Touched Vertebra (TV) on Standing Xray is a Good Predictor for LIV. TV on Prone Xray is Better

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**Introduction**

The goal of scoliosis surgery is to obtain deformity correction, balance the trunk, and prevent deformity progression while fusing an ‘ideal’ number of vertebrae levels. Determining the ideal fusion length is challenging as too short a fusion may allow the curve to progress resulting in decompensation or “adding on” (*1*) and longer fusion may limit a patient’s flexibility. There are multiple criteria utilized to determine the lowest instrumented vertebra, which has the greatest impact on decompensation or adding on and patient flexibility.

Surgeons utilize end vertebra, neutral vertebra, and stable vertebra along with bending films to determine the lowest instrumented vertebra. Recent studies have investigated the idea of the ‘touched vertebra’ to assist in determining the lowest instrumented vertebra (LIV). (*2, 3*) The ‘touched vertebra’ is defined as “the last vertebra touching the central sacral vertical line.” (*2, 3*) Cho et al refined this further and proposed the idea of the ‘last substantially touched vertebra’ which is defined as “the most proximal lumbar vertebrae where the central sacral vertical line either intersected the pedicle outline or was medial to the pedicle outline.” (*3*) Qin et al. compared the long-term outcomes of 104 Lenke 1A patients fused using the non-substantially touched vertebra (nSTV) and substantially touched vertebra (STV). (*4*) The incidence of distal adding-on was significantly higher in the nSTV group than the other cohorts studied. (*4*) Cao et al evaluated validity of using last touched vertebra (LTV) in 116 consecutive adolescent idiopathic scoliosis (AIS) patients who underwent posterior fusion for Lenke type 2A curves. (*5*) Distal adding-on was present in 16 patients (13.8%) at follow-up. Adding-on was significantly more common when LIV was proximal to LTV. They concluded that LIV at or distal to LTV may prevent postoperative adding-on in Lenke type 2A curve.

Lee et al retrospectively reviewed 229 AIS patients with Lenke type 3C, 5C, or 6C curves that underwent surgery. (*6*) They found lesser curve correction and increased post op disc wedging in patients with fusion to L3, when the LTV = L5. They concluded that LIV at L3 may be sufficient in cases with LTV ≥ L4. However, in LTV = L5, they cautioned about stopping fusion at L3, as this may lead to suboptimal correction which in turn could possibly worsen disc wedging distal to LIV. Kim et al reviewed radiographic parameters of 66 AIS patients with TL/L curves fused to L3 or L4. (*7*) Acceptable results were found in patients with L4 fusions and L3 fusions where the L3 crosses the CSVL on side bending x-rays (XRs) and had rotation < Grade II. In patients with > grade II rotations and failure of L3 to cross the midline on ‘active’ side bending XRs, fusion to L3 (25 patients) led to significantly higher number of unsatisfactory results (15 patients, 68.2%). In the latter group of patients, they concluded that the fusion should be extended to L4.

The role of touched vertebra and the grade of rotation in determining ‘proper’ LIV is becoming more evident. However, the LTV in all these studies was determined on standing XRs. Some of these also utilized bending XRs. Bending XRs are inherently variable depending upon patient’s or operator’s effort. Lack of standardization of the bending techniques and variability of the ‘bending effort’ further limits its utility. Cheh et al evaluated preoperative supine radiograph and side bending XRs in operated AIS patients. (*8*) They found that the supine XRs were highly predictive of side-bending XRs and could be used to predicting curve flexibility and structure. Multiple studies have shown that the Cobb angle and rotation decrease when patient lies down. The end vertebra also moves proximally and the number of vertebra included in the major curve decrease. All this suggests that determining LIV on lying down XRs can potentially lead to saving levels. At our institution, we have utilized the last substantially touched vertebra and rotation < grade II on prone lying down XRs to determine LIV. Our hypothesis is that determining LIV on prone XRs allows to save fusion levels, obtain comparable correction without ‘adding on’ or decompensation at follow up.

**Methods**

An ambispective review was performed after Institutional Review Board approval. This study consisted of three groups.

Group I: Patients where touched vertebra on prone (TVP) was used to determine LIV. AIS patients who underwent posterior spinal fusion by a single surgeon (VS) between 2006-2015 and who had complete set of XRs with minimum two year follow up were included. The LIV was determined by identifying the last substantially touched vertebra (LTV) on prone x-ray as described by Cho et al. (*3*). If the touched vertebra is neutral or nearly neutral (Nash and Moe 0 or 1), the surgeon fused at LTV. However, if the touched vertebra is rotated (Nash and Moe > 2), the surgeon chooses the next distal neutral vertebra (Nash and Moe 0 or 1) and performs a longer fusion or chooses proximal neutral vertebra and performs a selective thoracic fusion. For this study, however, selective thoracic fusion was excluded. This was done as a ‘selective thoracic fusion’ is often a clinical decision based on a patient’s clinical appearance, especially in double major curves. Including those patients in the group would have skewed the data due to large number of levels saved compared to fusing both the curves.

Group II: Patients where touched vertebra on standing (TVS) was utilized for LIV determination. AIS patients who underwent all pedicle screw based posterior spinal fusions from multiple surgeons excluding the surgeon in the TVP cohort. Surgeons in this group have not utilized TVP to determine LIV. Due to standardization of XR for pre-op planning in the recent past, some of their patients have also had prone XRs taken. However, these prone XRs were not utilized in determining the LIV. The availability of these XRs allowed us to compare the potential saving of fusion levels. As in Group I, selective thoracic fusion was excluded.

Group III: Non-operative AIS patients from 2014-2016 who were Risser 4/5 and Cobb <35 degrees. The purpose of this cohort was to determine ‘acceptable’ end vertebra tilt, translation with respect to CSVL and disc wedging.

*Data Analysis*

The following radiographic parameters were collected for each cohort: Cobb angle, coronal balance, LIV tilt, LIV translation, and disc angle. Stable vertebra, end vertebra, neutral vertebra, touched vertebra on prone, touched vertebra on standing were also collected for Groups I and II. Median and interquartile ranges (IQR) were used for assessment of central tendencies. Since mean tends to be influenced by the outliers, which can skew the data, median values were utilized instead. Wilcoxon signed-rank test were used for statistical analysis with p-values < 0.05 considered significant. Statistical analyses were performed by an independent biostatistician with SAS for Windows, version 9.3 (SAS Institute, Cary NC).

**Results**

*Demographics and Preoperative XR Measurements*

In Group I, one hundred and two adolescent idiopathic scoliosis patients met the eligibility criteria. The median age was 14.5 (13.4-16.1). 21 (20.6%) were males. In Group II, twenty six patients met the eligibility criteria. The median age was 14.6 yrs (13.7-16.0). 9 (34.6%) were males. In Group 3, 132 non-operative AIS patients met the eligibility criteria. The median (IQR) age was 15.9 (14.8-17). Eighty three (61.9%) were Risser 4 and 51 (38.1%) were Risser 5

The median preoperative Cobb angle for Group I (53.8 (47-64)) was not significantly different compared to Group II (53.5 (60-60.7)), p = 0.89. The median preoperative coronal balance for Group 1 (1.8 (1-2.8)) was not significantly different compared to Group II (2 (0.9-2.9)), p = 0.82.

*Postop XR Measurements*

The median postoperative Cobb angle was significantly higher in Group II (19.7 (13.4-24)) compared to Group I (13.8 (7-20.1)), p = 0.023. The median postoperative coronal balance was not significantly different (Group I: (1.5(0.5-2.7)); Group II: (1.8 (1.1-3.1)), p = 0.41). (Table 1)

*Final XR Measurements*

The median final Cobb angle was significantly higher in Group II (20 (15-26) compared to Group I (12.4 (7-19.6)), p = 0.008. The median final coronal balance was not significantly different (Group I: (0.9 (0.5-2.7)); Group II: (0.7 (1.1-3.1)), p = 0.32). (Table 1)

*LIV tilt, disc wedging and LIV translation:*

Group I: Preoperative LIV tilt angle was 22 (14.3-26), final LIV title angle was 5 (2-7.5), preoperative disc angle was 5 (2.6-7.3), final disc angle was 1.2 (0.6-3), preoperative LIV translation was 1.5 (0.9-1.9), and final LIV translation was 0.7 (0.2-1.2). (Table 1)

Group II: Preoperative LIV tilt was 19.2 (15-22), final LIV tilt was 6 (2-7), preoperative disc angle was 6.5 (2.2-9.7), final disc angle 3 (2-6), preoperative LIV translation was 1.6 (0.9-1.9), and final LIV translation was 0.9 (0.4-1). (Table 1)

Compared to Group I patients, control (Group III) patients had similar coronal balance (1.4 vs 0.9, p =0.18), but significantly higher disc wedging (4 vs 1.2°, p>0.001), and LIV tilt (10 vs 5° p<0.001). All final radiographic values for the Group I were significantly lower than the control cohort except for LIV translation. (Table 2)

*Touched Vertebra Standing*

A subsequent analysis evaluated the location of LIV in the Group II in relation to the prone touched vertebra. Thirteen patients were fused distal to, 7 were fused proximal to, and 6 were fused at the TVP. All radiographic parameters at postop were not significant except for disc wedging. Median postoperative disc wedging was significantly higher in patients with LIV proximal to TVP (5.6 (5-6.7), p=0.020) than in those fused to TVP or distally. (Table 3) After analyzing patients fused distal to and at the TVP versus patients fused proximally, we found the proximal TVP group had significantly higher disc wedging at postop and final. (Table 4)

*Number of levels saved*

For Group I, the median TVP value compared to TVS within a patient was 1 (1-1) level proximal. For Group II, in the cases where the patients were fused distal to the TVP, this cohort could have saved an average of 2.2 (0-4) fusion levels by fusing at TVP.

*LIV at Nash and Moe Grade 0 or 1 versus proximal*

In group 1, 74 patients were fused to TVP which was also neutral vertebra (Nash and Moe 0) or almost neutral (Nash and Moe 1). Twenty eight patients were fused to TVP which was more rotated (> Nash and Moe 1). There were no difference between the two groups with respect to pre-op Cobb, post-op Cobb and coronal balance. However, in patients fused at more rotated vertebra level, final LIV translation was significantly higher (1.2 cm vs 0.5 cm, p=0.005).

**Discussion**

The long-term impact of spinal fusion is considerable. Studies have shown concern regarding the long-term impact of spine degeneration as it relates to fusion length. (*9, 10*) The primary aim of scoliosis surgery is to obtain correction and balance while minimizing fusion levels. This is usually accomplished by fusing the structural curves and in most cases leaving non-structural curves unfused. Lenke et al detailed the different curves that needed to be fused based on their classification system but did not address the levels that should be included in the fusion area. (*11*) Determining the LIV is often based on the relationship of the last touched vertebra to the central sacral vertical line. The ‘touched vertebra’ has gained greater acceptance with the use of all pedicle screw systems that allow for 3 dimensional correction force. In 2012, Cho et al in 2012 the ‘last substantially touched vertebra’ as a potentially risk factor for ‘adding-on’ in Lenke 1A curve. (*3*) Their results led them to recommend the distal fusion for Lenke 1A-R curves be at the last substantially touched and neutral vertebra. (*3*)

Cao et al evaluated 116 AIS patients who underwent posterior thoracic fusion surgery for Lenke type 2A curve. (*5*) Eighteen patients in their cohort had LIV proximal to the LTV, 43 patients had LIV distal to LTV and 55 patients had LIV at LTV. They found distal adding-on in 16 of the 116 patients (13.8%), which was significantly higher when LIV was proximal to LTV (9 patients, 50%). After stepwise logistic regression they concluded that LIV at or distal to the LTV may prevent postoperative adding-on in Lenke type 2A curve. Qin et al reviewed 104 AIS patients with Lenke Type IA curves, who underwent posterior thoracic fusion. (*4*) Twenty three of their patients had distal adding-on (22.1%). Adding-on developed in 66.7% of the patients with LIV proximal to last substantially touched vertebra. Logistic regression analysis showed that the distance between LIV and last substantially touched vertebra as the only independent factor associated with the incidence of adding-on (odds ratio = 27.1, 95% confidence interval = 2.3–311.2, p = 0.002). They concluded that selecting last substantially touched vertebra as LIV could yield a promising outcome for Lenke 1A curves.

Vertebra rotation as assessed on Nash and Moe grading system has been shown to be quite important. Choosing LTV with a higher grade of rotation can lead to decompensation and disc wedging. Kim et al reviewed XRs of 66 AIS patients with thoraco-lumbar/ lumbar curves. (*7*) Patients were grouped according to the distal fusion level; L3 group (fusion to L3, n=58) and L4 group (fusion to L4, n=8). (*7*) The L3 group was subdivided further based on side bending XRs into L3A (L3 crosses the CSVL with rotation < grade II, n=33) and L3B (L3 does not cross the CSVL or rotation > grade II, n=25). Significantly lesser curve and LIV tilt correction was found in the L3B group. They reported unsatisfactory results (LIV tilt > 10° or coro­nal balance > 15 mm) in 3 L3A patients (9.1%), 15 L3B patients (68.2%), and in 1 L4 patient (12.5%). This was statistically significant. They concluded that fusion to L3 should only be considered in patients when L3 crosses the CSVL and has rotation < grade II. Otherwise, their recommendation is to extend fusion to L4. We also found that rotation is an important factor in obtaining a more horizontal LIV (lower disc wedging) and better balanced LIV (better LIV translation). In our study, Grpup 1 patients fused proximal to NV or NV=1 had significantly higher median disc angulation and LIV translation at final follow up.

Supine side-bending radiographs are a prominent approach to determine curve flexibility. (*12-14*) However, Klepps et al in a prospective study found that side bending XRs underestimate the amount of curve correction that can be obtained at surgery. (*15*) The best role of side bending is in determining curve structurality and possibly disc mobility below the proposed LIV. Cheh et al suggested that most of the information from supine bending XRs could be obtained from a lying down supine XRs. (*8*) They found in a review of 675 patients that supine XRs could predict curve type, flexibility and structurality with the added advantage that it can be standardized as it does not involve any effort on patients and operators part. (*8*)

Prone films were first introduced in the literature by Kleinman et al with their evaluation of the efficacy of preoperative ‘push prone’ films. (*16*) Keenan et al reviewed 52 patients with right thoracic Lenke I curves to compare measurements on supine versus standing XRs. (*17*) They found that the Cobb angle decreases on supine XRs and this was true irrespective of end plate selection for cobb measurement. Yazici et al reviewed 33 structural curves in 25 AIS patients and found that the cobb angle and rotation decreases on supine imaging. (*18*) The average apical rotation of 22.75 degrees on standing XRs decreased to 16.78 degrees on supine CT scout films. Cecen et al studied rotation changes between supine and prone lying down imaging on CT scan in 50 apical vertebrae (34 patients). (*19*) They found that no significant difference between the two positions for Lenke 1A and 3c thoracic group but significantly lesser rotation in supine position in Lenke 3c lumbar subgroup. We utilize prone over supine XRs to decrease radiation exposure to breasts and as it closely mimic the operating position as well. We also felt that in supine position, lying on the rib hump against a flat table could introduce some unaccounted rotational correction.

In this study we found that one level (IQR, 1-1) was saved by fusing at the touched vertebra on prone as opposed to standing. The patients in Group I (LTV on prone XR) also had significantly lower final Cobb angles (12.4 vs 20) and disc angles (1.2 vs 3) than Group II patients. This was seen despite both groups having comparable preoperative radiographic measurements. Overall, both the Group I and Group II were fused at a median L3. However, within a patient, we found that if the Group II had fused to the prone touched vertebra, they could have saved approximately 2 levels of fusion. Since the rotation decreases on lying down, determining LIV on prone XRs can lead to shorter fusion levels without risk of decompensation. However, TVP alone without consideration of degree of rotation can lead to decompensation. Patients with fusion proximal to neutral or near neutral vertebrae in Group I were found to have significantly higher LIV translation at final follow up. Cho et al also recommended fusing to one level above the neutral vertebra in Lenke 1A curve subtypes to prevent adding-on. Kim et al also found coronal imbalance and significantly higher LIV tilt in patients fused to vertebrae with Nash and Moe Grade II or higher rotation. However, the long term impact of higher disc wedging, LIV tilt is unknown. In our study these values in both the groups were within the ‘acceptable’ limits that were measured from the controls. Of course the control population is an unfused scoliosis, but does provide us with a reference point.

The limitation of our study is its retrospective nature and smaller sample size in comparative Group II. However, each patient in both groups was utilized to measure touched vertebra on standing and prone XRs which served as a good comparison to measure number of levels saved. Prone XRs are a simple and reproducible measure to determine LIV and appear to save fusion levels with no loss of correction, adding on or imbalance in our study.

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Table 1. Median radiographic values compared between touched vertebra on prone (Group I) and touched vertebra on standing cohort (Group II)

|  |  |  |  |
| --- | --- | --- | --- |
|  | Group I  N = 102 | Group II  N = 26 | p – value |
| Preoperative Cobb | 53.8 (47-64) | 53.5 (50-60.7) | 0.89 |
| Postoperative Cobb | 13.8 (7-20.1) | 19.7 (13.4-24) | 0.023 |
| Final Cobb | 12.4 (7-19.6) | 20 (15-26) | 0.008 |
| Preoperative Coronal Balance | 1.8 (1-2.8) | 2 (0.9-2.9) | 0.82 |
| Postoperative Coronal Balance | 1.5 (0.5-2.7) | 1.8 (1.1-3.1) | 0.41 |
| Final Coronal Balance | 0.9 (0.4-1.6) | 0.7 (0-1.3) | 0.32 |
| Preoperative LIV Tilt | 22 (14.3-26) | 19.2 (15-22) | 0.16 |
| Postoperative LIV Tilt | 4.9 (1.6-8.9) | 4.2 (2.9-7) | 0.71 |
| Final LIV Tilt | 5 (2-7.5) | 6 (2-7) | 0.72 |
| Preoperative Disc Angle | 5 (2.6-7.3) | 6.5 (2.2-9.7) | 0.43 |
| Postoperative Disc Angle | 1.3 (0.4-2.7) | 2.8 (1.6-5.3) | <0.001 |
| Final Disc Angle | 1.2 (0.6-3) | 3 (2-6) | 0.002 |
| Preoperative LIV Translation | 1.5 (0.9-1.9) | 1.6 (0.9-1.9) | 0.95 |
| Postoperative LIV Translation | 0.7 (0.4-1.1) | 0.9 (0.4-1.2) | 0.40 |
| Final LIV Translation | 0.7 (0.2-1.2) | 0.9 (0.4-1) | 0.44 |

Table 2. Median values of selected radiographic parameters for the control (Group III) and touched vertebra on prone (Group I) cohort at final follow up.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Group I  N = 102 | Group III  N = 132 | p – value |
| Coronal Balance | 0.9 (0.4-1.6) | 1.4 (0.5-2.2) | 0.023 |
| Disc Wedge | 1.2 (0.6-3) | 4 (2-5) | < 0.001 |
| LIV Tilt | 5 (2-7.5) | 10 (7-13) | < 0.001 |
| LIV Translation | 0.7 (0.2-1.2) | 0.7 (0.4-1.1) | 0.53 |

Table 3. Sub-analysis of Group II evaluating the radiographic parameters of different fusion locations relative to the touched vertebra prone location

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Above TV Prone  N = 7 | At TV Prone  N = 6 | Below TV Prone  N = 13 | p – value |
| Preoperative Cobb | 52.2 (40-56.4) | 55 (50.5-60.7) | 54.4 (50.7-68) | 0.24 |
| Postoperative Cobb | 23 (15.8-33.9) | 18.9 (13.4-24) | 17.8 (10-23) | 0.34 |
| Final Cobb | 23 (19-26) | 20.5 (16-22) | 19 (7.5-26) | 0.64 |
| Preoperative Coronal Balance | 31.9 (26.6-34.5) | 12.8 (6.4-31.9) | 16.4 (0-25.3) | 0.14 |
| Postoperative Coronal Balance | 1 (0-3.1) | 2.9 (1.9-3.7) | 1.5 (1.1-2.6) | 0.34 |
| Final Coronal Balance | 0.8 (0.3-1.2) | 1.2 (0.5-3.1) | 0.5 (0-1.3) | 0.45 |
| Preoperative LIV Tilt | 17.5 (14-19) | 15 (14.5-16) | 20 (15-22) | 0.44 |
| Postoperative LIV Tilt | 3.4 (2.5-4.5) | 5.6 (3.7-9.5) | 4.4 (3.2-6) | 0.29 |
| Final LIV Tilt | 4.5 (2-6) | 9 (2-9) | 5 (2-7) | 0.56 |
| Preoperative Disc Wedge | 4 (0-8) | 6 (2.5-7.8) | 7 (2.8-10) | 0.58 |
| Postoperative Disc Wedge | 5.6 (5-6.7) | 2.1 (1.6-2.8) | 2 (1.5-3.7) | 0.020 |
| Final Disc Wedge | 5 (4-6) | 3 (1.5-3) | 2 (1-3) | 0.11 |
| Preoperative LIV Translation | 2 (1.6-2.6) | 1.2 (1-1.3) | 1.2 (0.7-1.7) | 0.19 |
| Postoperative LIV Translation | 1.1 (0.7-1.9) | 0.9 (0.6-1.6) | 0.7 (0.1-1.1) | 0.25 |
| Final LIV Translation | 0.9 (0.8-1.3) | 0.9 (0.4-1.8) | 0.4 (0.3-1) | 0.22 |

Table 4. Sub-analysis of Group II evaluating the radiographic parameters of different fusion levels relative to touched vertebra prone location

|  |  |  |  |
| --- | --- | --- | --- |
|  | Above TVP  N = 7, Median (IQR) | Below/At TVP  N = 19, Median (IQR) | P |
| Preoperative Cobb | 52.2 (40-56.4) | 54.4 (50.5-68) | 0.11 |
| Postoperative Cobb | 23 (15.8-33.9) | 17.8 (12-24) | 0.17 |
| Final Cobb | 23 (19-26) | 19.5 (10-26) | 0.39 |
| Preoperative Coronal Balance | 31.9 (26.6-34.5) | 14.7 (0-25.3) | 0.07 |
| Postoperative Coronal Balance | 1 (0-3.1) | 2 (1.2-2.9) | 0.35 |
| Final Coronal Balance | 0.8 (0.3-1.2) | 0.6 (0-1.3) | 0.83 |
| Preoperative LIV Tilt | 17.5 (14-19) | 19.6 (14.5-22) | 0.53 |
| Postoperative LIV Tilt | 3.4 (2.5-4.5) | 4.5 (3.2-8.9) | 0.17 |
| Final LIV Tilt | 4.5 (2-6) | 5.5 (2-8) | 0.53 |
| Preoperative Disc Wedge | 4 (0-8) | 6.5 (2.5-10) | 0.38 |
| Postoperative Disc Wedge | 5.6 (5-6.7) | 2.1 (1.5-3.7) | 0.012 |
| Final Disc Wedge | 5 (4-6) | 2.5 (1-3) | 0.052 |
| Preoperative LIV Translation | 2 (1.6-2.6) | 1.2 (0.9-1.7) | 0.09 |
| Postoperative LIV Translation | 1.1 (0.7-1.9) | 0.9 (0.2-1.1) | 0.24 |
| Final LIV Translation | 0.9 (0.8-1.3) | 0.5 (0.3-1) | 0.24 |