


CLINICAL ARTICLE

Clinical Results of Utilizing the Satellite Rod Technique in Treating Ankylosing Spondylitis Kyphosis

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Objective: According to the literature, there are no clinical reports documenting the use of the satellite rod technique in the treatment of ankylosing spondylitis kyphosis. The purpose of this retrospective study was to compare the clinical outcome of patients with ankylosing spondylitis kyphosis who adopted satellite rods versus those who did not.

Methods: Patients with ankylosing spondylitis kyphosis who underwent one or two-level pedicle subtraction osteotomy (PSO) were reviewed, and total of 119 patients (112 males and seven females, average age 39.89 ± 6.61 years) were eligible and included in this present study. Anterior–posterior and lateral full-length spine X-ray films were performed preoperatively and at the two-year follow-up visit. Global kyphosis (GK), lumbar lordosis (LL), thoracolumbar kyphosis (TLK), thoracic kyphosis (TK), and osteotomy angle (OA) were measured. The complications of every group of patients were collected. Pre- and postoperative health-related quality of life instruments, including the Bath Ankylosing Spondylitis Functional Index (Basfi) and Scoliosis Research Society outcomes instrument-22 (SRS-22), were recorded. The patients were divided into three groups based on features of their osteotomy including PSO levels and whether the satellite rod technique was applied. Patients who underwent one-level PSO without the satellite rod technique were categorized in the one-level group. Patients who underwent one-level PSO with the satellite rod technique were classified in the satellite rod group. Patients who underwent two-level PSO without the satellite rod technique were included in the two-level group. The paired sample *t* test was used to compare pre- and postoperative parameters. One-way ANOVA was performed for multiple group comparisons.

Results: The average follow-up time is 29.31 ± 3.66 months. The patients' GK were significantly improved from 46.84 ± 20.37 degree to 3.31 ± 15.09 degree. OS achieved through each osteotomy segment of one-level group (39.78 ± 12.29 degree) and satellite rods group (42.23 ± 9.82 degree), was larger than that of two-level group (34.73 ± 7.54 and 28.85 ± 7.26 degree). There was no significant difference between the one-level group and the satellite rod group in achieving the OS. Thirteen patients experienced different complications (10.92%). Three patients experienced rod fracture in the one-level group. There was no rod fracture or screw failure in the satellite rod group or the two-level group.

Conclusion: The satellite rod technique is also recommended for patients who undergo PSO osteotomy to correct ankylosing spondylitis kyphosis deformities.

Key words: Ankylosing spondylitis; Pedicle subtraction osteotomy; Rod fracture; Sagittal imbalance; Satellite rod technique

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Introduction

Patients with rigid spine kyphotic deformity caused by ankylosing spondylitis (AS) require surgical intervention to correct ankylosing spondylitis kyphosis, restore sagittal balance and the patient's horizontal gaze, relieve pain, and finally improve the patient's quality of life.¹⁻⁵ Since Smith-Petersen *et al.*⁶ first reported the anterior opening wedge osteotomy technique, many different osteotomy techniques have been developed to correct patient sagittal imbalance and have achieved good clinical and radiographical outcomes and higher patient satisfaction rates for ankylosing spondylitis (AS) kyphotic deformities.^{1,4-7} Many studies have reported that one-level anterior opening wedge osteotomy can achieve a 30°–40° correction angle.⁸ However, because opening wedge osteotomy could lead to a sharp lordotic angle and elongate the anterior column of the spine, which might result in vascular complications and neurologic complications, poly-level posterior wedge osteotomies are recommended.⁹ Van Royen *et al.* reported that one-level posterior wedge osteotomies achieved an approximately 9.5° correction angle.¹⁰ Hehne *et al.* also reported that poly-level posterior wedge osteotomies achieved a 10° corrected angle each level.¹¹ Because of the postoperative correction angle loss at postoperative follow-up, poly-level posterior wedge osteotomies are usually adopted for correcting nonrigid spine deformities or are combined with pedicle subtraction osteotomy (PSO) for correcting rigid spine deformities.⁹ PSO has become a widely adopted technique for correcting ankylosing spondylitis (AS) kyphotic deformities. Many authors have reported that each level of PSO can achieve a correction angle of approximately 30°–44°. ¹²⁻¹⁴ However, for severe ankylosing spondylitis kyphosis, one-level PSO cannot achieve satisfactory correction results. Chen *et al.* suggested two-level PSO for patients with severe deformities.¹ Two-level pedicle subtraction osteotomy can obtain approximately 60°–68° correction.^{1,15,16} PSO can result in severe iatrogenic instability, which requires fixation and fusion.¹⁷

Despite the satisfactory surgical outcomes achieved *via* one- or two-level PSO, the complications of the procedures still need to be considered, especially failure of the rods. Rod failure appears to be a common complication in patients who adopt spine surgery, especially in patients with spine deformities. Smith *et al.* reported that the rod fracture rate following corrective surgery with PSO for adult spinal deformity patients was approximately 22% after a minimum of 1 year of follow-up.¹⁸ Rod fracture can have a substantial negative impact on the clinical results due to pain and loss of deformity correction, and rod fracture even requires revision surgery. Older age, higher body mass index (BMI), preoperative and postoperative sagittal imbalance degree, a higher degree of rod contour angle and pseudarthrosis have been identified as risk factors for rod fracture.¹⁸ Although the rate of rod fracture is lower in patients with ankylosing spondylitis kyphosis than in those with other spine deformities,¹⁸⁻²⁰ rod fracture still cannot be ignored as a potential complication in patients with ankylosing spondylitis kyphosis. Rod fracture can lead to loss

of posterior fixation and correction, pain, and even result in neurological impairment.^{21,22} Revision surgery is generally recommended if the rods are broken.²³ To address the issue of rod fracture, many approaches have been proposed, such as using multiple rod configurations or satellite rods, adopting cobalt chrome rods, performing bone-to-bone osteotomies and implanting interbody supplementation.^{18,23-26} Hyun *et al.* reported that adopting the multiple rod construct could provide stability at the PSO site.²⁵ Palumbo *et al.* showed that the outrigger rod technique could also enhance spine stability.²⁴ Smith *et al.* reported that patients who adopted cobalt chrome rods had a lower rate of rod fracture compared with those who received titanium alloy rods or stainless steel rods.¹⁹ Deviren *et al.* reported that placement of interbody cages in PSO settings has a potentially stabilizing effect.²⁶ The study conducted by La Barbera *et al.* recommended 4-rod constructs based on accessory rods combined with cages adjacent to the PSO site for minimizing primary rod strains.²⁷ Patients underwent PSO, and the satellite rod technique effectively reduced rod stress and increased fixation stability, further reducing the rod failure rate.^{23,27}

According to the literature, there are no clinical reports documenting the use of the satellite rod technique in the treatment of ankylosing spondylitis kyphosis. We hypothesized that patients with ankylosing spondylitis kyphosis could benefit from adopting the satellite rod technique regardless of PSO level. In recent years, we have routinely adopted the satellite rod technique in patients who underwent one-level PSO for correcting ankylosing spondylitis kyphosis. Hence, the purpose of the present study was to: (i) compare the clinical outcomes of patients who adopted satellite rods *versus* those who did not; and (ii) discuss the advantages and disadvantages of satellite rods combined with two-level pedicle subtraction osteotomy.

Method and Patients

Patients

All the patient information was used with the consent of those patients. Patients with AS kyphosis who underwent one- or two-level PSO for treating deformities were included in the study. The inclusion criteria were as follows: (i) patients had rigid ankylosing spondylitis (AS) kyphosis deformities; (ii) pre- and postoperative full-length spine radiography images were obtained; (iii) patients underwent one- or two-level PSO osteotomy; and (iv) at least 2 years of follow-up data were available. Patients with any of the following were excluded: (i) any other spinal abnormality in addition to AS kyphosis in the sagittal alignment; (ii) coronal malalignment; (iii) spinal trauma; and (iv) history of spinal surgery. The patients were divided into three groups based on features of their osteotomy including PSO levels and whether the satellite rod technique was applied. Patients who underwent one-level PSO without the satellite rod technique comprised the one-level group. Patients who underwent one-level PSO with the satellite rod technique comprised the

satellite rod group. Patients who underwent two-level PSO without the satellite rod technique were included in the two-level group.

For all enrolled patients, clinical and demographic data were available from medical records. Patient were collected for all three groups. Implant-related complications included rod fracture, screw breakage and loosening. Pre- and postoperative health-related quality of life instruments, including the Bath Ankylosing Spondylitis Functional Index (Basfi) and Scoliosis Research Society outcomes instrument-22 (SRS-22), were used.

Radiographic Parameters

The sagittal spinal balance parameters, including the globe kyphosis (GK), lumbar lordosis (LL), thoracolumbar kyphosis (TLK), thoracic kyphosis (TK), were measured. GK was measured from the superior end plate of the T5 thoracic vertebra to the superior end plate of the S1 vertebra. LL was defined as the Cobb angle between the two lines parallel to the superior endplate of L1 and S1; TLK was defined as the Cobb angle between the two lines parallel to the superior endplate of T11 and the superior endplate of L2; TK was defined as the Cobb angle between the two lines parallel to the superior endplate of T5 and the inferior endplate of T12. Lordosis was described as negative and kyphosis as positive. Osteotomy angle (OA) was also measured and calculated. The OA was defined as the change in the preoperative and postoperative angle between the inferior endplate and the superior endplate of the osteotomy segment. Moreover, it was difficult to measure the patient's actual height due to spine deformities. Patients with the same sagittal imbalance degree and different heights may have different sagittal vertical axes (SVAs). Therefore, height bias may result in SVA bias in comparing the sagittal imbalance degree. The cervical 7 sacrum angle (C7SA) was defined as the angle formed by the C7 plumb line and the line passing through the center of C7 and the superior-posterior corner of the first sacrum vertebra.²⁸ To avoid the height bias on assessments of sagittal imbalance degree, the C7SA was also measured according to a previous study.²⁸ All the parameters were measured twice, and the averages were calculated.

Statistical Analysis

Data analysis was performed using SPSS version 23.0 for Windows. All the data are presented as the mean \pm SD. The paired sample *t* test was used to compare pre- and postoperative parameters. One-way ANOVA was performed for multiple group comparisons, and a *post hoc* test was used to calculate the *P* values for comparisons between groups. A *P* value less than 0.05 was considered to be significant in all analyses.

Results

Patients Characteristics

Finally, a total 119 patients (112 males and seven females, average age 39.89 ± 6.61 years) were eligible and included in this present study. All patients received rods with a diameter of 5.5 mm. 57 patients in one-level group, 29 patients in satellite rod group, and 33 patients in two-level group. The average follow-up time is 29.31 ± 3.66 months. In the one-level group, 41 patients underwent PSO at L3, and 16 patients underwent PSO at L2. In the satellite rod group, 18 patients underwent PSO at L3, and 11 patients underwent PSO at L2. In the two-level group, 24 patients underwent two-level PSO osteotomy at L1 and L3, 8 patients underwent a two-level PSO osteotomy at T12 and L2, and 1 patient underwent two-level PSO osteotomy at T12 and L3. In the one-level group, patients had an average of 7.86 ± 0.99 fusion segments. Patients in the satellite rod group had an average of 7.95 ± 1.68 fusion segments. The mean number of fusion segments in patients in the two-level group was 8.75 ± 0.84 .

Radiographic Improvement

All three groups had significant improvement in spine deformity (Table 1). LL was improved from -2.90 ± 18.25 to -46.39 ± 13.81 degrees ($P = 0.013$, $t = 23.511$). TK was improved from 47.66 ± 19.58 to 47.79 ± 19.43 degrees ($P = 0.905$, $t = -0.119$). TLK was improved from 31.41 ± 13.01 to 1.34 ± 18.86 degrees ($P < 0.001$, $t = 17.102$). GK was improved from 46.84 ± 20.37 degree to 3.31 ± 15.09 degrees ($P < 0.001$, $t = 25.951$). The preoperative GK of one-level group, satellite rod group and two-level group were 40.55 ± 17.15 , 37.73 ± 11.99 and 65.98 ± 19.30 degrees ($P < 0.001$), respectively. The two-level group patients had more severe preoperative spine deformities and degrees of

TABLE 1 The clinical and radiographic outcomes of all the patients

	Preoperative	Postoperative	<i>P</i>	<i>t</i>
LL	-2.90 ± 18.25	-46.39 ± 13.81	0.013	23.511
TK	47.66 ± 19.58	47.79 ± 19.43	0.905	-0.119
TLK	31.41 ± 13.01	1.34 ± 18.86	0.000	17.102
GK	46.84 ± 20.37	3.31 ± 15.09	0.000	25.951
Basfi	4.82 ± 1.80	3.25 ± 1.66	0.000	10.606
SRS-22	48.68 ± 7.55	83.22 ± 11.19	0.000	-30.806

Abbreviations: Basfi, bath ankylosing spondylitis functional index; GK, the globe kyphosis; LL, the lumbar lordosis; SRS-22, scoliosis research society outcomes instrument-22; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis.

TABLE 2 The preoperative radiographic parameters in three groups

	One-level group	Satellite rods group	Two-level group	P
LL	-6.81 ± 16.36	-8.81 ± 15.15	9.24 ± 18.71	0.000
TK	43.86 ± 24.32	48.12 ± 10.12	53.81 ± 15.27	0.066
TLK	31.50 ± 15.63	29.86 ± 12.29	32.66 ± 7.84	0.696
GK	40.55 ± 17.15	37.73 ± 11.99	65.98 ± 19.30	0.000
C7SA	21.01 ± 3.03	20.44 ± 4.08	33.56 ± 7.27	0.000
	One-level group vs satellite rods group t value	One-level group vs two-level group t value	Satellite rods group vs two-level group t value	
LL	0.553	-4.257	-4.184	
TK	-0.915	-2.118	-1.727	
TLK	0.500	-0.0398	-1.090	
GK	0.802	-6.472	-6.895	
C7SA	0.730	-11.459	-8.591	

Note: Statistically significant if $P < 0.05$.; Abbreviations: C7SA, cervical 7 sacrum angle; GK, the globe kyphosis; LL, the lumber lordosis; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis.

TABLE 3 The postoperative radiographic parameters in three groups

	One-level group	Satellite rods group	Two-level group	P
LL	-43.73 ± 12.82	-46.90 ± 12.29	-50.51 ± 15.96	0.078
TK	46.44 ± 24.47	46.94 ± 11.08	50.91 ± 15.19	0.557
TLK	3.12 ± 21.48	-6.06 ± 19.13	5.02 ± 10.58	0.040
GK	2.4 ± 17.18	4.08 ± 11.03	4.18 ± 14.74	0.826
C7SA	7.57 ± 4.85	8.44 ± 4.37	7.53 ± 3.96	0.651
	One-level group vs satellite rods group t value	One-level group vs two-level group t value	Satellite rods group vs two-level group t value	
LL	1.109	2.206	1.012	
TK	-0.106	-0.947	-1.175	
TLK	1.965	-0.476	-2.879	
GK	-0.479	-0.493	-0.031	
C7SA	-0.0847	0.035	0.856	

Note: Statistically significant if $P < 0.05$.; Abbreviations: C7SA, cervical 7 sacrum angle; GK, the globe kyphosis; LL, the lumber lordosis; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis.

sagittal imbalance than the one-level group and satellite rod group (Table 2). The postoperative GK of one-level group, satellite rod group and two-level group were 2.4 ± 17.18 , 4.08 ± 11.03 and 4.18 ± 14.74 degrees ($P = 0.826$), respectively. There was no meaningful difference between the one-level group and the satellite rod group in the degree of spine deformity and sagittal imbalance. However, there were no significant differences among the three groups in terms of postoperative spine deformity or sagittal imbalance (Table 3). After the operation, the one-level group and satellite rod group achieved larger OAs than the two-level group. One-level group achieved 39.78 ± 12.29 degrees OA. Satellite rod group achieved 42.23 ± 9.82 degrees OA. The superior osteotomy site of two-level group achieved 34.73 ± 7.54 degrees OA. The lower osteotomy site of two-level group 28.85 ± 7.26 degrees OA. There was no significant difference between the one-level group and the satellite rod group in achieving the OA.

Health-Related Quality of Life

After the operation, Basfi and SRS-22 scores were significantly improved in all of the patients (Table 1). Basfi score was improved from 4.82 ± 1.80 to 3.25 ± 1.66 ($P < 0.001$, $t = 10.606$). SRS-22 scores was improved from 48.68 ± 7.55 to 83.22 ± 11.19 ($P < 0.001$, $t = -30.806$). All the patients reported that they would like to recommend corrective surgery to other patients who had the same disease.

Complications

Table 4 shows that 13 patients experienced different complications (10.92%). Three patients experienced rod fracture in the one-level group. Two out of the three patients reported that they felt the breaking of the rod at 6 and 13 months after the operation, respectively. One out of the three patients was found to have rod fracture and no symptoms at the 2-year follow-up visit. All three patients underwent

TABLE 4 Major complications in three groups

	One-level group	Satellite rods group	Two-level group
Rod fracture	3 (5.26%)	0	0
Screw fracture	0	0	0
Surgical site infection	2 (3.5%)	1 (3.44%)	1 (3.03%)
Delayed wound healing	0	0	2 (6.06%)
Transient nerve injury	1 (1.75%)	0	2 (6.06%)
Permanent nerve damage	0	0	0
Pneumothorax	0	0	1 (3.03%)

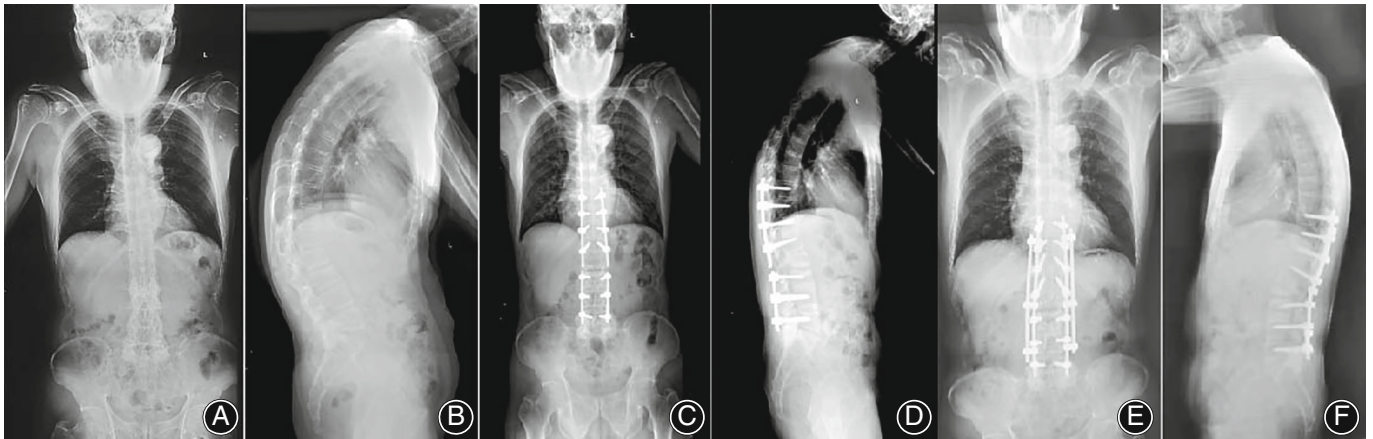


Fig. 1 A 57 years old male patient, who experience the rod fracture 13 months after operation (as C and D shows). The reoperation with satellite rod technique was performed for the patient (as the E and F shows)

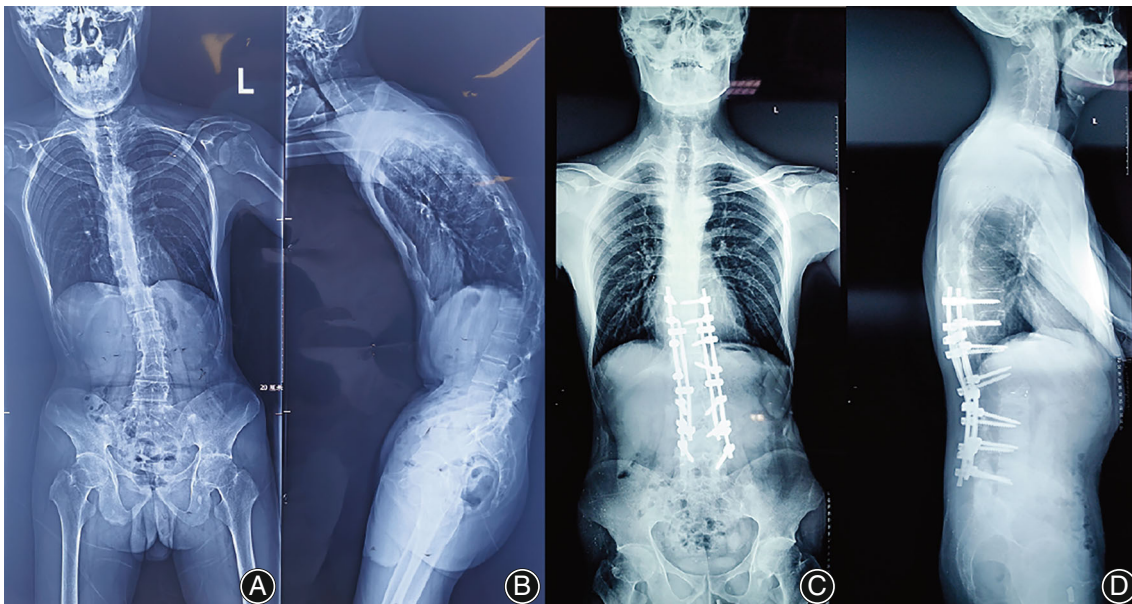


Fig. 2 A 27 years old male patients, who underwent one-level PSO osteotomy with satellite rod technique for correcting spine deformity

revision surgery with the satellite rod technique (Fig. 1). There was no rod fracture or screw failure in the satellite rod group (Fig. 2) or the two-level group (Fig. 3). Superficial

incision infections occurred in two patients in the one-level group, one patient in both the satellite rod group and two-level group. Those patients were given antibiotic treatment

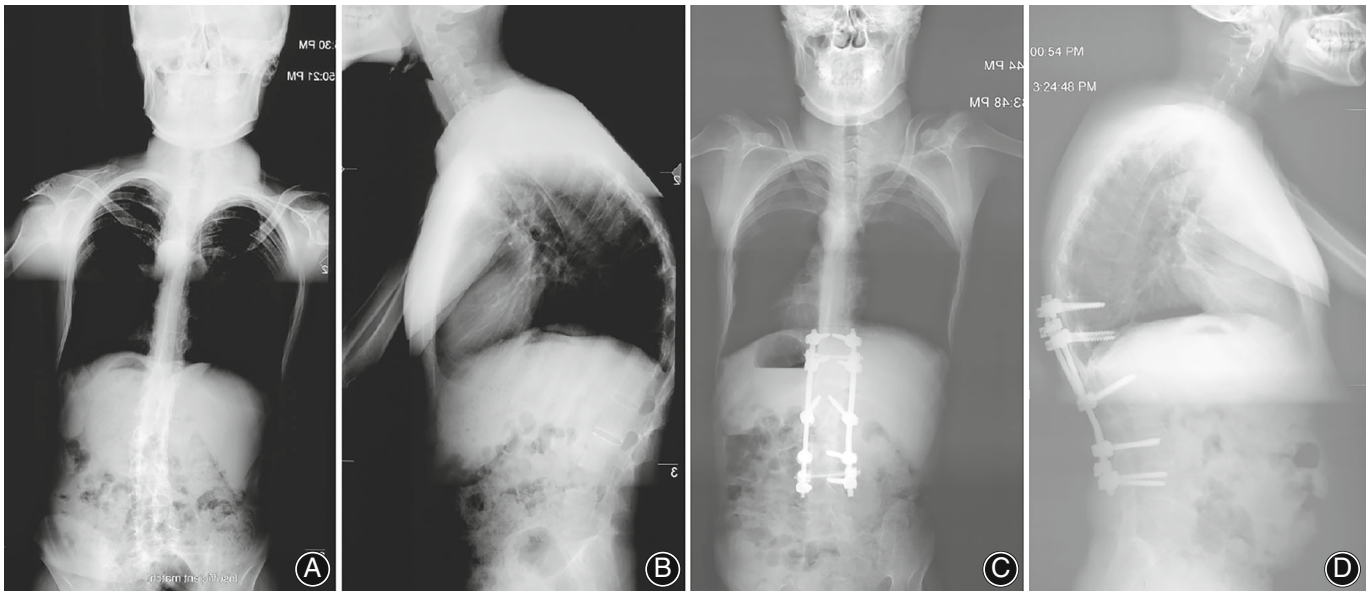


Fig. 3 A 36 years old male patients, who underwent two-level PSO osteotomy for correcting spine deformity

according to the bacterial culture and drug sensitivity test. Two patients experienced delayed wound healing due to fat liquefaction in the two-level group. For these patients, the treatment is increasing the frequency of wound dressing changes. One patient in the one-level group and two patients in the two-level group experienced transient nerve injury. All nerve injury symptoms disappeared within 3 months after the operation. No permanent nerve damage occurred. One patient in the two-level group experienced pneumothorax, and was treated with closed thoracic drainage.

Discussion

Clinical Outcome of Patients Who Adopted Satellite Rods Versus Those Who Did Not

PSO has been demonstrated to be associated with a high rate of instrument failure and pseudarthrosis.²⁹ Smith *et al.* reported that the rod fracture rate following corrective surgery with PSO for adult spinal deformity patients was approximately 22% after a minimum of 1 year of follow-up.¹⁸ These retrospective study results revealed that rod fracture complications were only found in three patients in the one-level group. Two out of the three patients reported that they felt the breaking of the rod at 6 and 13 months after the operation. One out of the three patients was found to have rod fracture and no symptoms at the 2-year follow-up visit. All the three patients adopted revision surgery. Rod fracture can substantially diminish the clinical results due to pain and loss of deformity correction, and, in some cases, it even requires revision surgery. Although the rate of rod fracture is lower in patients with ankylosing spondylitis kyphosis than in those with other spine deformities,^{18–20} rod fracture still cannot be ignored as a complication in patients with ankylosing spondylitis kyphosis.

Older age, higher BMI, pre- and postoperative sagittal imbalance degree, a higher degree of rod contour angle and pseudarthrosis, have been identified as risk factors for rod fracture.¹⁸ In recent years, we have routinely adopted the satellite rod technique in patients who have undergone one-level PSO osteotomy for correcting ankylosing spondylitis kyphosis. The results showed that there were no rod fractures occurred in patients who adopted satellite rods after one-level PSO osteotomy. It demonstrated that satellite rods could increase stability at the PSO site, share the stress on each rod and increase fatigue endurance, and reducing the rod failure rate.

Although, none of the patients underwent two-level PSO osteotomy with the satellite rod technique, no rod fractures were found in patients with two-level PSO osteotomy at our institution. Both the one-level group and the two-level group received two 5.5 mm diameter rods to correct the spine. All three groups had similar radiographic results at the 2-year postoperative follow-up visit. However, the average achieved OA in the one-level group was significantly larger than that in the two-level group. With a larger OA, sharper rod bending is generally needed for implanting the rod into the screws. Tang *et al.* demonstrated that rod fatigue life was largely dependent on the degree of rod bending, with more severe rod bending resulting in shorter rod fatigue life.³⁰ Rod bending brings about notch and stress, concentrating on areas of rod contour, and reducing fatigue endurance.³¹ After closing the PSO site, the load was placed posteriorly on the fixation rod, and the load could not be shared by the vertebral body and posterior column as the spine was intact.³² This increased the stress on the posterior fixation rods contoured areas and led to reduced rod fatigue resistance and rod fracture.³¹ Unlike other spinal deformities, late-stage ankylosing spondylitis patients generally have a stiff and fused spine. In those patients, the spine resembles a

long bone. After long bone fracture reduction and fixation, the stress is primarily concentrated on the fracture site. This is why plate fracture commonly occurs at the fracture site. The spine is flexible in patients with other spine deformities. Except for the PSO site, the flexible spine can disperse more stress on other rod areas. However, in patients with stiff and fused spines, the stress is mainly concentrated on the PSO site, similar to a long bone, after fracture reduction and fixation. Nevertheless, due to ankylosing spondylitis patients' osteotomy site superior fusion capacity, the rate of rod fracture is lower in patients with ankylosing spondylitis kyphosis than in those with other spine deformities.²⁰ In patients who underwent two-level PSO, the concentrated stress was shared by the rod sites posterior to the two PSO levels. What is more, the OA at each site was smaller than that of one-level PSO. The smaller OA at the osteotomy site means smaller degree of the rod bending. This may be why the two-level group had a lower rod fracture rate than the one-level group. In addition to the rod contour, the rod diameter and pseudarthrosis are also risk factors for rod fracture. The thicker the rod diameter is, the greater the stiffness and resistance to rod fracture, and the more stability it can supply to the spine. Stability is indispensable for osteotomy site fusion and reducing the rate of pseudarthrosis formation and rod fracture. Although a small diameter rod can lead to a decrease in the load on the instrument because of the lower overall stiffness, the stress is increased due to the predominant effect of the reduction of the resistant section of the rod on the lower stiffness of the rod.²⁹ Additionally, patients with larger diameter rods have a lower rod failure rate.¹⁸ The widely accepted satellite rod technique has been proven to decrease the rod stress and enhance the stability of the instruments.²³ In the present study, there was no significant difference between the one-level group and the satellite rod group in the achieved osteotomy angle. There was no difference between the one-level group and the satellite rod group in pre- and postoperative radiographic characteristics or the degree of sagittal imbalance. Consistent with previous studies, this study showed that patients with ankylosing spondylitis kyphosis could benefit from the satellite rod technique, lowering the risk of rod fracture by increasing stability at the PSO site, sharing the stress on each rod and increasing fatigue endurance.

Advantages and Disadvantages of the Satellite Rods and Two-Level PSO

The satellite rod technique is also recommended for patients who undergo one-level PSO osteotomy for correcting spine deformities. Although satellite rods can considerably reduce the von Mises stress values on the rods at the PSO level and

reduce instrument failure at the PSO site,³³ some satellite constructs could interfere with the fusion mass and tension-free wound closure, and lateral and posterior satellite rods could also affect wound closure.³³ Additionally, instrumentation that is too rigid can often result in inadequate stimulus and insufficient callus formation, further resulting in non-union.^{34,35} Two-level PSO osteotomy can produce a sufficient correction angle in a harmonious manner.³⁶ The von Mises stress on the rods at the PSO level can be shared, which can also reduce the instrument failure risk at the PSO site. However, two-level osteotomy also has several disadvantages compared with monosegment osteotomy: (i) there is more blood loss; (ii) the operative time is longer; and (iii) it calls for highly experienced and skilled surgeons.³⁶

Limitation

There are certain limitations in the present study. First, it is a retrospective study. Second, the number of patients was relatively small in each group. We could not implement the chi-square test because the number of cases of major complication was too small. Third, this study relied on relatively short-term follow-up results. Hence, a longer-term follow-up and larger cohort study need to be conducted.

Conclusion

Although patients with ankylosing spondylitis kyphosis have a lower postoperative rod fracture rate. These patients can still benefit from the satellite rod technique. The satellite rod technique is also recommended for patients who undergo osteotomy to correct ankylosing spondylitis kyphosis deformities. Larger cohort studies with larger sample size are needed to biomechanically demonstrated whether two-level osteotomy can reduce local stress and rod fracture risk.

Author's Contribution

Chao Liu and Fanqi Hu: Correction of data and Original draft preparation.

Xuesong Zhang, Fangcai Li and Kai Song: Conceptualization, supervision, reviewing and editing, financial support. Wenhao Hu, Zhen Zhang, Guoquan Zheng: Data analysis and interpretation.

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