Lowest instrumented vertebra selection in Lenke 3C and 6C scoliosis: what if we choose lumbar apical vertebra as distal fusion end?

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Received: 6 April 2011 / Revised: 17 October 2011 / Accepted: 20 October 2011 / Published online: 5 November 2011
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Abstract

Purpose The aim of this study was to investigate whether or not post-op curve behaviour differs due to different choices of lowest instrumented vertebra (LIV) with reference to lumbar apical vertebra (LAV) in Lenke 3C and 6C scoliosis.

Methods We reviewed all the AIS cases surgically treated in our institution from 2002 through 2008. Inclusion criteria were as follows: (1) patients with Lenke 3C or 6C scoliosis who were treated with posterior pedicle screw-only constructs; (2) 2-year radiographic follow-up. All the included patients were categorized into three groups based on the relative position of LIV and LAV: Group A—the LIV was above the LAV; Group B—the LIV was at the LAV; Group C—the LIV was below the LAV. All the radiographic parameters were then compared among the groups. All image data were available in our picture archiving and communication systems. Standing antero-posterior (AP) and lateral digital radiographs were reviewed at four times (pre-op, post-op, 3-month and 2-year). In each standing AP radiograph, centre sacral vertical line (CSVL, the vertical line that bisects the proximal sacrum) was first drawn, followed by measuring T1-CSVL, LIV-CSVL, (LIV + 1)-CSVL, LAV-CSVL and thoracic AV-CSVL distance. In addition, the Cobb angles of major thoracic and lumbar curves were measured at the four times and the correction rates were then calculated.

Results Of the 278 patients reviewed, 40 met the inclusion criteria; 11 of these were included in Group A (LIV above LAV), another 11 in Group B (LIV at LAV) and the remaining 18 in Group C (LIV below LAV). At 2-year follow-up, the lumbar vertebrae such as LIV, LIV + 1 and LAV were all more deviated than before surgery in Group A (LIV above LAV), whereas in Group B and C (LIV at and below LAV) they were all less deviated than before surgery. No significant differences were found in thoracic or lumbar correction rate, global coronal balance and incidence rate of trunk shift among the three groups.

Conclusion In conclusion, in Lenke 3C and 6C scoliosis, post-op lumbar curve behaviour differs due to different choices of LIV with reference to LAV, that is, the deviation of lumbar curve improves when the LIV is either at or below the LAV but deteriorates when the LIV is above the LAV. Although the greatest correction occurs when the LIV is below the LAV, choosing LAV as LIV can still be the optimal option in certain cases, since it can yield similar correction while preserving more lumbar mobility and growth potential.

Keywords Adolescent idiopathic scoliosis · Lowest instrumented vertebra · Radiographic measurement · Spinal imbalance · Curve behaviour

Introduction

To select lowest instrumented vertebra (LIV) is to determine the distal end of the fusion. This selection is crucial because the location of the LIV is highly correlated with post-op outcome. Inappropriate LIV selection can result in aggravation of the unfused curve, distal adding on, or spinal imbalance [1, 2].

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Our current study focused on type 3C and 6C scoliosis. As the both curve types share the same treatment strategy, patients with either a type 3C or 6C curve were included in one case cohort. According the classification developed by Lenke [3], when a patient has either a type 3C or 6C curve, both the thoracic and thoracolumbar/lumbar curves should be included in the arthrodesis. Essentially, type 3C and 6C curves are largely identical with only minor differences; both type 3C and 6C curves consist of thoracic and thoracolumbar/lumbar curves, each of which are structural. The main difference between type 3C and 6C curves lies in which curve is defined as the major curve: for a type 3C curve, the thoracic curve is the major curve, because the Cobb angle of the thoracic curve is larger than that of the thoracolumbar/lumbar curve. Likewise, for a type 6C curve, the thoracolumbar/lumbar curve is the major curve, because the Cobb angle of the thoracolumbar/lumbar curve is larger than that of the thoracic curve.

While LIV selection is of vital importance in Lenke 3C and 6C scoliosis, how to select the LIV remains inconclusive [4–6]. We are mainly interested in investigating whether or not post-op curve behaviour differs due to different choices of LIV with reference to lumbar apical vertebra (LAV). We raise this issue because of the observation that different choices of LIV can produce completely opposite outcomes. A comparative study, therefore, would help us find an evidence-based approach to LIV selection, and hence improve clinical outcomes. In addition, few studies are based on posterior pedicle screw-only constructs, an approach which is becoming increasingly used in the management of adolescent idiopathic scoliosis (AIS) [7, 8]. The effect of the new constructs on post-op curve behaviour needs to be examined.

As such, the aim of this study was to investigate if post-op curve behaviour differs when LIV ends above, at, or below LAV in Lenke 3C and 6C scoliosis treated with posterior pedicle screw-only constructs.

Materials and methods

We reviewed all the AIS cases surgically treated in our institution from 2002 through 2008. Collection and analysis of radiographic and clinical data were performed by two authors who were not directly involved in the patients' surgery. Inclusion criteria were as follows: (1) patients with Lenke 3C or 6C scoliosis who were treated with posterior pedicle screw-only constructs; (2) 2-year radiographic follow-up. All the included patients were categorized into three groups based on the relative position of LIV and LAV: Group A—the LIV was above the LAV; Group B—the LIV was at the LAV; Group C—the LIV was below the

LAV. All the radiographic parameters were then compared among the groups.

All image data were available, and all measurements were performed in our picture archiving and communication systems. Standing anteroposterior (AP) and lateral digital radiographs were reviewed at four times (preoperative, immediate, 3-month and 2-year postoperative). In each standing AP radiograph, centre sacral vertical line (CSVL, the vertical line that bisects the proximal sacrum) was first drawn, followed by measuring T1-CSVL, LIV-CSVL, (LIV + 1)-CSVL, LAV-CSVL and thoracic AV-CSVL distance (Fig. 1), enabling depiction of how deviation of different parts of the spine changed in the postoperative period. In addition, the Cobb angles of major thoracic and lumbar curves were measured at the four times, and then the correction rate was calculated: correction rate (CR) = (preoperative Cobb angle – postoperative Cobb angle)/(preoperative Cobb angle) × 100%. All measurements were performed by one of the two authors and repeated by another. The mean values of the measurements made by the two authors were used for the final analyses, and measurement errors were calculated.

Surgical techniques

All surgeries were performed by one of the two senior authors. All screws were placed under the guidance of fluoroscopy. Several surgical manoeuvres were utilized intraoperatively, including rod rotation, distraction on concave side, compression on convex side and sometimes in situ contouring.

Statistical analysis

Mean value was reported with the range in parentheses. ANOVA was used to compare the correction rates in the three groups. In each group, paired *t* test was used to compare the 2-year and pre-op parameters and Fisher's exact test was used to compare the incidence rate of global imbalance before surgery and at 2 years. Chi-square test was used to compare the incidence rate of trunk shift in the three groups. Pearson's and Spearman's correlation tests were used for detecting correlations between pre-op and post-op radiographic parameters. Significance level was defined as 0.05. The data were analyzed by means of STATA 10.1 software (Stata Corp., College Station, TX).

Results

Of the 278 patients reviewed, 40 met the inclusion criteria; 11 of these were included in Group A (LIV above LAV),

Fig. 1 Definitions of the radiographic parameters and determination of curve types: *CSVL* centre sacral vertical line, the vertical line which bisects proximal sacrum [3]; *AV* apical vertebra, the vertebra most deviated laterally from the *CSVL*; *LIV* lowest instrumented vertebra; *LIV + 1* the first vertebra below *LIV*; *AV-CSVL distance* distance in millimetres from the *CSVL* to the mid-point of the apical vertebra. The mid-point of a vertebral body is determined by drawing a cross (×) in the body: A line is drawn from the upper left corner to the lower right of the body/disc and from the upper right to the lower left of the body/disc. The intersection is the mid-point; when the mid-point is on the right side of the *CSVL*, the value of the deviation of the vertebra is defined as a positive value; when on the left side, it is

defined as a negative value; *T1-CSVL distance* distance in millimetres from the *CSVL* to the mid-point of the T1; *Lenke 3C curve* the main thoracic and thoracolumbar/lumbar curves are structural (side bending Cobb $\geq 25^\circ$ or T10–L2 kyphosis $\geq +20^\circ$). And the *CSVL* falls medial to lateral aspect of lumbar apical vertebral body. The main thoracic curve is the major curve and is greater than, equal to, or no more than 5° less than the Cobb measurement of the thoracolumbar/lumbar curve; *Lenke 6C curve* the thoracolumbar/lumbar curve is the major curve and measures at least 5° more than the main thoracic curve, which is structural (side bending Cobb $\geq 25^\circ$ or T10–L2 kyphosis $\geq +20^\circ$)

another 11 in Group B (*LIV* at *LAV*) and the remaining 18 in Group C (*LIV* below *LAV*). In Group C, the *LIV* was at *LAV + 1* (the first vertebra below *LAV*) in 13 patients, at *LAV + 2* (the second vertebra below *LAV*) in 2 patients and at *LAV + 3* (the third vertebra below *LAV*) in the remaining 3 patients. Of the total 40 patients, 19 had Lenke 3C scoliosis and the remaining 21 had Lenke 6C scoliosis. Mean age at surgery was 17.4 years, range 12–23.7. The *LIV* was T12 in 10 patients, L1 in 4 patients, L2 in 7 patients, L3 in 11 patients and L4 in the remaining 8 patients.

In our picture archiving and communication systems, precision of length measurement was 0.1 mm and precision of angle measurement was 0.1° . Average error in length measurement was 2.8 mm (range, 0–5.2 mm) and average error in angle measurement was 4.1° (range, 0° – 7.2°).

In general, the degree of either thoracic kyphosis or lumbar lordosis did not show significant change at 2 years than before surgery in Group A, whereas in Group B and C it decreased significantly at 2 years than before surgery (Table 1).

Thoracic correction rates were 0.60, 0.55 and 0.47 in Group A, B and C, respectively. There was no significant

difference in thoracic correction rate in the three groups ($P > 0.05$). Similarly, lumbar correction rates were 0.39, 0.42 and 0.40 in Group A, B and C, respectively. There is no significant difference in lumbar correction rate among the three groups either ($P > 0.05$) (Fig. 2).

Differences in post-op lumbar curve behaviour

The results of the radiographic measurements regarding lumbar curve behaviour are shown in Table 2 and Fig. 3. At 2-year follow-up, the *LIV*, *LIV + 1* and *LAV* in Group A were all more deviated than before surgery, whereas in Group B and C they were less deviated than before surgery. On average, the *LIV* deviation at 2 years was 8.9 mm larger than before surgery in Group A ($P < 0.023$), 6 mm less than before surgery in Group B ($P < 0.044$) and 5 mm less than before surgery in Group C ($P < 0.030$). Similarly, the *LIV + 1* deviation at 2 years was on average 2.8 mm larger than before surgery in Group A ($P > 0.241$), 2.4 mm less than before surgery in Group B ($P > 0.247$) and 1.1 mm less than before surgery in Group C ($P > 0.304$). The deviation of the *LAV* at 2 years was on average 0.7 mm larger than before surgery in Group A ($P > 0.401$), 5.7 mm less than before surgery in Group B ($P < 0.046$)

Table 1 Radiographic Measurements Regarding Thoracic Kyphosis or Lumbar Lordosis

Measurement	Pre-op	Post-op	3-month	2-year	<i>P</i> value
Thoracic kyphosis (°)					
Group A	22.7 (9.7, 35.7)	18.1 (9.6, 26.6)	18.5 (14.7, 30.4)	25.6 (17.8, 33.3)*	0.479
Group B	33.2 (18.5, 48.0)	22.1 (8.0, 36.2)	22.7 (13.2, 31.3)	24.6 (13.3, 34.0)*	0.041
Group C	38.8 (27.1, 50.5)	25.9 (20.7, 31.1)	25.3 (17.8, 33.7)	26.0 (16.9, 35.1)*	0.015
Lumbar Lordosis (°)					
Group A	42.5 (34.6, 50.5)	39.0 (35.8, 42.1)	42.4 (38.9, 50.8)	50.1 (39.2, 61.0)*	0.203
Group B	51.8 (42.1, 61.4)	32.4 (20.6, 44.2)	33.2 (23.2, 42.6)	34.0 (24.2, 43.8)*	0.004
Group C	53.0 (43.8, 62.1)	39.9 (36.1, 43.6)	41.2 (34.5, 51.2)	42.1 (33.8, 50.4)*	0.010

* Compared with the Pre-op value using paired *t* test, and the *P* value is given in the next cell

Fig. 2 No significant differences were found in thoracic or lumbar correction rate among the three groups. In other words, different choices of LIV with reference to LAV yield similar results in terms of correction rate

and 10.7 mm less than before surgery in Group C ($P < 0.001$).

In addition, the relative position of LIV and LAV was determined for each patient. The LIV was at LAV-3 in 4 patients, at LAV-2 in 6 patients, at LAV-1 in 1 patient, at LAV in 11 patients, at LAV + 1 in 13 patients, at LAV + 2 in 2 patients and at LAV + 3 in 3 patients. The relative position of LIV and LAV was found to be highly correlated with the 2-year LAV deviation ($P = 0.012$, Pearson's correlation test; $P = 0.010$, Spearman's correlation test), it was also found to be significantly correlated with the change in LAV deviation (2-year—preoperative) ($P = 0.012$ Pearson's correlation test; $P = 0.012$, Spearman's correlation test). Pre-op flexibility of lumbar curve, however, did not show significant correlation with the 2-year LAV deviation or change in LAV deviation (2-year—preoperative).

Post-op spinal balance

T1 deviation was the parameter used in determining global coronal balance. In none of the three groups did the 2-year T1 deviation vary significantly from the pre-op measurement ($P > 0.05$) (Table 3, Fig. 4). In group A, a global imbalance greater than 20 mm was found in 3 patients before surgery and in 3 patients at 2 years (Fisher's exact test, $P > 0.364$). None of these patients had global imbalance both before surgery and at 2 years. In Group B, a global imbalance greater than 20 mm was found in 5 patients before surgery and in 6 patients at 2 years (Fisher's exact test, $P > 0.302$). Two of these patients had global imbalance both before surgery and at 2 years. In Group C, a global imbalance greater than 20 mm was found in 8 patients before surgery and in 6 patients at 2 years (Fisher's exact test, $P > 0.213$). Three of these

Table 2 Radiographic measurements regarding lumbar curve behaviour

Measurement	Pre-op	Post-op	3-month	2-year	P value
LIV deviation (mm)					
Group A	−5.1 (−12.2, 2.1)	−23.5 (−27.0, −20.1)	−18.5 (−24.7, −12.4)	−14.0 (−22.8, −5.2)*	<0.023
Group B	−34.7 (−41.2, −28.2)	−25.7 (−32.5, −19.0)	−28.8 (−36.5, −21.2)	−28.6 (−35.7, −21.6)*	<0.044
Group C	−34.1 (−39.2, −28.9)	−26.8 (−31.2, −22.4)	−28.3 (−33.1, −23.5)	−29.0 (−33.9, −24.1)*	<0.030
LIV + 1 deviation (mm)					
Group A	−18.5 (−24.0, −13.0)	−29.8 (−33.3, −26.3)	−25.4 (−32.6, −18.1)	−21.2 (−30.5, −12.0)*	>0.241
Group B	−26.9 (−33.2, −20.6)	−22.0 (−29.8, −14.2)	−24.4 (−33.1, −15.6)	−24.5 (−32.7, −16.2)*	>0.247
Group C	−18.9 (−24.3, −13.6)	−16.1 (−19.7, −12.6)	−17.1 (−21.2, −13.0)	−17.8 (−22.5, −13.2)*	>0.304
LAV deviation (mm)					
Group A	−27.2 (−31.1, −23.2)	−32.2 (−35.4, −29.0)	−29.8 (−36.3, −23.3)	−26.5 (−33.6, −19.4)*	>0.401
Group B	−36.0 (−42.3, −29.8)	−28.0 (−34.9, −21.2)	−30.3 (−37.3, −23.3)	−30.4 (−36.9, −23.8)*	<0.046
Group C	−46.4 (−52.9, −39.9)	−34.4 (−39.9, −28.8)	−36.0 (−41.5, −30.5)	−35.7 (−41.5, −30.0)*	<0.001

Translation-deviation from the CSVL

Mean value reported with the range in parentheses

LIV lowest instrumented vertebra, LIV + 1 the first vertebra below LIV, LAV lumbar apical vertebra

* Compared with the pre-op value using paired *t* test; P value is given in the next cell

Fig. 3 At 2-year follow-up, the LIV, LIV + 1 and LAV were all more deviated than before surgery in Group A, whereas in Group B and C they were less deviated than before surgery. In other words,

post-op lumbar curve behaviour differs due to different choices of LIV with reference to LAV

Table 3 Radiographic measurements regarding post-op spinal balance

Measurement	Pre-op	Post-op	3-month	2-year	<i>P</i> value
T1 deviation (mm)					
Group A	−15.5 (−21.1, −10.0)	−19.1 (−24.7, −13.6)	−15.4 (−20.0, −10.8)	−14.3 (−21.3, −7.3)*	>0.396
Group B	−17.1 (−26.4, −7.7)	−26.4 (−38.2, −14.5)	−24.7 (−30.7, −18.7)	−22.3 (−28.9, −15.6)*	>0.187
Group C	−7.7 (−18.2, 2.8)	−17.2 (−26.7, −7.7)	−15.0 (−21.6, −8.3)	−4.6 (−15.3, 6.1)*	>0.200
Thoracic AV deviation (mm)					
Group A	34.1 (26.1, 42.1)	−8.1 (−13.9, −2.3)	−1.2 (−5.3, 2.9)	2.3 (−3.5, 8.0)*	<0.001
Group B	26.7 (13.5, 39.9)	−5.1 (−16.4, 6.1)	−3.6 (−13.7, 6.6)	0.6 (−8.9, 10.0)*	<0.001
Group C	25.1 (12.4, 37.8)	0 (−10.7, 10.0)	1.4 (−7.1, 9.9)	10.0 (−2.0, 22)*	<0.002

Translation-deviation from the CSVL

Mean value reported with the range in parentheses

thoracic AV thoracic apical vertebra

* Compared with the pre-op value using paired *t* test; the *P* value is given in the next cell

Fig. 4 The parameter of T1 deviation determined global coronal balance. In none of the three groups did the 2-year T1 deviation vary significantly from the pre-op measurement, that is, the surgery neither improved nor worsened global coronal balance. In addition to global balance, the onset of trunk shift was also investigated. Trunk shift was

determined with the parameter of thoracic AV deviation. According to the definition, trunk shift was found in 3 patients at 2-year follow-up in each group. No significant difference in incidence rate of trunk shift was found in the three groups

patients had global imbalance both before surgery and at 2 years. In summary, in each of the three groups, surgery neither improved nor worsened global coronal balance.

In addition to global balance, the onset of trunk shift was also investigated. Trunk shift was determined when thoracic AV shifted to the other side of the CSVL after surgery and remained on that side at 2 years with a deviation of greater than 5 mm. In accordance with this definition, trunk shift was found in 3 patients at 2-year follow-up in each

group; no significant difference in incidence rate of trunk shift was found in the three groups (Chi-square test, $P > 0.726$).

Discussion

In order to ensure positive outcomes after surgical treatment of AIS patients, appropriate selection of LIV is crucial. Failure to do so can lead to aggravation of the unfused

curve, distal adding on or spinal imbalance [9–12]. Lenke 3C and 6C curves in particular pose a substantial challenge in terms of the surgeon's decision, guidelines for LIV selection for these two curve types remain inclusive [13–15]. In our clinical practice, we sometimes observe that different choices of LIV can produce completely opposite outcomes. As such, we proposed a hypothesis that post-op curve behaviour differed due to different choices of LIV with reference to LAV in Lenke 3C and 6C scoliosis. To verify the hypothesis, we performed the current study in an effort to find an evidence-based means of selecting LIV, and hence improve clinical outcomes.

Post-op lumbar curve behaviour differs due to different choices of LIV with reference to LAV

In the current study, at 2-year follow-up, the lumbar vertebrae such as LIV, LIV + 1 and LAV were all more deviated than before surgery in Group A (LIV above LAV), whereas in Group B and C (LIV at and below LAV), they were all less deviated than before surgery. In other words, when the LIV ended above the LAV, the lumbar curve became more deviated from the CSVL, i.e. the deviation of the lumbar curve deteriorated, whereas when the LIV ended either at or below the LAV, the lumbar curve became less deviated, i.e. the deviation of the lumbar curve improved. As for the extent of the improvement and deterioration, on average, the LIV deviation at 2 years was 8.9 mm larger than before surgery in Group A ($P < 0.023$), 6 mm less than before surgery in Group B ($P < 0.044$) and 5 mm less than before surgery in Group C ($P < 0.030$). And the deviation of the LAV at 2 years was on average 0.7 mm larger than before surgery in Group A ($P > 0.401$), 5.7 mm less than before surgery in Group B ($P < 0.046$) and 10.7 mm less than before surgery in Group C ($P < 0.001$) (Fig. 5).

In addition, significant correlations were found between the pre-op level of LIV and 2-year LAV deviation and between the pre-op level of LIV and the change in LAV deviation (2-year—preoperative).

In summary, choosing either LAV or a vertebra below LAV as LIV can significantly improve the deviation of the lumbar curve, while choosing a vertebra above LAV as LIV cannot.

Correction rate and post-op spinal balance

In the current study, the results showed that thoracic correction rates were 0.60, 0.55 and 0.47 in Group A, B and C, respectively. Lumbar correction rates were 0.39, 0.42 and 0.40 in Group A, B and C, respectively. No significant differences were found in either thoracic or lumbar correction rate among the three groups. In other words, different choices of LIV with reference to LAV yield similar

results in terms of correction rate. As for post-op spinal balance, both global coronal balance and onset of trunk shift were evaluated. In each group, overall, surgery neither improved nor worsened global coronal balance. And in each group, trunk shift was found in 3 patients at 2-year follow-up. This indicates that there is no significant difference in global coronal balance and incidence rate of trunk shift among the three groups. As such, we conclude that different choices of LIV with reference to LAV yield similar results in terms of correction rate and post-op spinal balance.

Selection of LIV in Lenke 3C and 6C scoliosis

In a type-3C or 6C curve, generally, the main thoracic and thoracolumbar/lumbar components should be considered for arthrodesis according to Lenke's classification. 3C curves are also potentially amendable to selective thoracic fusion. When considering the potential to perform a selective fusion, the ratio criteria of MT:TL/L structural characteristics of Cobb magnitude, AVT, AVR and flexibility ratios must be assessed. When these ratios of the major curve intended for selective fusion to the minor compensatory curve are ≥ 1.2 , selective fusion should be possible [16].

In addition, for either 3C or 6C curves, when the main thoracic and thoracolumbar/lumbar components are considered for arthrodesis, the fusion does not necessarily need to extend to the lowest end vertebra. How to select LIV in Lenke 3C and 6C scoliosis remains inconclusive. Longer fusion can result in better correction, whereas shorter fusion can save more lumbar mobility and growth potential. Stable vertebra (SV), lowest end vertebra (LEV) and neutral vertebra (NV) are commonly used for determining LIV [17–19]. In the current study, we proposed an option of using LAV as a reference to determine LIV in Lenke 3C and 6C scoliosis. Our results suggest that different choices of LIV in relation to LAV yield similar results in terms of correction rate and post-op spinal balance, whereas in terms of lumbar curve deviation, the best improvement occurs when the LIV is below the LAV, moderate improvement when the LIV is at the LAV and no improvement when the LIV is above the LAV. On the other hand, the efficacy of correction is not the only consideration when selecting LIV, conserving growth potential and lumbar spine mobility is also important. Choosing LAV as LIV can preserve at least one lumbar vertebra compared with choosing a vertebra below LAV as LIV. As such, although the greatest correction occurs when the LIV is below the LAV, choosing LAV as LIV can still be the optimal option in certain cases, since it can yield similar correction while preserving more lumbar mobility and growth potential.

Fig. 5 Examples of the three groups are shown in this figure. Example of Group A: a 16-year-old girl with Lenke 3C scoliosis, the pre-op LAV was at L3 and the LIV was at T12. The deviation of LAV increased from 35.2 to 41 mm due to surgery. Example of Group B: an 18-year-old girl with Lenke 3C scoliosis, the pre-op LAV was at

L2 and the LIV was also at L2. The deviation of LAV decreased from 37.8 to 17.4 mm due to surgery. Example of Group C: a 16-year-old girl with Lenke 3C scoliosis, the pre-op LAV was at L1 and the LIV was at L2. The deviation of LAV decreased from 38 to 19 mm due to surgery

Conclusions

In Lenke 3C and 6C scoliosis, post-op lumbar curve behaviour differs due to different choices of LIV with

reference to LAV, that is, the deviation of lumbar curve improves when the LIV is either at or below the LAV but deteriorates when the LIV is above the LAV. Although the greatest correction occurs when the LIV is below the LAV,

choosing LAV as LIV can still be the optimal option in certain cases, since it can yield similar correction while preserving more lumbar mobility and growth potential.

Acknowledgements The authors thank the Danish Strategic Research Council for financial support. The authors thank Linda Marie Nygaard for her revisions of the manuscript, and also thank Astrid Hedegaard Konradsen for her excellent work in radiographic follow-up.

Conflict of interest None.

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