The Role of Intraoperative Fluoroscopy in Assessing Lowest Instrumented Vertebra Selection in Lenke 1A Adolescent Idiopathic Scoliosis

Abstract

Objective: To evaluate the use of intraoperative fluoroscopic imaging (II) in the selection of the Lowest Instrumented Vertebra (LIV) in corrective surgery for Adolescent Idiopathic Scoliosis (AIS).

Design: Retrospective radiographic cohort study of thirty-one patients with AIS who underwent corrective spinal fusion surgery in a single tertiary centre. Patients had Lenke 1A thoracic curves with fractional lumbar curves. Radiographic measurements including thoracic and lumbar Cobb angles and the coronal disc angle below the LIV (LIV+1) were measured on pre-operative standing radiographs, bending radiographs, CT, intraoperative fluoroscopy (after screw insertion before rod insertion), and postoperative radiographs.

Results: Mean lumbar Cobb angle decreased from 37.1° pre-operatively to 14.8° at latest follow-up ($p<0.001$). Mean correction 62.4%. Mean LIV+1 disc angle decreased from 8.48° on standing radiographs to 1.87° intraoperatively and 1.35° at most recent follow-up. Intraoperative measurements were significantly smaller than all pre-operative modalities ($p<0.001$) and closely matched postoperative values. No significant change was evident from early to most recent follow-up.

Conclusions: Intraoperative imaging may provide valuable visualisation of distal coronal balance during LIV selection in Lenke 1A AIS.

Introduction

Adolescent Idiopathic Scoliosis (AIS) is a musculoskeletal disorder that emerges between the ages of 10-16. It is a 3-Dimensional spinal deformity comprised of lateral curvature, vertebral rotation and kyphotic changes. (1) Severe cases (with a Cobb angle typically > 50°) often require surgical correction to prevent curve progression.

Posterior instrumented fusion remains the preferred surgical technique for many patients with AIS. The primary goals are to correct the deformity across the 3 planes, achieving as balanced a correction as possible. Consequences of poor coronal balance include truncal shift, increased risk of adding-on and the need for revision surgery.

Planning for surgical correction involves deciding how far to fuse the spine. The most distal vertebra fused to is known as the Lowest Instrumented Vertebra (LIV). Selection of the LIV is a debated topic, as fusion of a more proximal vertebra preserves lumbar motion segments. However, fusing too proximally carries the risk of curve progression in the unfused segments (2). Modern techniques are moving away from maximum fusion towards the minimum fusion required for stability, as a more distal fusion reduces lumbar flexibility and increases the risk of compensatory hypermobility and degeneration below the fusion (2).

LIV selection has traditionally been decided through the use of standing and bending X-ray films, and radiographic landmarks. Historically, the Stable Vertebra, the vertebra most closely bisected by the central sacral vertical line (CSVL), was chosen. This evolved to the Last Touched Vertebra (LTV), the most proximal vertebra touched by the central sacral vertical line. A more modern version of the LTV is the Last Substantially Touched Vertebra, the most proximal vertebra that the CSVL bisects fully, not just touches (2).

Bending X-ray films demonstrate lumbar curve flexibility, how much the curve can correct. A more flexible curve will show a greater reduction in Cobb angle and can be considered a non-structural curve. This suggests these vertebrae do not need to be included in the fusion. The efficacy of these images is highly dependent on patient effort and technique. They show the spine in a loaded position with potential for muscle guarding, shoulder tilt and rotation of the spine. This results in poor reproducibility and can over- or underestimate flexibility of the curve. Consequently, LIV selection may be inappropriate. There is existing evidence in the role of unloaded imaging in selection of the LIV. Fulcrum Bending films involve lying a patient on their side over a padded support, using passive correction of their curve to provide a better objective assessment of flexibility not dependent on patient effort. One study found them to provide the best prediction of postoperative correction in moderate thoracic curves (40-65°) (3).

Traction Under General Anaesthesia (TUGA) is a radiographic technique whereby the patient is anaesthetised and lies prone whilst longitudinal force is applied to the head and legs. This limits the influence of both gravity and muscle guarding on curve flexibility. Several studies have found TUGA to be the best predictor of surgical

correction, especially in large thoracic curves (2). Existing literature suggests the progression of imaging accuracy is standing X-ray to side-bending, fulcrum bending and then TUGA. Each modality removes a further factor that can distract the curve from its true flexibility.

Whilst these techniques are well discussed there is still limited evidence for the use of intraoperative imaging during corrective spinal fusion. For assessment of the LIV intraoperatively, the operating surgeon looks at vertebral tilt and evaluates the potential for this to level. This is then confirmed on intraoperative imaging. This study aimed to determine whether intraoperative fluoroscopic assessment of the LIV+1 disc angle more closely reflects the final postoperative alignment compared to bending X-ray films and CT. This may provide useful information to support intraoperative decision making regarding LIV selection.

Methods

Study Design: A retrospective radiographic cohort study was conducted at a single tertiary centre.

Data Collection: A database of AIS patients with Lenke 1A curves who underwent corrective posterior spinal fusion surgery between January 2023 and May 2025 at the Children's Hospital for Wales was identified. Patients with neuromuscular and congenital scoliosis were excluded. Patients were included if they had complete pre-operative standing and side-bending radiographs, pre-operative CT, intraoperative fluoroscopic imaging, and postoperative radiographs for analysis. Intraoperative imaging was taken after screw placement prior to rod insertion.

Synapse 5 radiology software was used to measure:

1. Pre- operative standing (thoracic and lumbar) Cobb angle
2. Pre-operative left bending (thoracic and lumbar) Cobb angle
3. Pre-operative CT (thoracic and lumbar) Cobb angle
4. Levels fused and the LIV selected was identified on postoperative X-Ray
5. Intervertebral angle at LIV+1 in each of the images above, on intraoperative imaging and postoperative imaging.
6. Postoperative residual thoracic and lumbar curves on initial and most recent postoperative X-ray.

Statistical Analysis: Statistical analyses were performed using IBM SPSS Statistics. Continuous variables are presented as mean ± standard deviation (SD), whilst categorical variables are presented as frequencies and percentages.

Radiographic measurements obtained from standing radiographs, side-bending radiographs, CT, intraoperative fluoroscopy, and postoperative radiographs were compared using paired statistical tests. LIV selection was determined pre-operatively by the operating surgeon according to standard clinical practice and was not altered based on the measurements analysed in this study. Differences in LIV+1 disc angle

across the six imaging modalities were assessed using the Friedman test. Pairwise comparisons between imaging modalities were performed using Wilcoxon signed-rank tests. No adjustment for multiple comparisons was applied. Lumbar Cobb angle measurements before and after surgery were compared using paired Student's t-test.

Spearman's rank correlation coefficient was used to assess associations between pre-operative radiographic measurements and postoperative measurements. Correlation analyses were used to evaluate relationships between intraoperative LIV+1 disc angle measurements and postoperative outcomes, such as residual lumbar curve magnitude. Mann-Whitney U test was also used as part of threshold analyses to determine whether intraoperative LIV+1 disc angle (threshold of 2°) was associated with postoperative radiographic outcomes. Patients were split into groups; intraoperative LIV+1 disc angle ≤2° (n = 23) and >2° (n = 8).

All statistical tests were two-tailed, and statistical significance was defined as $p < 0.05$.

Outcomes: Primary outcome was the LIV+1 disc angle measured on intraoperative fluoroscopy and postoperative X-ray. Secondary outcomes included the residual lumbar Cobb angle, percentage lumbar curve correction and associations between intraoperative LIV+1 disc angle and postoperative radiographic outcomes.

Results

31 patients (28 female, 3 male) with right-sided Lenke 1A AIS who underwent posterior spinal fusion were included. Mean age at surgery was 14 years. Mean Cobb angle measurements of the thoracic and lumbar curves are shown for all imaging modalities in Table 1. LIV selected was most commonly L3 or L4 (35.5% and 29.0% respectively). Mean follow-up duration was 16 ± 7.4 months. One patient required removal of metalwork and revision surgery due to infection.

Table 1. Mean pre-operative Cobb angle across different imaging modalities (n=31)

Measurement	**Mean (°) (95% CI)**
Pre-operative plain film thoracic Cobb angle	71.6 (66.2 – 77.0)
Pre-operative plain film lumbar Cobb angle	37.1 (31.9 – 42.2)
Pre-operative left bending film thoracic Cobb angle	78.8 (73.0 – 84.7)
Pre-operative left bending film lumbar Cobb angle	25.9 (20.4 – 31.4)
Pre-operative CT thoracic Cobb angle	62.7 (56.2 – 67.8)
Pre-operative CT lumbar Cobb angle	31.4 (26.6 – 36.2)

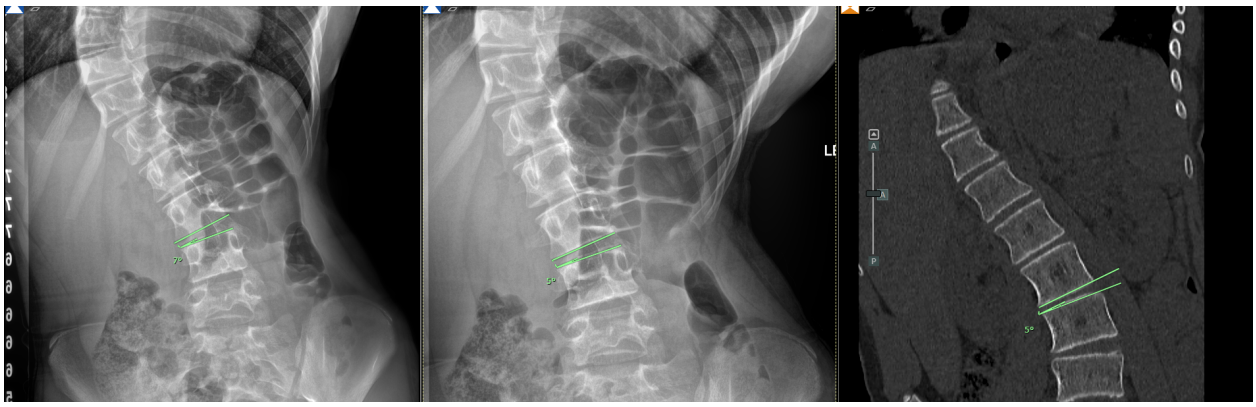
The lumbar curves demonstrated substantial flexibility across the group, with mean lumbar Cobb angle decreasing by 11.2 ° from plain film to left bending films. Mean lumbar Cobb angle decreased from 37.1° pre-operatively to 14.8° at latest follow-up, a mean reduction of 22.3 °. This reduction was statistically significant (paired t-test, $t(30) = 11.72$, $p < 0.001$). Mean residual lumbar curve was 14.8°, with a mean percentage curve correction of 62.4%.

The mean disc angle at LIV+1 in the coronal plane showed a progressive decrease in size across the six imaging modalities (Table 2). On pairwise comparative analysis, no significant difference in disc angle size was identified between CT and bending films (mean difference 0.42°, $p = 0.509$). An example of LIV+1 disc angle measured in each imaging modality for one patient is shown in Figure 1.

Table 2. Mean disc angle at LIV+1 across different imaging modalities (n=31)

Imaging	**Mean coronal disc angle at LIV+1 (°) (95% CI)**
Pre-operative plain film X-ray	8.48 (6.79 – 10.18)
Pre-operative left bending X-ray	4.77 (3.43 – 6.12)
Pre-operative CT	5.19 (3.97– 6.42)
Fluoroscopic intraoperative imaging (II)	1.87 (1.30 – 2.44)
First postoperative X-ray	1.68 (0.96 – 2.39)
Latest postoperative X-ray	1.35 (0.88 – 1.83)

Figure 1. Representative radiographic images showing LIV+1 disc angle across each of the imaging modalities.
(From left to right, top: Plain film X-ray, Left bending X-ray and Pre-operative CT)



(From left to right, bottom: Intraoperative imaging, first postoperative X-ray, latest postoperative X-ray)

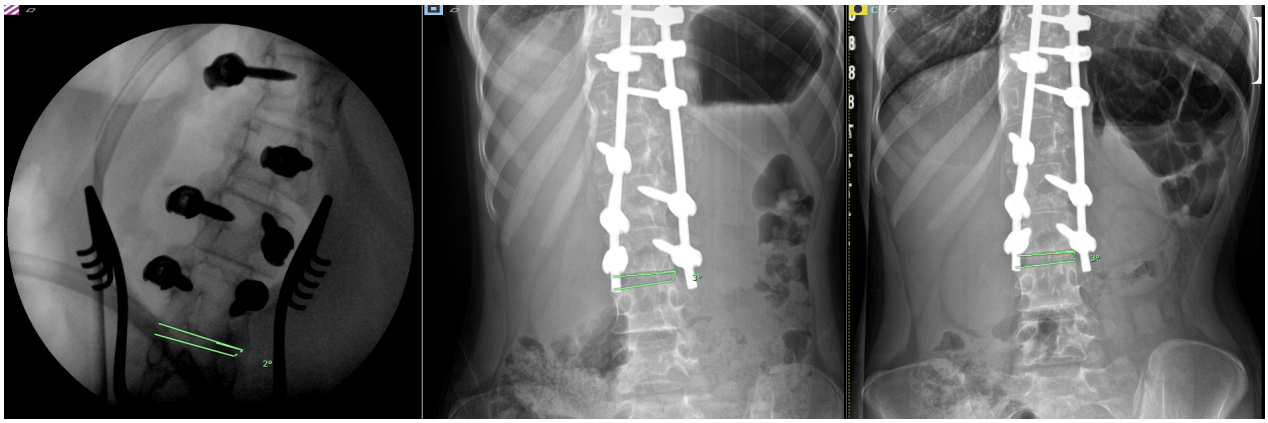
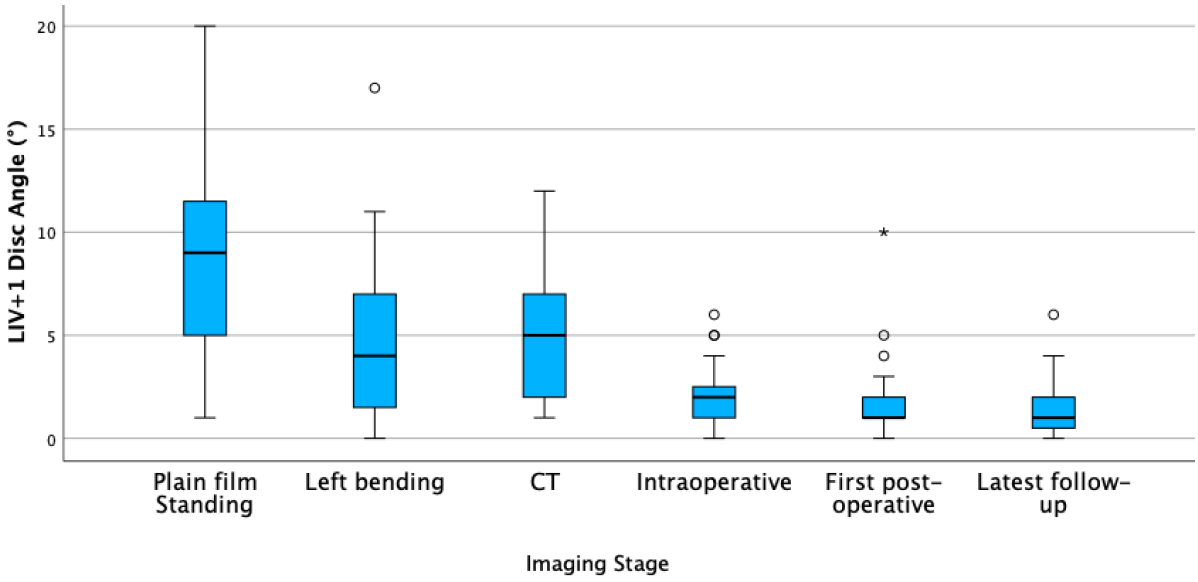


Figure 2. Distribution of LIV+1 disc angles across imaging stages



Friedman analysis demonstrated a significant difference in LIV+1 disc angle across the six assessment stages ($\chi^2(5) = 96.763$, $p < 0.001$). Wilcoxon signed-rank testing demonstrated significantly lower LIV+1 disc angles on intraoperative imaging compared with standing radiographs ($Z = -4.788$, $p < 0.001$) and CT imaging ($Z = -4.645$, $p < 0.001$). Comparison of first postoperative and latest follow-up radiographs demonstrated no significant change in LIV+1 disc angle ($Z = -0.595$, $p = 0.552$). The mean reduction in LIV+1 disc angle from standing X-ray to intraoperative imaging was 6.61°, whereas the mean difference between intraoperative imaging and latest follow-up radiographs was 0.52°. Pairwise comparisons between imaging modalities are shown in Table 3.

Table 3. Pairwise comparisons of LIV+1 disc angle measurements between imaging modalities

II = intraoperative imaging

Comparison	Mean difference (°)	p
Standing vs II	6.61	<0.001
Left bending vs II	2.90	<0.001
CT vs II	3.32	<0.001

Correlation and threshold analyses were performed to assess the relationship between intraoperative LIV+1 disc angle measurements and postoperative radiographic outcomes. No significant correlation was identified between intraoperative LIV+1 disc angle and LIV+1 disc angle at latest follow-up (Spearman's rho = 0.085, p = 0.651). Similarly, no significant correlation was identified between intraoperative LIV+1 disc angle and residual lumbar Cobb angle (Spearman's rho = -0.130, p = 0.484).

Threshold analyses showed no significant associations between an intraoperative LIV+1 disc angle threshold of 2° and postoperative radiographic outcomes. Latest postoperative LIV+1 disc angle (Mann-Whitney U = 76.0, p = 0.450), residual lumbar Cobb angle (p = 0.619), percentage lumbar curve correction (p = 0.982), or postoperative change in LIV+1 disc angle (p = 0.142).

Discussion

The aim of this study was to assess whether intraoperative imaging during posterior spinal fusion surgery for AIS can provide useful information for the selection of the LIV in Lenke 1A curves. An important part of LIV selection is assessment of lumbar curve flexibility. In this cohort, the lumbar curves demonstrated substantial flexibility, with a mean lumbar curve correction of 62.4% following surgery. This is consistent with the theory of "compensatory lumbar curves" in Lenke 1A AIS, whereby the lumbar curve distal to the structural thoracic curve can undergo spontaneous correction following fusion of the thoracic deformity (4). These findings support the principle of selective thoracic fusion, which aims to preserve lumbar motion segments whilst achieving the best coronal balance (5).

Currently, curve flexibility and LIV selection is predominantly decided through pre-operative bending x-ray films. We hypothesised that intraoperative imaging obtained during corrective surgery may provide a more accurate representation of the curve and therefore can be used to help identify the LIV. Bending films have significant limitations related to patient technique, such as pain, understanding instructions, body habitus and effort. Additionally, many patients rotate their spine and pelvis during bending. Intraoperative imaging removes these variables and may be more consistent with the postoperative state (6).

In this study we measured the coronal intervertebral disc angle at the LIV+1 across multiple imaging modalities. This angle is a marker of distal curve magnitude and coronal balance. The main finding was that the intervertebral disc angle at LIV+1 was significantly smaller on intraoperative imaging than any pre-operative radiographs or CT.

Additionally, there was no significant difference in LIV+1 disc angle between CT and bending films. Bending films assess active spine flexibility, whereas supine CT images eliminate the effects of gravity and loading on the curve. This study provides evidence that these imaging modalities demonstrate similar characteristics of the deformity. This similarity raises the question whether bending films provide information that is not already available from routine pre-operative CT imaging. Furthermore, both CT and bending films displayed significantly larger LIV+1 disc angles than intraoperative imaging. This suggests that pre-operative flexibility assessments may underestimate the degree of correction possible once the spine has been unloaded.

In comparison to TUGA, intraoperative imaging has the advantage of both anaesthesia removing guarding, but also muscle dissection and operative manoeuvres. As surgical techniques and equipment improve, correction is also improving. Modern pedicle screw constructs are allowing stronger correction which can facilitate more proximal fusion (7). This information is only available to the surgeon once the screws are inserted and supports further evaluation of intraoperative imaging as an adjunct to decisions regarding fusion level selection.

The most clinically relevant finding was that the intraoperative imaging measurement most closely matched both the immediate and latest follow-up X-ray disc angle. The correction achieved was maintained throughout follow-up, with the mean difference between intraoperative imaging and latest follow-up X-ray only 0.52°. Furthermore, there was no significant difference between first postoperative and latest follow-up X-ray disc angle. Friedman test identified significant differences across the six imaging modalities, and the mean-rank pattern showed a progressive reduction in disc angle from standing plain film X-ray to CT and bending films and then intraoperative imaging and postoperative follow-up. There was little difference between intraoperative and postoperative measurements. The Wilcoxon signed rank test confirmed that intraoperative measurements were significantly smaller than all pre-operative image types. These findings suggest that intraoperative imaging after screw placement may be a more accurate predictor of whether the LIV disc can be balanced once rods and compression and distraction are applied, achieving a balanced distal disc which remains stable over time. Maintaining distal disc alignment may reduce the risk of adjacent segment degeneration, although this requires long-term investigation.

Despite the close agreement between intraoperative and postoperative LIV+1 disc angle measurements, no intraoperative disc angle threshold was identified that could reliably predict postoperative radiographic outcomes. Correlation analyses also showed no significant relationship between intraoperative LIV+1 disc angle and postoperative measurements, such as residual lumbar curve. This may reflect the relatively small sample size and the narrow range of intraoperative disc angles observed. 74.2% of patients had an intraoperative disc angle ≤2°, and this limited variability reduced the

ability to identify a clinically meaningful threshold. Whilst we were unable to identify a specific intraoperative disc angle threshold that can predict successful LIV selection, there is still evidence that once the LIV+1 disc is corrected intra operatively, the correction is maintained and remains stable over follow-up.

A limitation of this study is the relatively small sample size, which may have limited the statistical power. Additionally, only patients who underwent corrective surgery were included, representing a cohort with larger curves. Radiographic measurements are subject to observer variability, and all measurements were performed by a single observer with no inter-observer reliability assessment. Whilst standardised measurement techniques were used, future studies should include repeat measurements by independent observers. As a retrospective study with 31 patients, no a priori sample size calculation was performed. Larger prospective studies will be required to confirm these findings. A further limitation is that LIV selection was not altered on the basis of the intraoperative imaging findings, as this was a retrospective observational study. Consequently, while intraoperative assessment appeared to correlate more closely with the final postoperative alignment than pre-operative flexibility imaging, this study cannot determine whether its use would improve clinical outcomes. Prospective studies in which intraoperative imaging informs LIV selection are required to answer this question.

Conclusion:

This study demonstrates that intraoperative fluoroscopic assessment of the LIV+1 disc angle in patients with Lenke 1A AIS more closely reflected the final postoperative alignment. Intraoperative imaging measurements were repeatedly smaller than those from standing, side bending, and CT images.

No specific intraoperative LIV+1 disc angle threshold predictive of postoperative outcomes was identified. However, intraoperative fluoroscopy more closely reflects postoperative disc alignment than conventional flexibility assessments and may represent a useful adjunct in LIV assessment. Prospective studies are required to determine whether incorporating these findings into surgical decision-making improves fusion level selection and patient outcomes.

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