Extensive fusion for Lenke 3C and 6C scoliosis: a two year radiographic follow-up

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Abstract

Purpose To investigate the correction effectiveness, incidence rate of distal adding on, and post-operative spinal balance in Lenke 3C and 6C AIS treated with extensive fusion using posterior pedicle screw-only constructs.

Methods We reviewed all AIS cases surgically treated in our institution between 2002 and 2008. The inclusion criteria were as follows: (1) Lenke 3C or 6C scoliosis patients who were treated with extensive fusion using posterior pedicle screw-only constructs; (2) minimum two year radiographic follow-up; (3) the lowest instrumented vertebra (LIV) ended at L2, L3 or L4 level. All image data were available in our picture archiving and communication systems (PACSs), and all radiographic measurements were performed. Standing anteroposterior (AP) and lateral digital radiographs were reviewed at four different time points (pre-op, post-op, three months, and two years). In each standing AP radiograph, CSVL (center sacral vertical line, the vertical line bisecting the proximal sacrum) was first drawn, followed by measurement of the translation (deviation from the CSVL) of some key vertebrae, such as the lowest instrumented vertebra (LIV), LIV+1 (the first vertebra below LIV), lumbar apical vertebra, thoracic apical vertebra and T1, enabling depiction of how translation of different parts of the spine changes over time. Additionally, the Cobb angles of major thoracic and lumbar curves were

measured at the different time points and the correction rate was calculated.

Results Of the 278 patients reviewed, 25 met the inclusion criteria. Immediately after surgery, satisfactory corrections were achieved from the perspective of not only Cobb angle but also vertebral translation. And the corrections were well retained in the following two years. The incidence rate of distal adding-on was low in this group of patients. In the course of two years following surgery, only six patients had an increase of greater than 5 mm in LIV+1 translation, and among which only two patients had greater than 10 mm. Regarding global balance, overall, it neither improved nor deteriorated after extensive fusion. Furthermore, trunk shift was found in only three patients at two year follow-up.

Conclusions In Lenke 3C and 6C scoliosis, extensive fusion can produce satisfactory corrections from the perspectives of both Cobb angle and vertebral translation and rarely causes significant distal adding-on, global imbalance or trunk shift.

Introduction

Extensive fusion is a surgical treatment option for adolescent idiopathic scoliosis (AIS). It is distinguishable from selective thoracic or lumbar fusion in that the arthrodesis encompasses the main thoracic as well as thoracolumbar/lumbar curves [1–4]. Our study focused on Lenke 3C and 6C scoliosis. Type 3C curves constitute the majority of type 3 curves, because types 3A and 3B curves are rare. Similarly, type 6C curves represent all type 6 curves, because there are no curve types 6A and 6B. In this single-case cohort, patients with either a type 3C or 6C curve were studied, because both curve types share the same treatment strategy. According to a new classification system [5], when

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a patient has either a type 3C or 6C curve, both the thoracic and thoracolumbar/lumbar curves should be included in the arthrodesis. Essentially, types 3C and 6C curves are largely identical with only minor differences: both consist of thoracic and thoracolumbar/lumbar curves, each of which are structural. The main difference between lies in which part of the spine is defined as the major curve. For a type 3C curve, the major curve is thoracic, because the Cobb angle of the thoracic curve is larger than that of the thoracolumbar/lumbar curve. Likewise, for a type 6C curve, the major curve is thoracolumbar/lumbar, because the Cobb angle of the thoracolumbar/lumbar curve is larger than that of the thoracic curve.

Few studies have focused on these two curve types in particular. Many previous studies include different curve patterns, which may obscure findings specific to a certain group of patients. In addition, few studies are based on posterior pedicle-screw-only constructs, an approach which is becoming progressively widespread in the treatment of AIS. The effect of the new constructs on post-operative curve behaviour needs to be examined. Furthermore, certain issues regarding Lenke 3C and 6C scoliosis need to be thoroughly investigated in relation to how effective extensive fusion is in terms of correction, how high the incidence rate of distal adding on is and whether or not post-operative spinal balance can be achieved in the long run. Thus, the purpose of this study was to investigate correction effectiveness, incidence

rate of distal adding on and post-operative spinal balance in Lenke 3C and 6C AIS treated with extensive fusion using posterior pedicle-screw-only constructs.

Materials and methods

We reviewed all AIS cases surgically treated in our institution between 2002 and 2008. Collection and analysis of radiographic and clinical data were performed by individuals not directly involved in the patients' surgery. The inclusion criteria were as follows: (1) Lenke 3C or 6C scoliosis patients who were treated with extensive fusion using posterior pedicle-screw-only constructs; (2) minimum two year radiographic follow-up; (3) the lowest instrumented vertebra (LIV) ended at L2, L3 or L4 level. All image data were available in our picture archiving and communication systems (PACS), and all radiographic measurements were performed. Standing anteroposterior (AP) and lateral digital radiographs were reviewed at four different time points (preoperatively, postoperatively, three months and two years). In each standing AP radiograph, centre sacral vertical line (CSVL), the vertical line bisecting the proximal sacrum, was first drawn, followed by measurement of the translation (deviation from the CSVL) of some key vertebrae, such as the LIV, LIV+1 (the first vertebra below LIV), lumbar apical vertebra, thoracic apical vertebra and T1

Fig. 1 Definitions of the radiographic parameters: *CSVL* centre sacral vertical line, the vertical line which bisects proximal sacrum [3]; *AV* apical vertebra, *LIV* lowest instrumented vertebra, *LIV+1* the first vertebra below *LIV*, *AVT* apical vertebra translation, distance in millimetres from the *CSVL* to the midpoint of the apical body. The midpoint of a vertebral body is determined by drawing a cross (X) 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 midpoint; when the midpoint is on the right side of the *CSVL*, the value of the vertebral deviation is defined as a positive value; when on the left side, it is defined as a negative value. *T1 translation* distance in millimetres from the *CSVL* to the midpoint of the T1

(Fig. 1), enabling depiction of how translation of different parts of the spine changes over time. The CSVL should bisect the cephalad aspect of the sacrum and be perpendicular to the true horizontal. Pelvic obliquity secondary to limb-length inequality of <2 cm was ignored. In those cases and when the discrepancy was >2 cm, the coronal radiograph was made with the appropriately sized lift under the short limb [3]. Additionally, the Cobb angles of major thoracic and lumbar curves were measured at the different time points, and the correction rates (CR) were then calculated: $CR = (\text{pre-operative Cobb angle} - \text{post-operative Cobb angle}) / \text{pre-operative Cobb angle}$. Distal adding on was defined as an increase in the number of vertebra included within the Cobb distally. All measurements were performed by one of the authors and repeated by another. The average measurement values obtained by the two authors were used for the final analyses, and measurement errors were calculated.

Statistical analysis

Distributions of variables are presented as means $\pm$ standard deviation (SD). For each parameter, repeated measures analysis of variance (ANOVA) were used to test whether there was significant difference among different time points. Paired *t* test was used to detect the difference between the two time points. Significance level was defined as 0.05. Data were analysed by with STATA 10.1 software (Stata Corp., College Station, TX, USA).

Results

Of the 278 patients reviewed, 25 met the inclusion criteria and were included; ten of these were Lenke 3C and the remaining 15 Lenke 6C. Mean age at surgery was 18.2 (range

13–23.7) years. The lowest LIV was L2 in six patients, L3 in 11 and L4 in the remaining eight. In the PACSs, length measurement precision was 0.1 mm and angle measurement precision was 0.1° . Average error in length measurement was 1.5 mm (range 0–3.9 mm) and average error in angle measurement was 3.5° (range 0–5.2°). Lateral radiographs revealed no significant changes in spinal alignment over time. Results of the radiographic measurements are shown in Table 1 and Fig. 2.

Correction effectiveness of extensive fusion

The average correction rates for thoracic and lumbar curves immediately after surgery were 0.55 and 0.52, respectively. These corrections were retained in the following two years. Vertebral translation correction was also satisfactory. On average, translation of both the thoracic and lumbar AV, decreased significantly after surgery (Fig. 3). These corrections were also retained in the following two years (Fig. 4). In only five of the 25 patients was the lumbar AVT larger than before surgery at two year follow-up. Lumbar AVT increased on average by 7.1 mm in the five patients and decreased on average by 15 mm in the remaining 20 patients.

Incidence rate of distal adding on

According to the definition of distal adding on, two of the 25 patients presented with distal adding on.

Postoperative spinal balance

The parameter of T1 translation determined global coronal balance. In general, global balance deteriorated

Table 1 Measurements at four time periods

Measurement	Pre-operative	Post-operative	Three month	Two year	P value
Thoracic Cobb ($^\circ$)	57.5 (35.0, 94.8)	25.8 (3.4, 41.9) *	28.7 (0.7, 53.0) *†	29.3 (0.7, 55.8) *†	<0.001
Lumbar Cobb ($^\circ$)	58.0 (36.5, 99.7)	28.0 (11.3, 54.3) *	31.5 (13.2, 56.0) *†	33.7 (13.2, 68.5) *†	<0.001
T1 translation (mm)	−8.9 (−41.6, 34.6)	−20 (−55.0, 26.1) *	−15.7 (−38.4, 14.6) *	−8.9 (−38.2, 53.0) †	<0.001
Thoracic AV translation (mm)	28.0 (−10.3, 79.0)	0.3 (−42.6, 47.6) *	3.3 (−27.2, 38.0) *	9.7 (−28.0, 64.6) *†	<0.001
Lumbar AV translation (mm)	−43.0 (−74.3, −25.8)	−31.2 (−52.5, −14.8) *	−32.4 (−58.4, −15.2) *	−32.5 (−58.2, −14.4) *	<0.001
LIV translation (mm)	−33.5 (−56.0, −18.7)	−24.8 (−41.4, −11.4) *	−26.2 (−45.8, −13.2) *	−26.9 (−49.3, −11.6) *	<0.001
LIV+1 translation (mm)	−20.0 (−38.6, −3.6)	−15.9 (−31.6, −4.0) *	−16.8 (−36.0, −4.6) *	−17.4 (−37.3, −2.0)	<0.001

Mean value reported with the range in parentheses; for each parameter, repeated measures ANOVA was used to test if there is an overall significant difference between the means at the different time points

Translation deviation from the centre sacral vertical line (CSVL), AV apical vertebra

* Significantly different from the corresponding pre-operative value, $P < 0.05$

† Significantly different from the corresponding post-operative value, $P < 0.05$

Fig. 2 Satisfactory corrections were achieved from the perspectives of both Cobb angle and vertebral translation and well retained in the following two years. Additionally, global balance, represented by the parameter of T1 translation, deteriorated immediately after surgery.

However, it improved consistently in the following two years. At two year follow-up, it showed no significant difference compared with before surgery

immediately after surgery. However, it improved consistently in the following two years. At the two year follow-up, T1 translation showed no significant difference compared with before surgery. A global imbalance >20 mm was found in ten patients before surgery and ten at two years. Four of these

patients had global imbalance both before surgery and at two years. In addition to global balance, the onset of trunk shift was also investigated. Trunk shift was determined when thoracic AV shifted from one side to the other of the CSVL due to the surgery and remained on that side at two years with a

Fig. 3 A 12-year-old girl with Lenke 3C scoliosis underwent correction surgery. Immediately after surgery, satisfactory correction was achieved, i.e. Cobb angle and vertebral translation decreased significantly due to the surgery

Fig. 4 A 15-year-old girl with Lenke 6C scoliosis underwent correction surgery. In the course of two years following surgery, the correction was well retained in terms of both Cobb angle and vertebral translation.

translation >5 mm. In accordance with this definition, trunk shift was found in three patients at two year follow-up.

Discussion

Extensive fusion, a widely accepted procedure for treating AIS, is characterised by its inclusion of both thoracic and lumbar curves in the arthrodesis. In addition to extensive fusion, selective thoracic and lumbar fusions are also treatment options for AIS [6–13]. According to a new classification system for AIS, extensive fusion is mainly appropriate for treating Lenke 3 and 6 scoliosis [5]. Because Lenke 3A and 3B scoliosis types are rare, and because there are no Lenke 6A and 6B types, extensive fusion is actually mainly for Lenke 3C and 6C scoliosis. Our study focused on these two types of scoliosis treated with extensive fusion using pedicle-screw-only constructs and aimed to investigate correction effectiveness, incidence rate of distal adding on and postoperative spinal balance.

Correction effectiveness of extensive fusion for Lenke 3C and 6C scoliosis

Extensive fusion resulted in satisfactory corrections from the perspective of not only Cobb angle but also vertebral translation. Cobb angle is the most commonly used parameter for evaluating curve correction. Regarding Cobb correction, segmental instrumented fusion has been demonstrated in the literature to correct the curves well with minimal loss of correction over time, which are not specific

for 3C or 6C curves. However, Cobb angle alone is not always sufficiently comprehensive in the evaluation; we occasionally observe that surgery improves the Cobb angle but deteriorates vertebral translation, especially in Lenke 1C patients treated with selective thoracic fusion. In Lenke 1C patients, although surgery significantly improves lumbar Cobb angle, the lumbar spine is often more deviated from the CSVL after surgery and hence the entire spine becomes unbalanced [14, 15]. Thus, vertebral translation should also be taken into consideration when evaluating curve correction. In this study, Cobb angle and vertebral translation improved significantly after surgery in both the thoracic and lumbar regions. After two years, only five of the 25 patients had larger lumbar AVT than before surgery. The reason the lumbar AVT increased could be the shorter fusion extent in the distal end in these five patients. Having a fusion end that is too short can result in insufficient correction of the lumbar curve, so that the vertebral translation of the lumbar spine may not be well decreased. In summary, we conclude that extensive fusion in Lenke 3C and 6C scoliosis can produce satisfactory corrections from the perspectives of both Cobb angle and vertebral translation.

Incidence rate of distal adding on

Distal adding on, a postoperative complication in patients with AIS, is characterised by main curve progression and often accompanied by unsatisfactory clinical outcomes and a high risk of re-operation. In this study, distal adding on was defined as an increase in the number of vertebrae included within the Cobb distally [16–18]. According to the

definition, two of the 25 patients presented with distal adding on. The incidence rate is much lower than that of Lenke 1A scoliosis. Wang et al. [19] reported that 22 of 45 Lenke 1A patients had an increase >5 mm in LIV+1 translation at 1-year follow-up, 13 of which were >10 mm. In conclusion, extensive fusion rarely causes significant distal adding on in Lenke 3C and 6C scoliosis.

Post-operative spinal balance

A global imbalance >20 mm was found in ten patients before surgery and in ten at two year follow-up. Four of these patients had global imbalance both before surgery and at 2 years. In other words, overall global coronal balance neither improved nor deteriorated after extensive fusion. However, the manner in which global balance changed over time is interesting. Initially, the average global balance deteriorated due to surgery and then improved consistently in the following two years. At two year follow-up, the average global balance was similar to that before surgery. The mechanism of this phenomenon is still unclear; balance reflex could be the main cause, although further studies are needed to warrant the claim. Furthermore, although T1 translation is one of the parameters for evaluating global spinal balance, it may not be appropriate for evaluating trunk shift, because T1 translation only represents translation of the upper part of the thoracic spine. When the thoracic spine is tilted, it cannot represent the translation of the entire thoracic spine. Therefore, we defined thoracic AVT as the parameter of leftward spinal imbalance, which can be determined if the thoracic AV is >5 mm further from the CSVL on the left side. This definition was established because the thoracic AV was on the right border of the thoracic curve. If the thoracic AV is on the left side of the CSVL, then the bulk of the thoracic spine must also be on the left side, which can be considered as leftward imbalance. In accordance with this definition, trunk shift was found in three patients at two year follow-up. In summary, we conclude that extensive fusion rarely causes global imbalance and trunk shift in Lenke 3C or 6C scoliosis.

Treatment strategies for Lenke 3C and 6C scoliosis

Although 3C and 6C curves should be considered for extensive fusion according to Lenke's classification system [5], 3C and 6C curves are also potentially amendable for a selective fusion [20]. Extensive fusion provides more correction, whereas selective fusion provides the potential for spontaneous minor curve correction and maintains more lumbar motion segments. 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 [20]. In addition, although extensive fusion is defined as an arthrodesis that encompasses the main thoracic as well as thoracolumbar/lumbar curves, 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. In eight of 25 patients in this study, LIV was at the same level as the lumbar apical vertebra (Fig. 3). Although this is a shorter fusion, acceptable correction was achieved. However, to guarantee satisfactory correction, we believe it is better that fusion end below lumbar apical vertebra. Further studies are needed to compare the outcomes of different choices of LIV. One limitation of this study is that only 25 patients were assessed. A larger cohort is desirable to achieve a more valid conclusion.

Conclusions

In Lenke 3C and 6C scoliosis, extensive fusion can produce satisfactory corrections from the perspectives of both Cobb angle and vertebral translation and rarely causes significant distal adding on, global imbalance or trunk shift.

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