

The Efficacy of Proximal Lumbar Curve Flexibility in Patients with Main Thoracic Adolescent Idiopathic Scoliosis Treated by Selective Thoracic Fusion Surgery

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Study Design: Retrospective radiographic study

Purpose: To evaluate the efficacy of the proximal lumbar curve flexibility compared with the traditional whole lumbar curve flexibility in patients with main thoracic adolescent idiopathic scoliosis (MT-AIS).

Overview of Literatures: Traditionally the flexibility of the whole lumbar curve was measured, and the flexibility of the proximal lumbar curve was not analyzed in any study.

Methods: Twenty-eight MT-AIS patients treated by anterior selective thoracic fusion (STF) were evaluated after mean follow-up of 50.1 months (range, 25 to 116 months). The male : female ratio was in 5 : 23. The mean age at surgery was 14 years and 8 months (range, 11.4 to 18.4 years). The lumbar curve was divided into the proximal and distal curves by the lumbar apex.

Results: The mean final correction rates (CR)/(flexibilities) of the MT, lumbar, proximal lumbar, and distal lumbar curves were 65.2%/(50.5%), 61.9%/(92.8%), 65.3%/(90.9%), and 36.4%/(134%), respectively. With the final lumbar CR, the lumbar flexibility ($r = 0.267$, $p > 0.05$) and the proximal lumbar flexibility ($r = 0.327$, $p > 0.05$) was similarly correlated. The mean lumbar CR was similar to the proximal lumbar CR (61.9% vs. 65.3%, $p = 0.305$). And the correlation between the flexibility and the CR was significant only in the proximal lumbar curve ($r = 0.457$, $p < 0.05$), but not in the lumbar curve ($r = 0.267$, $p > 0.05$) or the distal lumbar curve ($r = 0.175$, $p > 0.05$).

Conclusions: The proximal lumbar curve flexibility may be an alternative method of measuring the lumbar flexibility in MT-AIS patients treated by STF.

Key Words: Adolescent idiopathic scoliosis, Selective thoracic fusion, Lumbar flexibility, Proximal lumbar flexibility

Introduction

The surgeon should decide which curve should be fused in the surgical treatment of adolescent idiopathic scoliosis (AIS). The preoperative curve flexibility in the coronal

plane is one of the most important indicators of whether the curve is structural. The method for measuring the curve flexibility is reliable if the curve flexibility approximates the final curve correction rate and has a high index of reproducibility. The curve flexibility by active side bending in the supine position is a method commonly used to measure

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the curve flexibility, even though several other methods have been introduced.

Most reports related to the curve flexibility described the relationship between the thoracic and lumbar curves. Lenke et al. [1] reported that the lumbar curve was corrected spontaneously and continuously after anterior or posterior selective thoracic fusion (STF) in a single thoracic curve (spontaneous lumbar curve correction, SLCC). On the other hand, Patel et al. [2] reported that the preoperative lumbar curve flexibility and final thoracic correction rate were important factors affecting the degree of SLCC, and it was also important if the lowest fusion included the lumbar curve or not.

To the authors' knowledge, there are no reports dividing the lumbar curve into the proximal and distal areas in order to analyze the spontaneous lumbar response after STF for patient with main thoracic (MT) AIS. After STF, most lumbar coronal correction occurred in the proximal area above the lumbar apex [3], and the authors reported similar results [4,5]. The authors explained the results that the proximal lumbar coronal curve could be corrected more than the distal lumbar area, because that the proximal lumbar curve became more lordotic (mobilized) in the sagittal plane immediately after surgery. The mobility of the spinal segment increases as the segment becomes lordotic. Immediately after surgery, the distal lumbar area became less lordotic (stabilized) in the sagittal plane whereas the proximal lumbar area became more lordotic (mobilized). As the lumbar response was different at the proximal and the distal areas, and most of the lumbar coronal correction occurred in the proximal area, they believed that the curve flexibility of the proximal lumbar area might be meaningful.

This retrospective radiographic study examined whether the curve flexibility of the proximal lumbar area would be more meaningful than the whole lumbar curve flexibility after STF for patients with MT AIS.

Materials and Methods

1. Materials

The plain radiographs of 28 patients with MT AIS treated by anterior STF were evaluated retrospectively. The patients underwent surgery between September 1994 and May 2004 in Klinikum Karlsbad-Langensteinbach, Germany. The mean age at surgery was 14 years and 8 months

(range, 11.4 to 18.4 years). There were 5 males and 23 females. The mean follow-up was 50.1 months (range, 25 to 116 months). The images contained curves with Lenke's lumbar modifier A, B, and C. The following cases were excluded to minimize selection bias: cases with a proximal thoracic Cobb angles $> 25^\circ$ on side-bending (Lenke type 2 curves), cases with lumbar modifier A in which the body center of the lumbar apex did not cross the center sacral vertical line and cases where distal fusion exceeded more than one level distal to the lower end vertebra (EV) of the MT curves. A senior surgeon (JH) performed the surgery using the standard surgical approach of one incision, a double thoracotomy to obtain access to the entire MT vertebrae and occasionally up to the first lumbar vertebra [6]. The instruments used were a Moss Miami Spine System (Depuy Spine, Inc., Raynham, MA, USA) in 23 patients and a Moss Spine System (Depuy Spine) in 5 patients.

2. Methods

The measurement in each patient was performed by the first author (KHN) using 8 plain radiographs; posteroanterior and lateral long cassette standing radiographs without a brace preoperatively, immediate postoperatively and at the last follow-up period, as well as preoperative long cassette active bending radiographs in the supine position. The immediate postoperative radiographs were checked 7 to 14 days after surgery. According to the literature, which reported that most coronal motion occurs between the lowest instrumented vertebra and lumbar apical vertebra (AV) after STF [3], and the similar results of the authors [4,5], the lumbar curve was divided into the proximal and distal curves by the lumbar apex. The proximal lumbar curve was measured from the lower endplate of the upper EV to that of AV, and the distal lumbar curve was measured from the lower endplate of AV to that of the lower EV. The preoperative flexibility and correction rates after surgery and at the last follow-up period were measured in the MT, lumbar, proximal and distal lumbar curves.

The mean curve flexibilities or correction rates were compared, and the correlations between the curve flexibility, between the correction rates, and between the curve flexibility and correction rates were analyzed. Statistical analysis was performed using SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA). T-tests were used to compare the means, and Pearson's correlation and linear regression analyses were applied. A p -value < 0.05 was considered significant.

Results

The upper EV of lumbar the curve was at T10 (4 cases), T11 (12 cases), or T12 (12 cases), and the mean upper EV was at approximately T11 (11.3). The lumbar lower EV was at L3 (4 cases), L4 (16 cases), or L5 (4 cases), and the mean lower EV was at approximately L4 (16.0). The lumbar AV was at L1 (3 cases), L2 (9 cases), L3 (15 cases), or L4 (1 cases), and the mean AV was between L2 and L3 (14.5).

The mean curve segment was 3.3 in the proximal lumbar curve and 1.4 in the distal lumbar curve. In most cases, the distal fusion stopped at T11 or T12 (27 cases) and in 1 case at L1. The distal fusion level (mean, 11.8) was similar to the neutral vertebra level (mean, 11.7), and 0.5 segments lower than the lower EV level (mean, 11.3). The coronal C7 plumb line was well maintained from - 4.3 mm before surgery to - 6.6 mm at the last follow-up. Finally, 3 cases were decompensated by the definition of a trunk shift > 20 mm, and 9 cases by 10 mm.

1. Correlations between the correction rates

During the follow-up, the lumbar curve was corrected

continuously from 14.2° to 13.6° but the MT curve correction was lost from 14.0° to 18.1°. The proximal lumbar was corrected continuously from 10.5° to 9.0° but the distal lumbar curve correction was lost from 3.3° to 4.6° (Table 1).

Finally, the MT curve was more corrected (65.2%, 52.5° to 18.6°) than the curve flexibility (50.5%). The lumbar curve was less corrected (61.9%, 35.0° to 13.6°) than the curve flexibility (92.8%). The proximal lumbar curve was less corrected (65.3%, 25.8° to 9.0°) than the curve flexibility (90.9%). On the other hand, the distal lumbar curve was much less corrected (36.4%, 9.0° to 4.6°) than the curve flexibility (133.4%) (Table 2). Finally, 76% of the lumbar curve correction occurred at the proximal lumbar curve. As the curve segment was 3.3 and 1.4 in the proximal and distal lumbar curves, respectively, the mean correction rates per segment was 23% in the proximal lumbar curve and 17% in the distal lumbar curve.

The MT and lumbar correction rates differed immediately after surgery (73.6% and 59.5%, respectively) ($p = 0.000$), which became similar at the last follow-up (65.2% and 61.9%, respectively) ($p = 0.289$) (Tables 2 and 3). The correlation between the MT and lumbar correction rates were moderate after surgery ($r = 0.347$, $p = 0.050$), and at the last follow-up ($r = 0.584$, $p = 0.001$) (Table 4).

Table 1. The mean coronal Cobb angles of the curves (degrees)

	Main thoracic	Lumbar	Proximal lumbar	Distal lumbar
Side-bending	26.2	2.9	2.6	- 2.2
Preoperative	52.0	35.0	25.8	9.0
After surgery	14.0	14.2	10.5	3.3
At last follow-up	18.1	13.6	9.0	4.6

Table 2. The flexibility and the correction rates of the curves

	Main thoracic (%)	Lumbar (%)	Proximal lumbar (%)	Distal lumbar (%)
Flexibility	50.5	92.8	90.9	133.4
CR after surgery	73.6	59.5	59.2	73.7
CR at last FU	65.2	61.9	65.3	36.4

CR: Correction rate, FU: Follow-up.

Table 3. The time-matched comparison of the correction rates by paired t-test (p -value)

	Lumbar CR	Proximal lumbar CR	Distal lumbar CR
MT - CR after surgery	0.000	0.003	0.000
MT - CR at last FU	0.289	0.991	0.001
Lumbar CR after surgery		0.916	0.000
Lumbar CR at last FU		0.305	0.000

CR: Correction rate, MT: Main thoracic, FU: Follow-up.

The proximal lumbar coronal correction rate was similar to the lumbar correction rate after surgery (59.5% vs. 59.2%, respectively) ($p = 0.916$), and at the last follow-up (61.9% vs. 65.3%, respectively) ($p = 0.305$). In addition, the above two correction rates were strongly correlated after surgery ($r = 0.769$, $p = 0.000$) and at the last follow-up ($r = 0.725$, $p = 0.000$) (Fig. 1). However, there was a significant difference between the distal lumbar correction rate and the lumbar correction rate after surgery (73.7% vs. 59.5%, respectively) ($p = 0.000$) and at the last follow-up (36.4% vs. 65.3%, respectively) ($p = 0.000$). In addition, the above two were not significantly correlated after surgery ($r = 0.058$, $p > 0.05$), and at the last follow-up ($r = 0.096$, $p > 0.05$).

2. Correlations between the flexibilities

The proximal lumbar flexibility was similar to the lumbar flexibility (90.9% vs. 92.8%) ($p = 0.674$) but the distal lum-

bar flexibility was larger (133.4%) and different from the lumbar flexibility ($p = 0.001$).

The MT flexibility (50.5%) was not correlated with the lumbar flexibility (92.8%) ($r = 0.118$, $p > 0.05$), the proximal lumbar flexibility (90.9%) ($r = 0.118$, $p > 0.05$), or the distal lumbar flexibility (133.4%) ($r = 0.132$, $p > 0.05$) (Table 5). The proximal lumbar flexibility ($r = 0.647$, $p = 0.000$) and distal lumbar flexibility ($r = 0.678$, $p = 0.000$) showed a strong correlation with the lumbar flexibility.

3. The correlations between the correction rates and the flexibilities

The correlation between the flexibility and correction rate of the MT curve was moderate after surgery ($r = 0.392$, $p = 0.039$) but insignificant at the last follow-up ($r = 0.267$, $p = 0.169$) (Table 6). In the lumbar curve, the above correlation was not significant after surgery ($r = 0.333$, $p > 0.05$) and at

Table 4. The time-matched correlation between the correction rates (r)

	Lumbar CR	Proximal lumbar CR	Distal lumbar CR
MT - CR after surgery	0.374 ^{a)}	0.283	0.037
MT - CR at last FU	0.584 ^{b)}	0.342	0.026
Lumbar CR after surgery		0.769 ^{b)}	0.058
Lumbar CR at last FU		0.725 ^{b)}	0.096

MT: Main thoracic, CR: Correction rate, FU: Follow-up.

^{a)} Significant correlation at 0.05 level, ^{b)} Significant correlation at 0.01 level.

Table 5. The correlation between the flexibilities (r)

	Lumbar F	Proximal lumbar F	Distal lumbar F
MT - F	0.118	0.118	0.132
Lumbar F		0.647 ^{b)}	0.678 ^{b)}

F: Flexibility, MT: Main thoracic.

^{a)} Significant correlation at 0.05 level, ^{b)} Significant correlation at 0.01 level.

Table 6. The correlation between the flexibilities and the correction rates (r)

	MT-F	Lumbar F	Proximal lumbar F	Distal lumbar F
MT - CR after surgery	0.392 ^{a)}			
MT - CR at last FU	0.267			
Lumbar CR after surgery		0.333	0.502 ^{b)}	0.321
Lumbar CR at last FU		0.267	0.327	0.342
Proximal Lumbar CR after surgery		0.331	0.576 ^{b)}	
Proximal Lumbar CR at last FU		0.238	0.457 ^{a)}	
Distal Lumbar CR after surgery		0.054		0.171
Distal Lumbar CR at last FU		0.061		0.175

F: Flexibility, MT: Main thoracic, CR: Correction rate, FU: Follow-up.

^{a)} Significant correlation at 0.05 level, ^{b)} Significant correlation at 0.01 level.

the last follow-up ($r = 0.267, p > 0.05$). In addition, in the distal lumbar curve, the above correlation was insignificant after surgery ($r = 0.171, p > 0.05$) and at the last follow-up ($r = 0.175, p > 0.05$). Only the proximal lumbar curve showed a significant correlation between the flexibility and correction rate after surgery ($r = 0.576, p = 0.001$) and at the last follow-up ($r = 0.267, p = 0.015$).

Interestingly, after surgery, the lumbar correction rate was not significantly correlated with the lumbar flexibility ($r = 0.333, p = 0.083$) but was moderately correlated ($r = 0.502, p = 0.007$) (Table 6, Fig. 2). At the last follow-up, the lumbar correction rate was not significantly correlated with the lumbar flexibility ($r = 0.267, p = 0.169$) or proximal lumbar flexibility ($r = 0.327, p = 0.090$) (Fig. 3). On the other hand,

the proximal lumbar correction rate was moderately associated with the proximal lumbar flexibility ($r = 0.576, p = 0.001$ after surgery; $r = 0.457, p = 0.015$ at last follow-up). However, the proximal lumbar correction rate was not associated with the lumbar flexibility ($r = 0.331, p = 0.086$ after surgery; $r = 0.238, p = 0.224$ at last follow-up).

Discussion

After STF using the recently developed segmental pedicle screw fixation system, the MT correction rate was reported to exceed the MT flexibility, even though the lumbar correction was far less than the lumbar flexibility. This study

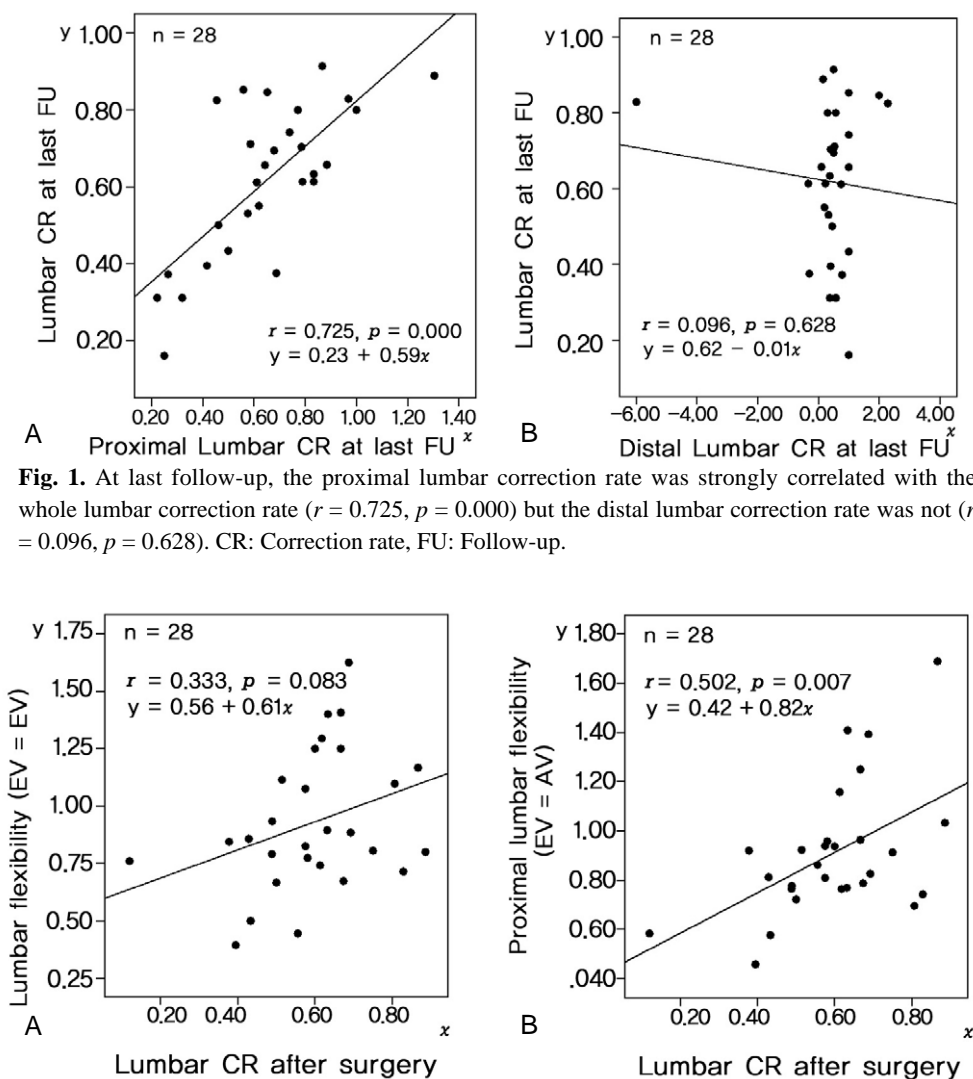


Fig. 1. At last follow-up, the proximal lumbar correction rate was strongly correlated with the whole lumbar correction rate ($r = 0.725, p = 0.000$) but the distal lumbar correction rate was not ($r = 0.096, p = 0.628$). CR: Correction rate, FU: Follow-up.

Fig. 2. Immediately after surgery, the proximal lumbar flexibility was moderately correlated with the lumbar coronal correction rate ($r = 0.502, p = 0.007$). However, the whole lumbar flexibility was not associated with the lumbar coronal correction rate ($r = 0.333, p = 0.083$). EV: End vertebra, AV: Apical vertebra, CR: Correction rate.

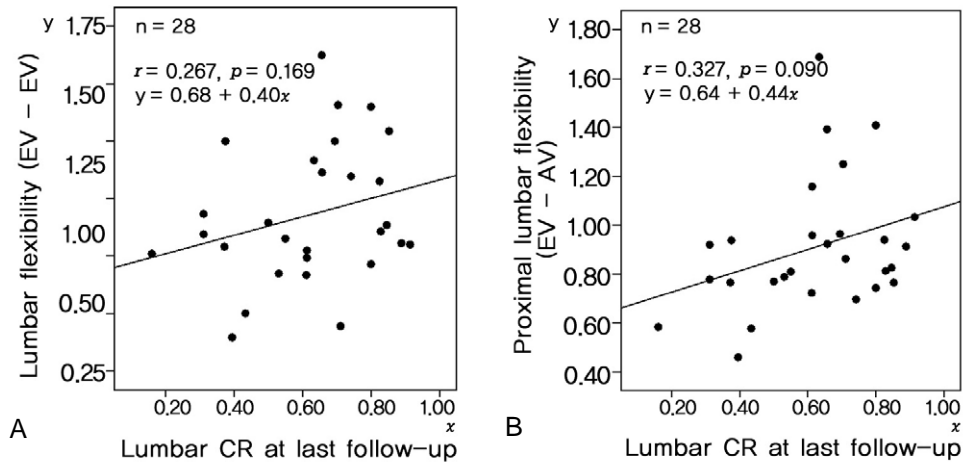


Fig. 3. At the last follow-up, the whole lumbar flexibility ($r = 0.267$, $p = 0.169$) and proximal lumbar flexibility ($r = 0.327$, $p = 0.090$) showed no significant correlations with the whole lumbar coronal correction rate. EV: End vertebra, AV: Apical vertebra, CR: Correction rate.

showed similar results in that the MT correction rate after surgery (73.6%) exceeded the MT flexibility (50.5%), even though the lumbar correction rate after surgery (59.5%) was far less than the lumbar flexibility (92.8%). However, during the follow-up, the MT correction was lost, and the lumbar correction increased continuously (final correction of 65.2% and 61.9%, respectively).

An interesting finding was obtained by dividing the lumbar curve into the proximal and distal curves. During the follow-up, the proximal lumbar correction rate increased continuously (59.2% to 65.3%) similar to the whole lumbar curve. However, the distal lumbar correction was lost in a similar manner to the MT curve (73.7% to 36.4%), and there was no spontaneous curve correction in the distal lumbar curve (Table 2). Although the MT correction rate was different from the lumbar correction after surgery, the final correction rates were similar. These results were attributed to the spontaneous lumbar coronal correction, most of which occurred in the proximal lumbar curve.

To the authors' knowledge, no study has analyzed the lumbar response after STF for a patient with MT AIS, by dividing the lumbar curve into the proximal and distal areas. According to the authors' report [4], after STF for MT AIS, the proximal and distal lumbar curves responded differently in the sagittal and coronal planes. The proximal lumbar curve became more lordotic (mobilized) in the sagittal plane immediately after surgery, while the distal lumbar curve became less lordotic (stabilized), which can explain why most lumbar correction occurred at the proximal lumbar curve. In addition, the proximal lumbar correction rate was similar to the whole lumbar correction rate after surgery and

at the last follow-up. The above correction rates showed a strong correlation. However, the distal lumbar correction rate was far different from the whole lumbar correction rate after surgery and at the last follow-up, and the above correction rates showed no significant correlation.

The mean proximal lumbar flexibility was similar to the mean lumbar flexibility. However, the mean distal lumbar flexibility was larger and different from the mean lumbar flexibility. Moreover, the proximal or the distal lumbar curve showed a similar correlation with the flexibility of the MT or lumbar curve. This result might be due to the measurement methods used. The correction rate was measured in the standing radiographs. However, the flexibility was a mixed parameter measured in both the standing and supine radiographs. In addition, in the supine position, the distal lumbar curve with more lordosis might be more mobile in the coronal plane.

The correlation between the flexibility and correction rate in a certain curve was significant only in the proximal lumbar curve after surgery and at the last follow-up, while the whole lumbar or the distal lumbar curves showed no association. This result might be because the whole lumbar curve was a mixture of proximal and distal lumbar curves with different curve characteristics. In addition, the proximal lumbar flexibility showed a higher correlation with the whole lumbar correction rate than the whole lumbar flexibility. And, the proximal lumbar flexibility showed a higher correlation with the proximal lumbar correction rate than the whole lumbar flexibility, which appeared natural. Anyway, the proximal and distal lumbar curves responded in a different manner.

In summary, after STF for MT AIS, so called spontaneous lumbar correction occurred mainly at the proximal lumbar curve, and the proximal lumbar curve reflected the whole lumbar curve more than the whole lumbar curve itself in terms of the curve flexibility or correction rate. This was attributed to the whole lumbar curve being a mixture of proximal and distal lumbar curves with different curve characteristics. The different characteristics and responses of the proximal and distal lumbar curve after STF were attributed to the following. If the lumbar curve was fixed at the sacrum, an abrupt MT correction would deviate the C7 plumb line to the right side. At the same time, the unfused proximal lumbar segments among the motion segments in the mobile transitional zone, approximately at the level of T10 to L2, would compensate for the right deviation of the C7 plumb line by a spontaneous lumbar coronal correction, which moves the C7 plumb line to the left side. At this time, the lumbar curve below the lumbar apex, including the low lumbar curve above the sacrum, might restrict the excessive deviation of the trunk to the right or left side. This supposition is based on the fact that the proximal lumbar curve became more lordotic (mobilized) in the sagittal plane immediately after surgery, while the distal lumbar curve became less lordotic (stabilized) [4].

Conclusions

After anterior STF in patients with MT-AIS, most of the lumbar coronal correction occurred at the proximal lumbar curve, and the proximal lumbar flexibility was more associated with the lumbar coronal correction rate than the tradi-

tional lumbar flexibility. The proximal lumbar flexibility may be an alternative index of spontaneous lumbar coronal correction after STF to the traditional lumbar flexibility.

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