



Spontaneous Remodeling of Spinal Canal After Sagittal Translation in Pedicle Subtraction Osteotomy for Correction of Thoracolumbar Kyphosis in Ankylosing Spondylitis

Junyao Cheng¹, Kai Song¹, Yan Liang², Xiangyu Tang¹, Bing Wu¹, Guoying Zhang¹, Yongfei Zhao¹, Zheng Wang¹

■ **BACKGROUND:** Sagittal translations (STs) secondary to osteotomy for the correction of ankylosing spondylitis (AS) kyphosis have drawn great attention, which is considered closely related to neurologic deficits and terrible fusion. Despite being discussed in several cases, there were no relevant reports about the transformation of ST and the spinal canal remodeling in AS patients.

■ **METHODS:** Retrospective analysis was conducted on 16 patients with ST for the treatment of AS kyphosis through pedicle subtraction osteotomy during January 2011 to December 2014 in our hospital. Full-length free-standing spinal radiographs were available for all patients before and after surgery and also at the final follow-up. Radiologic parameters including global kyphosis (GK), thoracolumbar kyphosis (TLK), lumbar lordosis (LL), sagittal vertical axis (SVA), and ST were measured. Rates of ST transformation after the surgery and at 1-year follow-up were compared.

■ **RESULTS:** The average follow-up was 22 months, ranging from 12–36 months. There was no internal fixation failure during this period. The preoperative GK was $59.9 \pm 21.0^\circ$, TLK was $38.0 \pm 13.0^\circ$, LL was $7.4 \pm 26.5^\circ$, and SVA was 27.2 ± 8.6 mm. The postoperative GK was $15.7 \pm 2.1^\circ$, TLK was $5.6 \pm 2.6^\circ$, LL was $-36.1 \pm 2.9^\circ$, and SVA was 6.1 ± 4.3 mm. ST was 7.1 ± 2.7 mm after surgery and 1.2 ± 1.0 mm at 1-year follow-up. The difference was statistically significant ($P < 0.05$).

The rate of ST transformation was $84.9\% \pm 9.7\%$. According to Scoliosis Research Society surveys, the preoperative and the final follow-up satisfaction score was

1.6 ± 0.3 and 4.7 ± 0.4 respectively ($P < 0.05$). Remodeling of the spinal canal happened to all the patients with different degrees.

■ **CONCLUSIONS:** All patients with ST after pedicle subtraction osteotomy for AS kyphosis occurred with spontaneous remodeling of the spinal canal at 1-year follow-up, by which ST can decrease in different degrees or even disappear, and favorable fusion can be achieved even without bone grafting into the osteotomy vertebra.

INTRODUCTION

Ankylosing spondylitis (AS) is a kind of chronic inflammation rheumatic disease that mainly involves the axial skeleton,¹ which may cause progressive osteoblastic-type change on spinal ligaments, and finally leads to stiffness kyphosis. AS patients with severe kyphosis cannot look horizontally when standing upright, and cannot lie on their whole back when lying down.² In recent years, as a relatively safe and effective osteotomy method, the pedicle subtraction osteotomy (PSO) has been widely applied. Through 1- or 2-level PSO performed on thoracolumbar or lumbar segments, AS kyphosis can be well corrected.³⁻⁷ However, it's liable to generate sagittal translation (ST) during osteotomy closure, accompanied by osseous staircase on the inner wall of the spinal canal that should be smooth.

Theoretically, ST increases the incidence of neurologic deficits and has become 1 of the key problems surgeons pay close attention to. During the exploring of ST, we find that the spinal canal of ST patients can remodel to different extents during a certain

Key words

- Ankylosing spondylitis
- Sagittal translation

Abbreviations and Acronyms

AS: Ankylosing spondylitis
LL: Lumbar lordosis
ST: Sagittal translation

From the Departments of ¹Orthopaedics, Chinese People's Liberation Army General Hospital (301 Hospital), and ²Spinal Surgery, Chinese Peking University People's Hospital, Beijing, PR China

To whom correspondence should be addressed: Zheng Wang, Ph.D.
[E-mail: wzspine@163.com]

Junyao Cheng, Kai Song, and Yan Liang were co-first authors.

Citation: World Neurosurg. (2019) 128:e245-e251.
<https://doi.org/10.1016/j.wneu.2019.04.128>

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

1878-8750/\$ - see front matter © 2019 Elsevier Inc. All rights reserved.

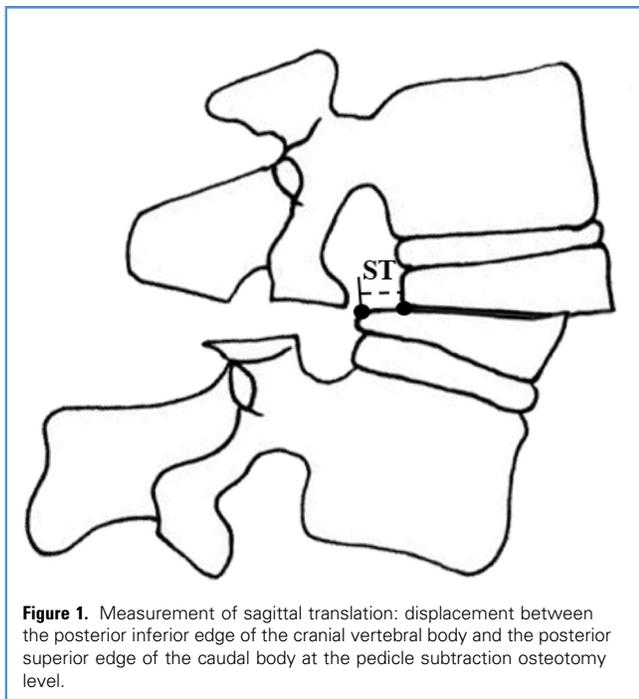


Figure 1. Measurement of sagittal translation: displacement between the posterior inferior edge of the cranial vertebral body and the posterior superior edge of the caudal body at the pedicle subtraction osteotomy level.

period. Through remodeling, the ST of all patients decreases or even disappears. Previously, there was no relative report about spinal canal remodeling of AS patients with ST. This research aims at observing the change of ST in this kind of patient and illustrates the phenomena of spinal canal spontaneous remodeling.

MATERIALS AND METHODS

Patient Demographics

Retrospective analysis was conducted on AS patients treated in our hospital from January 2011 to December 2014. Inclusion criteria were 1) patients had ST after PSO for the correction of thoracolumbar kyphosis in AS; 2) follow-up for 1 year or more with complete radiographic and clinical data. Exclusion criteria were 1)

Table 1. Comparison Between Preoperative and Final Follow-Up (FU) Sagittal Parameters

Measurements	Preoperative	Final FU	P
GK	59.9 ± 21.0	15.7 ± 2.1	0.00
TLK	38.0 ± 13.0	5.6 ± 2.6	0.00
LL	7.4 ± 26.5	-36.1 ± 2.9	0.00
SVA	27.2 ± 8.6	6.1 ± 4.3	0.00

Positive value indicates lumbar kyphosis, and negative value indicates lumbar lordosis. FU P < 0.05.

GK, global kyphosis; TLK, thoracolumbar kyphosis; LL, lumbar lordosis; SVA, sagittal vertical axis.

Table 2. Comparison Between Preoperative and Last Follow-Up (FU) SRS-22 Surveys

SRS-22	Preoperative	Final FU	P
Appearance	1.4 ± 0.5 (1.0–2.6)	4.2 ± 0.6 (3.0–5.0)	0.00
Mental	2.4 ± 0.7 (1.0–3.4)	4.3 ± 0.5 (3.2–5.0)	0.00
Pain	2.7 ± 0.7 (1.2–3.6)	4.0 ± 0.6 (3.2–5.0)	0.00
Function	2.4 ± 0.5 (1.6–3.2)	3.8 ± 0.6 (2.8–4.6)	0.00
Satisfaction	1.6 ± 0.3 (1.0–2.0)	4.7 ± 0.4 (4.0–5.0)	0.00

FU P < 0.05.

previous spinal operation; 2) pathologic fracture or pseudarthrosis on spine; and 3) accepted the medical treatment possibly influencing ossification after surgery. Sixteen cases were selected: 14 males and 2 females. The average age was 38.6, between 28 and 55. The average follow-up was 22.0 months, ranging from 12 to 36 months.

Radiologic and Clinical Data

Radiographic parameters were global kyphosis (GK, included angle between the upper end plate of the upper end centrum with largest inclination and the lower end plate of the lower centrum with largest inclination); thoracolumbar kyphosis (TLK, included

Table 3. Comparison Between Postoperative and Final Follow-Up (FU) Sagittal Translation (ST)

Patient	Postoperative ST (mm)	ST of Final FU (mm)	Rate of ST Transformation (%)	Segments of ST
1	4.2	0.8	80.9	L3
2	10.7	2.3	78.5	L2
3	5.8	0.8	86.2	T12
4	7.6	1.5	80.3	L2
5	9.8	0.4	95.9	T11
6	4.7	0.0	100.0	L3
7	5.5	0.7	87.3	L1
8	3.5	0.7	80.0	L1
9	7.5	1.6	78.7	L2
10	5.3	1.2	77.4	L1
11	11.7	3.9	66.7	L3
12	10.8	2.3	78.7	L2
13	7.8	0.0	100.0	L3
14	4.2	0.0	100.0	L2
15	7.8	1.5	80.8	L3
16	7.6	1.0	86.8	L1

FU, follow-up.

Table 4. Neurologic Deficits

	Sex	Age	Operation Time (hours)	Hemorrhage (mL)	Postoperative ST (mm)	ST Level	MEP; SSEP	Postoperative Neurologic Deficits	Prognosis	Reason Analysis
1	F	41	8.0	2000	7.5	L3	Normal	Left lower limb numb	Disappeared within 3 months	Excessive traction of dural sac and nerve root
2	M	28	6.8	1800	10.8	L2	Bi-SSEP and L-MEP disappeared after osteotomy closure	Decreased myodynamia and numbness of left lower limb	Decreased myodynamia and numbness of left lower limb limited relieved at 2-year FU	Deficits of cauda equina caused by bony step from ST
3	M	31	7.5	1400	7.7	L3	Normal	Left lower limb pain	Disappeared within 3 months	Insufficient resection of vertebral plate
4	M	39	7.7	800	9.8	T11	R-SSEP decreased after osteotomy closure	Decreased myodynamia and numbness of left lower limb	Decreased myodynamia and numbness of right lower limb limited relieved at 2-year FU	Insufficient resection and undermining decompression of vertebral plate

ST, sagittal translation; MEP, motor-evoked potentials; SSEP, somatosensory-evoked potentials; M, male; F, female; FU, follow-up; "-" denotes no value.

angle between the upper end plate of T10 centrum and the lower end plate of L2 centrum); lumbar lordosis (LL, included angle between the upper end plate of L1 and the upper end plate of S1, the positive value shows lumbar kyphosis and the negative value shows lumbar lordosis); sagittal vertical axis (SVA, distance between the plumb line of neck 7 and the rear upper angle of S1); and sagittal translation (ST, displacement between the posterior inferior edge of the cranial vertebral body and the posterior superior edge of the caudal body at the osteotomy level, Figure 1). All the image parameter measurements are implemented by 1 orthopedist and repeated by the other 2 orthopedists. Average values measured by 3 doctors are used for final data analysis.

Clinical data include the patient's age, gender, osteotomy levels, intraoperative blood loss, operation time, Scoliosis Research Society outcome questionnaire (SRS-22), incidence of neurologic deficits, and spinal canal remodeling.

Operation Method

After endotracheal intubation and general anesthesia, the patient had a prone position on the reversed V-shaped operation table with the belly jacked up. The posterior midline was taken as the operative incision and the bony structure were exposed to the edge of the transverse process. Pedicle screws were imbedded to at least

2 centrams above and below the osteotomy segments. According to the preoperative design, 1- or 2-level PSO was performed at the selected centrams. For patients with a large kyphotic angle, a cage would be implanted for the prevention of ST. The preflexed and shaped rods were embedded, and the nuts were locked with the operation table resetting simultaneously. After closure, the ventral surface of the dura and anterior wall of the spinal canal were carefully explored to observe the occurrence of ST and further through the intraoperative radiograph to determine the extent of ST. Autologous bone graft was implanted between processus transversus but not osteotomy interstice. Sensory evoked potential and motor evoked potential were kept working all through the operating process. The patients were bedridden for at least 48 hours after surgery and required to wear the detachable orthosis for movement within 6 months postoperatively.

Statistical Analysis

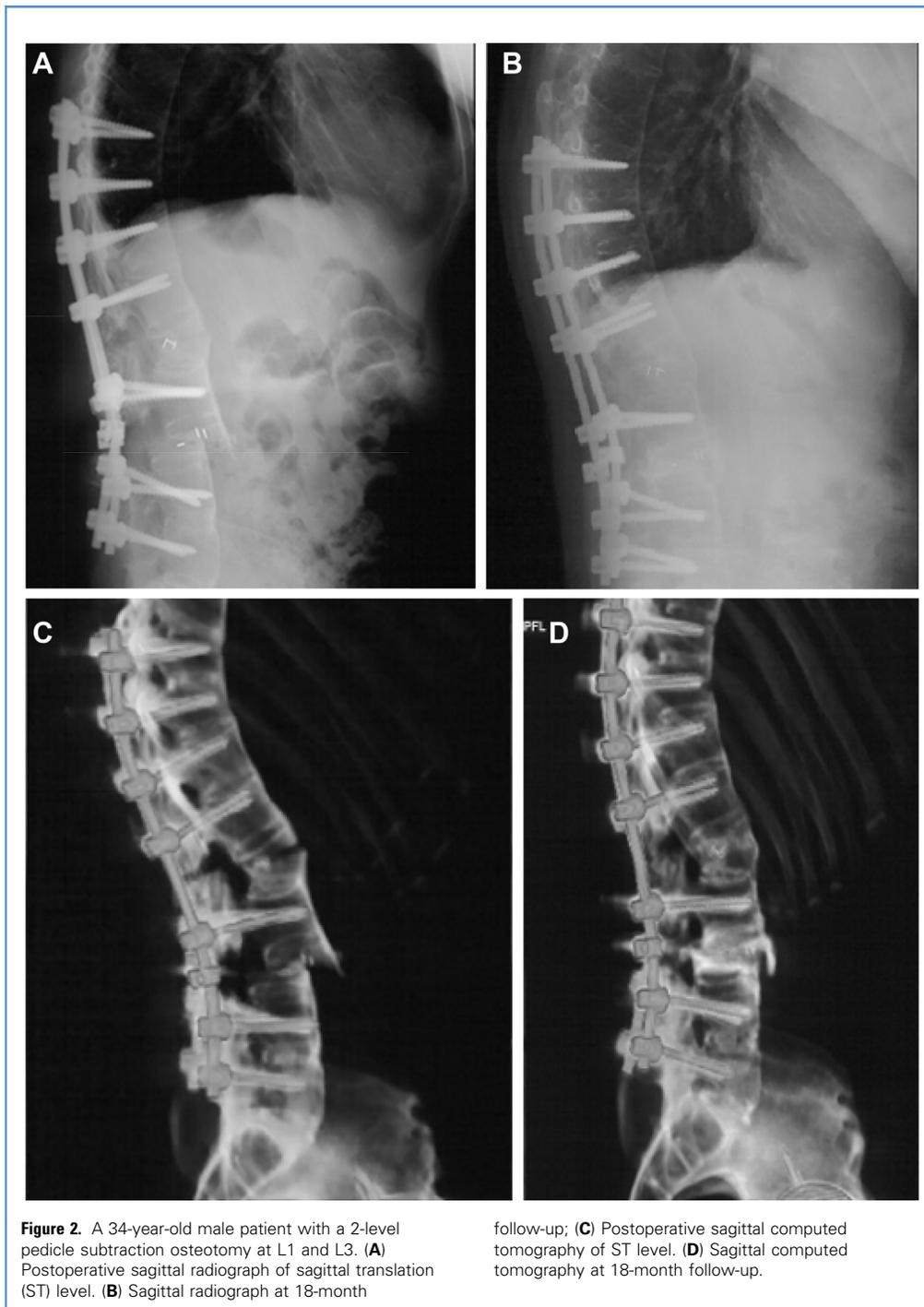
The radiographic measurement adopted Surgimap for Windows. The statistical analysis adopted SPSS17.0 for Windows. A continuous variable adopts the mean and standard deviation. The Student's t-test was used for comparison when meeting normal distribution. The categorical variable is shown by specific data and compared by chi-square test. The calculation of the rate of ST transformation is as follows: rate of ST transformation = (postoperative ST - ST at 1-year follow-up) / postoperative ST. In the measurement of radiographic parameters, the length measurement accuracy was 0.1 mm while for the angle measurement it was 0.1°. Up to the final follow-up, there was no fixation failure, orthopedic degree loss, or spinal fracture. This research has been approved by the Institutional Review Board at our hospital.

RESULTS

Among 16 patients, 5 accepted 1-level PSO: 1 for T11, 1 for L1, 1 for L2, 2 for L3; 11 accepted 2-level PSO: 4 for T12/L2, 6 for L1/L3, and 1 for L2/L4. The larger ST was selected for observation among

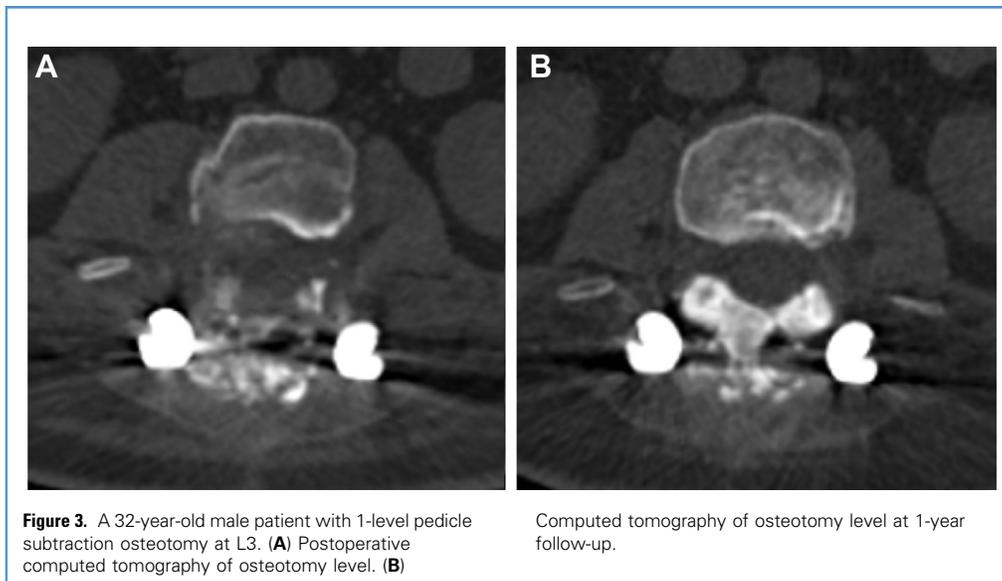
Table 5. Complications

Complications	Number	Incidence (%)
Neurologic deficits	4	25
Superficial infection	1	6.3
Tension vesicle	2	12.5
Retroperitoneal hematoma	1	6.3
Cerebrospinal fluid Leakage	1	6.3



patients with ST in both 2 osteotomy segments. The average operation time was 6.5 ± 1.1 (3.7–8.0) hours, and intraoperative blood loss was 1640 ± 690 (800–2700) mL. Preoperative GK was $59.9 \pm 21.0^\circ$, TLK was $38.0 \pm 13.0^\circ$, LL was $7.4 \pm 26.5^\circ$, SVA was 27.2 ± 8.6 mm, postoperative GK was $15.7 \pm 2.1^\circ$, TLK was $5.6 \pm 2.6^\circ$, LL was $-36.1 \pm 2.9^\circ$, SVA was 6.1 ± 4.3 mm (**Table 1**).

Preoperative Scoliosis Research Society satisfaction scores were 1.6 ± 0.3 and 4.7 ± 0.4 at the final follow-up (**Table 2**). Up to 1-year follow-up, ST was reduced from 7.1 ± 2.7 mm to 1.2 ± 1.0 mm, rate of ST transformation was $84.9\% \pm 9.7\%$. All patients occurred spinal canal remodeling, the incidence was 100% (**Table 3**).

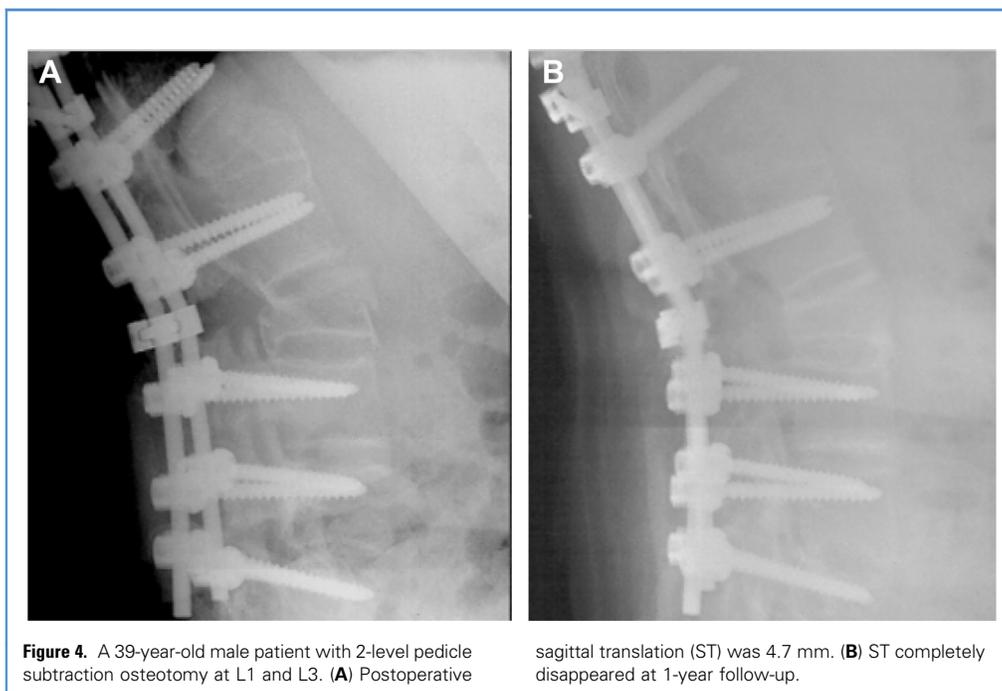


Complications were as follows: Among 16 cases, 4 suffered neurologic deficits, the incidence was 25%, wherein 2 had transient neurologic deficits that disappeared within 3 months; 2 had persistent neurologic deficits, with residual neural symptoms until the final follow-up (24 months and 27 months postoperatively) (Table 4). In addition, 1 patient had an incision superficial infection; 1 patient occurred cerebrospinal fluid leakage; 2 patients occurred abdominal tension vesicle; and 1 patient has

abdominal distension caused by a retroperitoneal hematoma (Table 5).

DISCUSSION

ST was initially defined by Chang et al⁸ as any measurable displacement >2 mm between the posterior inferior edge of the cranial vertebral body and the posterior superior edge of the



caudal body at the osteotomy level, which was considered as a basic mechanism in opening wedge osteotomy. However, with the development of orthopedic surgery, ST gained increasing attention as one of the most dangerous complications of osteotomy closely related to neurologic deficits and terrible fusion. When performing the operation, the surgeons try hard to make the osteotomy ends consistent with each other to reach an ideal closure, which is difficult to achieve. To a certain extent, ST is unavoidable. The small ones approximate allowance error range while the large ones tend to bring surgical risks.

With the development of osteotomy techniques, PSO is widely used for the correction of AS kyphosis in recent years. Under many situations the osteotomy closure would be accompanied by ST, which causes the cranial or caudal osteotomy end to protrude into the spinal canal. A bony step followed, and the space of spinal cord (cauda equina) would be occupied. In order to avoid potential risks, the surgeons always try hard to correct ST, which surely prolongs the anesthesia and operation time and possibly leads to increased bleeding. Meanwhile, in the process of adjusting ST, it also increases the risk of direct injury to the dural sac or even nerve roots by the sharp fracture surface. In this study the incidence of neurologic deficits was 25%, among which 12.5% showed as permanent neurologic complications, both higher than the overall incidence of patients who received PSO.^{3,7} In all probability, it is related to the patients enrolled, of whom the average ST reach is 7.1 mm. By reviewing the surgical records and comparing the intraoperative and postoperative radiographs, we found that the neurologic deficits were mainly due to the extent of laminectomy and undermining decompression, the excessive traction of dural sac and nerve root during ST reduction, and also the direct damage of bone steps. Two of 16 patients with permanent neurologic deficits in this research had abnormalities of intraoperative somatosensory-evoked potentials and motor-evoked potentials on the heel of osteotomy closure, suggesting that ST plays an important role in neurologic complications.

On the other hand, ST leads to the reduction of osteotomy interface. Some experts have worried about the possibility of fusion failure and emphasized that bone grafting should be carried out into the osteotomy vertebral. With similar concerns, we conducted an observation in patients with ST. Without intervertebral bone grafting, no failure of fusion or instrument occurred up to the final follow-up. Comparison of the postoperative and follow-up radiographs shows that ST decreased by different extents. Up to 1-year follow-up, all the enrolled patients had ST reductions while the bone step decreased or even disappeared. The anterior wall of the spinal canal was repaired, and favorable fusion was gradually achieved. In this study, ST decreased from 7.1 ± 2.7 mm postoperatively to 1.2 ± 1.0 mm at 1-year follow-up. The rate of ST transformation was $84.9\% \pm 9.7\%$ (67%–100%). **Figure 2** showed a 34-year-old male patient with 2-level PSO at L1 and L3, and ST took place at

L3, where a huge bony step occurred. At 18-month follow-up, the sagittal radiograph showed ST and the bony step almost disappeared, while ideal fusion was obtained and the streamline of the spinal canal was restored as the sagittal computed tomography indicated (see **Figure 2**). This phenomenon was defined as spontaneous remodeling of the spinal canal in AS patients. There were reports of vertebral spontaneous remodeling after burst fracture of the spinal canal^{9,11} but no relevant reports for AS patients with ST.

The remodeling of the spinal canal is best illustrated by the comparison of cross-sectional area change. However, for AS patients who accepted PSO, the posterior laminectomy was often an enlarged resection in order to avoid spinal cord (cauda equina) or nerve root damage. After the correction, the absence of the spinal posterior wall at the osteotomy level resulted in the cross-sectional area being unable to be measured. Despite the reconstruction of the posterior column being clearly observed on the horizontal computed tomography scan in the long-term follow-up, there was no postoperative contrast indicating the change of cross-sectional area. This phenomenon can be interpreted in **Figure 3**, showing a 32-year-old male patient with 1-level PSO at L3. The postoperative posterior boundary was unclear, so measurement of the cross-sectional area was not available. However, the comparison of postoperative and 1-year follow-up computed tomography of osteotomy level showed the reconstruction of posterior column and bony fusion of the anterior column clearly (see **Figure 3**). Therefore to illustrate the remodeling of the spinal canal in this study, the transformation of ST is more rational. At the 1-year follow-up, all 16 patients had experienced ST reduction. The incidence of spinal canal spontaneous remodeling was 100%. It was even observed that ST disappeared completely in some patients (**Figure 4**). The improvement of ST reflects the reduction of the occupying area, which is of great significance in avoidance of neurologic deficits.

It is still not clear about the mechanism of the spontaneous spinal canal remodeling. The forward sliding end is subject to greater tension compared with the other end around ST. The sclerotin of both bone cutting end can grow towards each other conforming to its forced direction, which submit to the lifting of nail and rod. The main reason might be the strong sacralization ability of AS patients, so the interceptive centrum is rebuilt toward the stress concentration area. It also explains why AS patients' spontaneous spinal canal remodeling degree and speed are obviously superior to those of common people with vertebral fractures. But the spontaneous spinal canal remodeling mechanism should further explored.

CONCLUSION

All patients with ST after PSO for AS kyphosis had spontaneous remodeling of the spinal canal at 1-year follow-up, by which time ST decreased in different degrees or even disappeared, and favorable fusion was achieved even without bone grafting into the osteotomy vertebra.

REFERENCES

1. Braun J, Sieper J. Ankylosing spondylitis. *Lancet*. 2007;369:1379-1390.
2. Stafford L, Youssef PP. Spondyloarthropathies: an overview. *Intern Med J*. 2002;32:40-46.
3. Cho KJ, Bridwell KH, Lenke LG, Berra A, Baldus C. Comparison of Smith-Petersen versus pedicle subtraction osteotomy for the correction of fixed sagittal imbalance. *Spine (Phila Pa 1976)*. 2005;30:2030-2037.
4. Song K, Zheng G, Zhang Y, et al. Hilus pulmonis as the center of gravity for AS thoracolumbar kyphosis. *Eur Spine J*. 2014;23:2743-2750.
5. Song K, Zheng G, Zhang Y, Zhang X, Mao K, Wang Y. A new method for calculating the exact angle required for spinal osteotomy. *Spine (Phila Pa 1976)*. 2013;38:E616-E620.
6. Chen IH, Chien JT, Yu TC. Transpedicular wedge osteotomy for correction of thoracolumbar kyphosis in ankylosing spondylitis: experience with 78 patients. *Spine (Phila Pa 1976)*. 2001;26:E354-E360.
7. Zheng GQ, Song K, Zhang YG, et al. Two-level spinal osteotomy for severe thoracolumbar kyphosis in ankylosing spondylitis. Experience with 48 patients. *Spine (Phila Pa 1976)*. 2014;39:1055-1058.
8. Chang KW, Chen HC, Chen YY, Lin CC, Hsu HL, Cai YH. Sagittal translation in opening wedge osteotomy for the correction of thoracolumbar kyphotic deformity in ankylosing spondylitis. *Spine (Phila Pa 1976)*. 2006;31:1137-1142.
9. de Klerk LW, Fontijne WP, Stijnen T, Braakman R, Tanghe HL, van Linge B. Spontaneous remodeling of the spinal canal after conservative management of thoracolumbar burst fractures. *Spine (Phila Pa 1976)*. 1998;23:1057-1060.
10. Dai LY, Jiang SD, Wang XY, Jiang LS. A review of the management of thoracolumbar burst fractures. *Surg Neurol*. 2007;67:221-231.
11. Yazici M, Atilla B, Tepe S, Calisir A. Spinal canal remodeling in burst fractures of the thoracolumbar spine: a computerized tomographic comparison between operative and nonoperative treatment. *J Spinal Disord*. 1996;9:409-413.

Conflict of interest statement: No funds were received in support of this work. No relevant financial activities outside the submitted work.

Received 21 January 2019; accepted 15 April 2019

*Citation: World Neurosurg. (2019) 128:e245-e251.
https://doi.org/10.1016/j.wneu.2019.04.128*

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

1878-8750/\$ - see front matter © 2019 Elsevier Inc. All rights reserved.