2** | <2mm | -- | Intranuclear calcification | Severe | Disrupted |
| **3** | >2mm | -- | -- | -- | -- |

Table 2. Demographics and surgical data.

|  |  |
| --- | --- |
| n  | 193 |
| male | 27 (13.99%) |
| female | 166 (86.01% |
| Age (years) | 14.44±2.01 |
| Main Cobb (°) |  |
| Pre-op | 51.0±11.3 |
| 2-year PO | 21.4±9.0 |
| 5-year PO | 21.2±9.3 |
| 10-year PO | 22.0±8.8 |
| # Levels Fused | 7.92±2.75 |
| Lenke 1 (n=101) | 7.87±2.06 |
| Lenke 2 (n=38) | 9.16±2.24 |
| Lenke 3 (n=4) | 9.75±1.71 |
| Lenke 4 (n=3) | 13.33±0.58 |
| Lenke 5 (n=38) | 5.47±2.81 |
| Lenke 6 (n=9) | 11.00±2.87 |
| Surgical Approach |  |
| PSF | 89 (46.11%) |
| ASF | 91 (47.15%) |
| PSF+AR | 13 (6.74%) |
| Implant Construct at the LIV |  |
| Hook | 14 (7.25%) |
| Screw | 179 (92.75%) |
| patients fused to LIV (n; %) |  |
| T8 | 1 (0.52%) |
| T9 | 1 (0.52%) |
| T10 | 1 (0.52%) |
| T11 | 22 (11.40%) |
| T12 | 55 (28.50%) |
| L1 | 27 (13.99%) |
| L2 | 23 (11.92%) |
| L3 | 51 (26.42%) |
| L4 | 11 (5.70%) |
| L5 | 1 (0.52%) |

Table 3. Contributors to the CRS at 10-year post-surgery.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Category | #patients  | % |
| Osteophytes | All | 78 | **40.41** |
|  | 1 (Pointed) | 59 | 30.57 |
|  | 2 (< 2mm) | 11 | 5.70 |
|  | 3 (> 2mm) | 8 | 4.15 |
| Schmorl's Nodes |  | 14 | **7.25** |
| Intradiscal Calcification | All | 3 | **1.55** |
|  | 1 (Rim) | 0 | 0.00 |
|  | 2 (Intranuclear) | 3 | 1.55 |
| Sclerosis | All | 56 | **29.02** |
|  | 1 (Moderate) | 53 | 27.46 |
|  | 2 (Severe) | 3 | 1.55 |
| Endplate Shape | All | 16 | **8.29** |
|  | 1 (Irregular) | 16 | 8.29 |
|  | 2 (Disrupted) | 0 | 0.00 |

Figure 1. Frequencies of the maximum composite radiographic scores (CRS) at pre-op, 1month, 2, 5, and 10 years of follow-up. (p-values indicate the score change over 10 years)



Figure 2. Incidence of significant disc degeneration (CRS≥3) in relation to distance from the lower instrumented vertebra (LIV).



Figure 3. Incidence of significant disc degeneration (CRS≥3) by lower instrumented vertebra (LIV).

