Results of Posterior Spinal Instrumentation Alone to Correct Adolescent Idiopathic Scoliosis: Siriraj Hospital's Experience

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Purpose: *To evaluate the results of posterior instrumentation in correcting adolescent idiopathic scoliosis in Siriraj Hospital.*
Methods: *A retrospective analysis was conducted on patients who had posterior instrumentation to correct adolescent idiopathic scoliosis at Siriraj Hospital between January 1999 and December 2006. All had a minimum of 2 years' follow-up.*
Results: *This study showed that this method is effective to correct a very large curve of more than 90°. In different constructs, this study revealed that there were no statistically significant differences between the groups with pedicle screw constructs and hybrid constructs in frontal and sagittal plane correction. Similarly, there was no statistically significant difference between Lenke Type 1, 3, and 5 groups in frontal and sagittal plane correction. Our results demonstrated a strong relationship between proximal junctional kyphosis, hybrid instrumentation (proximal hooks and distal pedicle screws), and preoperative larger sagittal thoracic Cobb angle (T5-T12 ≥ 40°).*
Conclusion: *The posterior instrumentation alone corrected adolescent idiopathic scoliosis satisfactorily at Siriraj Hospital. However, this study needs greater patient numbers and a long term follow-up period. Our results demonstrated a strong relationship between proximal junctional kyphosis, hybrid instrumentation (proximal hooks and distal pedicle screws). and preoperative larger sagittal thoracic Cobb angle (T5-T12 ≥ 40°).*

Keywords: *adolescent idiopathic scoliosis, posterior instrumentation, Cobb angle, proximal junctional kyphosis*

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Scoliosis has always been an interesting and difficult problem in orthopedics. Significant advances have occurred at a rapid pace over the past several years in the operative management of adolescent idiopathic scoliosis. Currently the surgical strategies rely on principles of biomecha nics, empirical rules, knowledge of the results of reported clinical studies, and the surgeon's experience. There is no clear consensus on the optimal instrumentation system to use and even less clear consensus on the optimal operative strategy for each curve type. The technique and strategy for surgical treatment are made according to the surgeon's training, experience, and knowledge.

Adolescent idiopathic scoliosis (AIS) is a complex, three-dimensional (3-D) deformity of the spine and rib cage.[1,2] Severe cases are treated with a surgical procedure that requires instrumentation and fusion of strategic spine segments.[3-5] The objective of the surgical procedure is not only to correct the deformity but, more importantly, to obtain a balanced posture and preserve spinal mobility.[5] To obtain maximum correction and preserve spinal mobility, it is necessary to determine both the optimal fusion extent and instrumentation strategies. A longer fusion allows a better control of the deformed spine segments but produces a reduction in postoperative spinal mobility,[6] whereas a shorter fusion may not adequately correct the misalignments and may lead to imbalance.[7-9] Surgical strategies involve important decisions before and during the surgery.

Traditionally, rigid curves have been treated with extensive anterior release with or without fusion; however, the absolute indications for this approach are unclear. The obvious disadvantages of extended anterior approach include a large transabdominal or thoraco-abdominal dissection with associated vascular manipulation, two large surgical procedures, increased operative time, and poor cosmesis. The use of pedicle screw fixation and extensive posterior releases may obviate the need for extensive abdominal surgery by enabling

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significant correction through a posterior only approach.

Anterior instrumentation is an established technique for idiopathic thoracolumbar and lumbar scoliosis. It gives a better coronal plane correction with shorter fusion length when compared to posterior instrumentation using hooks.[10] This technique has gained widespread acceptance since the introduction of solid rods in anterior instrumentation. However, a recent study suggested that anterior surgery was associated with significant deterioration of lung function.[11,12]

The use of pedicle screws in posterior scoliosis surgery is associated with shorter fusion length and better three-dimensional correction than hooks.[13] We have been performing segmental pedicle screw fixation for adolescent idiopathic scoliosis in our institution and have found them to be safe and effective in the correction of the scoliosis and maintenance of the correction. Segmental pedicle screw instrumentation has been shown to be safe and effective in the surgical correction of both coronal and sagittal plane deformity in thoracolumbar and lumbar scoliosis of <60°, with a short fusion length, comparable to anterior fusion techniques, and minimal loss of correction.[14] Advocates of pedicle screw constructs reported that the advantages for all pedicle screw constructs in adolescent idiopathic scoliosis (AIS) include three-column fixation; improved coronal, sagittal, and rotational correction; lower pseudarthrosis rates; lower implant failures; and fewer postoperative bracing requirements than conventional hook and wire constructs.[15-18] The purpose of our study is to evaluate the results of posterior instrumentation alone in correcting adolescent idiopathic thoracolumbar and lumbar scoliosis (AIS) at Siriraj Hospital.

Materials and Methods

A retrospective analysis by an independent physician (spine fellow) was conducted on patients with adolescent idiopathic scoliosis who had posterior instrumentation alone to correct adolescent idiopathic scoliosis at Siriraj Hospital between January 1999 and December 2006. All patients were selected from ICD 10 code (M411-Juvenile idiopathic scoliosis) between January 1999 and December 2006 by computer program. There were 37 patients (3 males and 34 females) after excluding incomplete records, incomplete radiographic data, inadequate follow-up period, syndromic scoliosis, anterior instrumentation, combined anterior & posterior instrumentation, and cases of revision surgery. All patients were classified according to the Lenke system. The data collection included sex, age at time of surgery, Lenke classification, Risser sign, type and level of instrumentation, operative time, estimated blood loss, transfusion volume, and length of hospital stay.

Surgical technique

All surgeries were performed at our institution by three senior spine surgeons. Pedicle screw construct or hybrid construct was used. The levels fused and instrumented were chosen between the end-vertebrae of the major curve. Local bone grafts were used in all cases without using autogenous iliac crest bone graft. Bone morphogenetic protein was not used in any patients.

Clinical evaluation

The clinical outcome of surgery was assessed by using medical record review. We evaluated clinical parameters, including deviation of C7 plumb line, pain, function, and satisfaction.

Radiographic evaluation

The preoperative radiographic evaluation for all patients included 36-inch long cassette posteroanterior and lateral radiographs taken with the patient standing. Curve flexibility was evaluated using supine right and left side bending posteroanterior radiographs of the spine, or traction radiographs. Postoperative radiographs consisted of standing posteroanterior and lateral radiographs taken on a 36-inch long-cassette. All radiographic measurements were made on the preoperative, postoperative and final postoperative radiographs of every patient by an independent physician. All radiographic parameters were measured at least two times. We considered repeated measurement if the repeated angle measurements indicated a difference of more than 5°.

Radiographic parameters included Cobb angle of major and minor curves in PA standing view of whole spine. Curve flexibility was evaluated on the preoperative side bending or traction radiographs. Frontal plane balance was evaluated using C7 plumb line over sacrum and lateral trunk shift. Sagittal plane balance was evaluated using thoracic kyphosis (T5-T12), lumbar lordosis (L1-S1) and proximal junctional angle.

Results

Patients and Operations

There were 37 adolescents with idiopathic scoliosis operated on at Siriraj Hospital between January 1999 and December 2006. There were 3 males and 34 females. Mean follow-up period was 3.6 years (range from 2 to 8 years). The average age at the time of surgery was 14 years (range from 10 to 19 years).

The average Risser sign at surgery was grade 3 (range from 2 to 5).

According to Lenke classification system,

26 patients had Type 1 (main thoracic; 70%), 2 had Type 3 (double major; 5%), and 9 had Type 5 (thoracolumbar/lumbar major; 24%). The mean thoracic curve was 54° (range from 30 to 93).The mean thoracolumbar/lumbar curve was 32° (range from 8 to 65). On lateral bending radiographs, the thoracic curves were reduced by an average of 19° (35%) and the thoracolumbar/lumbar by 15° (47%).

On traction radiographs, the thoracic curves were reduced by an average of 21° (39%) and the thoracolumbar/lumbar by 13° (40%). The mean thoracic kyphosis was 18° (range from 3 to 42) and mean lumbar lordosis was 52° (range from 38° to 70°).

Patient demographics for each type of curve indicated no statistically significant differences in age at time of surgery, gender, or Risser sign between different Lenke types. (Table 1) Twelve patients were treated with pedicle screw construct. There were 25 patients treated with hybrid construct (pedicle screws and hooks). The mean operating time was 3.8 hours (range from 3 to 5). The total estimated blood loss was on average 680 ml (range from 100 to 2000). The average transfusion volume was 1 unit (range from 0 to 3 units). Ten patients required no blood transfusion. The average stay in hospital after surgery was 11.5 days (range from 7 to 21).

Table 1. Patient Demographics

	Type of curve (n=37)		
	Lenke type 1 (n=26)	Lenke type 3 (n=2)	Lenke type 5 (n=9)
Mean age at time of surgery (years)	14	17	15
Gender(female/male)	24/2	2/0	8/1
Risser sign (median)	3	4	4

Radiographic Assessment

For frontal plane correction and balance, mean thoracic curve improvements were 18° (68%), 26° (66%), and 14° (60%) in Lenke Types 1, 3, and 5 groups, respectively. Mean thoracic curve correction losses were 0.6 (1%), 10 (13%), and 0.1(0.3%). More than 5° in loss of correction was found in 3 Type 1 patients and 2 Type 3 patients. (Table 2) The improvements of thoracolumbar/lumbar curve in the Lenke Type 3 2° (4%) and 2° (5%). More than 5° in loss of and thoracolumbar/lumbar curve correction losses were Type 5 groups were 81% and 81%. Mean correction were found in 4 Type 1 patients and 2 Type 5 patients. (Table 3)

Table 2. Thoracic curve correction in frontal plane

	Type of curve (n= 37)		
	Lenke Type 1	Lenke Type 3	Lenke Type 5
Number of patients	26	2	9
Mean preoperative thoracic curve (degrees)	57° *	76° *	34°*
Mean preoperative thoracic curve bending (degrees)	37°	61°*	21° *
Mean percent correction (%)	35%	20%	38%
Mean preoperative thoracic curve traction (degrees)	34° *	43° *	18° *
Mean percent correction (%)	40%	43%	47%
Mean postoperative thoracic curve (degrees)	18°	26°	14°
Mean percent correction (%)	68%	66%	60%
Mean follow-up thoracic curve (degrees)	19°	36°	14°
Mean percent loss of correction (degrees, %)	0.6° (1%)	10° (13%)	0.1° (0.3%)
Loss of correction >5° (number of patients)	3	2	0

P<0.05 between groups

Table 3. Thoracolumbar/lumbar curve correction in frontal plane

	Type of curve (n=27)		
	Lenke Type 1	Lenke Type 3	Lenke Type 5
Number of patients	19	2	6
Mean preoperative thoracolumbar/lumbar curve (degrees)	22° *	51° *	49° *
Mean preoperative thoracolumbar/lumbar curve bending (degrees)	8°	39°	28°
Mean percent correction (%)	62%	24%	43%
Mean preoperative thoracolumbar/lumbar curve traction (degrees)	14° *	31° *	26° *
Mean percent correction (%)	37%	38%	46%

Mean postoperative thoracolumbar/lumbar curve (degrees)	6°	10°	9°
Mean percent correction (%)	72%	81%	81%
Mean follow-up thoracolumbar/lumbar curve (degrees)	6°	12°	12°
Mean percent loss of correction (degrees,%)	0.3° (1%)	2° (4%)	2° (5%)
Loss of correction >5° (number of patients)	4	0	2

* P<0.05 between groups

There were clear-cut improvements in trunk balance in Lenke Type 1 and 5 groups. Mean lateral trunk shift was corrected from 25 mm to 13 mm in the Lenke Type 1 group. Mean correction of lateral trunk shift was corrected from 18 mm to 12 mm in the Lenke Type 5 group. The C7 plumb line was corrected from 19 mm to 11 mm in Lenke Type 1 and there was a correction from 20 mm to 11 mm in Lenke Type 5. (Table 4)

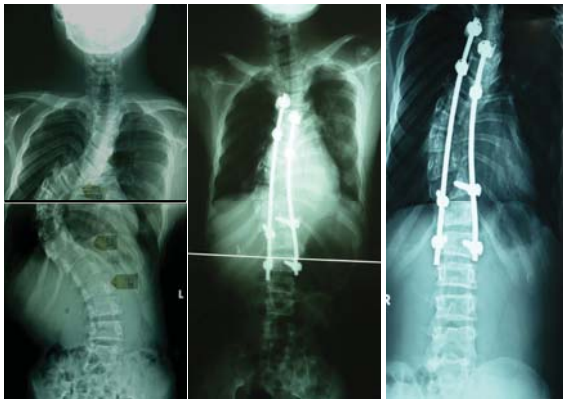
Table 4. Frontal plane balance correction

	Type of curve		
	Lenke Type 1	Lenke Type 3	Lenke Type 5
Lateral trunk shift (mm)			
▪ Mean preoperative	25	14	18
▪ Mean postoperative	13	14	12
▪ Mean last follow-up	11	13.5	11
C7 over the sacrum (mm)			
▪ Mean preoperative	19	12.6	20
▪ Mean postoperative	11	13	11

Frontal plane imbalance was revealed immediately after correction in 1 Type 3 patient and 3 Type 1 patients. All patients with immediate postoperative frontal plane imbalance were treated with hybrid constructs (proximal hooks and distal pedicle screws).

One Type 3 patient had progressive scoliosis since she was16 years old. This patient underwent posterior fusion and instrumentation with hybrid construct from T4-L1. Postoperative Cobb angle was corrected from 86° to 29 ° (T5-T12) and 36° to 1° (L1-L3). Immediate postoperative C7 plumb line deviation was revealed. This patient developed thoracic curve decompensation after 3 years follow-up. (Figure 1) However, there was no statistical difference between groups in frontal plane balance correction. During follow-up, all 4 of the patients with immediate postoperative frontal plane imbalance still had good clinical symptoms and satisfactory results.

For sagittal plane correction and balance, mean thoracic kyphosis was 16°, 34°, and 19° in Lenke Type 1, 3, and 5 groups, respectively. Mean thoracic kyphosis at postoperative period was 17.5°, 24.5°, and 19.2° in Lenke Type 1, 3, and 5 groups, respectively. In Lenke Type 3 group, thoracic kyphosis decreased 5° at the last follow-up, whereas Lenke Type 1 and 5 groups revealed no statistically significant increase of thoracic kyphosis. (Table 5)



(A) (B) (C)

Fig. 1 Preoperative (A), postoperative (B) and 3 years follow up (C) radiographs. The thoracic curve decompensation was progressed after 3 years follow up.

Table 5. Sagittal plane balance correction

	Type of curve		
	Lenke Type 1	Lenke Type 3	Lenke Type 5
▪ Mean thoracic kyphosis (degree)	16°	34°	19°
▪ Mean thoracic kyphosis at postoperative (degrees)	17.5°	24.5°	19.2°
▪ Mean thoracic kyphosis at last follow up (degrees)	18°	29°	24°
▪ Mean thoracic kyphosis change (degrees)	2° (increase)	5° (decrease)	7° (increase)
▪ Mean proximal junctional angle (degrees)	5°	3°	6°
▪ Proximal junctional kyphosis (number of patients)	2(8%)	0	2(22%)

Mean preoperative lumbar lordosis was 52.3° and mean lumbar lordosis at last follow-up was 52.1°. There was no statistically significant in different Lenke curve types. In our study, 4 patients (11%) had proximal junctional kyphosis. Two patients (8%) were Type 1 and 2 patients (22%) were Type 5. There was no patient with

proximal junctional kyphosis in the Lenke Type 3 group. However, there was no statistical difference between groups in sagittal plane balance correction. All 4 patients were treated with hybrid instrumentation (proximal hooks and distal pedicle screws). Three of 4 patients had a larger preoperative thoracic kyphosis angle (T5-T12 ≥ 40°). One of the 4 patients reported upper back pain and hardware prominence. During follow-up, this patient still had good clinical symptoms and satisfactory results. All 4 patients had normal physical activity. No patients were revised for proximal junctional kyphosis. There were no statistically significant differences between the pedicle screw constructs group and the hybrid constructs group in frontal and sagittal plane correction.

Clinical Results

Hospital records of all patients were retrieved. During follow-up, all patients except 4 had a good trunk balance clinically analyzed by a plumb line dropped from C7. One patient reported upper back pain which related to hardware prominent. This symptom resolved during follow-up. All patients had normal physical activity.

Complications

There were no neurologic complications, no repeat surgeries, no complication related to screw placement, no implant failures, and no infections. One patient developed surgical wound dehiscence at the upper part of the surgical wound which resolved after debridement and resuture.

Discussion

Surgical treatment of adolescent idiopathic scoliosis (AIS) consists of anterior/ posterior instrumentation and fusion or combined surgery. Anterior instrumentation and fusion for thoracolumbar and lumbar scoliosis was initially introduced by Dwyer and Schafer in 1974.[22] The technique was further popularized by Zielke and Pellin, who improved the instrumentation.[23] It gave a better coronal plane correction with shorter fusion length than posterior instrumentation using hooks.[10] This technique has gained widespread acceptance since the introduction of solid rods in anterior instrumentation. However, a recent study suggested that anterior surgery was associated with significant deterioration of lung function.[11, 12] The most recent instrumentation innovation for the treatment of adolescent idiopathic scoliosis (AIS) is the pedicle screw. Pedicle screws have been combined with hooks in hybrid constructs or used alone in all-screw constructs.

Exactly what combination of fixation techniques is most efficacious remains controversial. The concept of thoracic pedicle screws for treatment of AIS was described by Suk et al. in 1995.[18] They found significantly better coronal correction for all-screw constructs than all-hook constructs. In 1996, Hamill et al.[24] studied the hybrid construct using distal pedicle screws and thoracic hooks. They reported a statistically significant improvement of Cobb angle correction in the hybrid group than with Cotrel-Dobousset (hook) instrumentation alone. Liljenqvist et al. in 2002[25] and Storer et al. in 2005[26] reported no significant difference in immediate postoperative coronal correction, although long-term follow-up (2-12 years) showed that primary coronal curve correction was better maintained in the hybrid constructs group than in the all-hook group. The potential advantage of pedicle screw fixation needs to be balanced with a consideration of complications of screw placement.

The potential for risks and complications exists, especially in the narrow upper thoracic pedicles. These risks include possible neurologic injury, major vascular injury, and violation of the pleura. Kim et al.[27] reported significantly better major curve correction in the all-screw group over the hybrid group. Jason et al. in 2007[28] showed no statistically significant difference when comparing both constructs groups, although a trend was observed toward better correction of the main thoracic curve in the all-screw construct group. The all-screw group demonstrated a significant decrease in kyphosis which was not seen in the hybrid group.

In our study, the posterior instrumentation and fusion proved to be a safe and effective choice of surgery to correct adolescent idiopathic scoliosis (AIS) of both frontal and sagittal plane deformity. This study showed that this method is effective to correct a very large curve of more than 90°. This study revealed that there were no statistically significant differences between the groups with pedicle screw constructs and hybrid constructs in frontal and sagittal plane correction. Similarly, there was no statistically significant difference between groups of Lenke Type 1, 3, and 5 in frontal and sagittal plane correction. The frontal plane imbalance was revealed immediately after correction in 1 Type 3 patient and 3 Type 1 patients. All patients with immediate postoperative frontal plane imbalance were treated with hybrid constructs (proximal hooks and distal pedicle screws).

Theoretically, the biomechanical advantage achieved by using pedicle screws construct is more effective than the hybrid construct for correcting spine deformity, especially in rotational deformity. Four patients in this study had immediate postoperative frontal imbalance in hybrid constructs. The upper thoracic curve is often more rigid than the lower thoracic curve, although the upper thoracic curve seems to be compensatory.

Indications for inclusion of proximal thoracic curve into fusion during instrumentation of adolescent idiopathic scoliosis (AIS) patients

have been a matter of debate. Extension of fusion to T2 or T3 is controversial. Lenke et al.[29] recommend extending the instrumentation up to T2 to produce level shoulders and maintain coronal balance in structural upper thoracic curve. However, there is a lack of consensus about which curves need fusion and which do not. Therefore, pedicle screws were assumed to decrease the incidence of decompensation of the upper thoracic curve, especially for rigid curves. Average curve correction loss in our study revealed no significant difference in both constructs and in several types of Lenke classification. Mean thoracic curve correction losses were 0.6(1%), 10(13%), and 0.1 (0.3%) in the Lenke Type 1, 3, and 5 groups, respectively. More than 5° in loss of correction was found in 3 Type 1 patients and 2 Type 3 patients. Mean thoracolumbar/lumbar curve correction losses were 2° (4%) in the Type 3 group and 2° (5%) in the Type 5 group. More than 5° in loss of correction was found in 4 Type 1 patients and 2 Type 5 patients.

One patient in this study developed surgical wound dehiscence at upper part of surgical wound which resolved after debridement and resuture. There were no other serious complications, such as neurological deficit, no repeat surgeries, no complications related to screw placement, no implant failures, and no infections.

Proximal junctional kyphosis (PJK) following posterior instrumented spinal fusion has been observed in adolescent idiopathic scoliosis with little attention. Lee et al.[19] reported proximal kyphosis in 46% of patients at two-year follow-up after a review of 69 patients treated with posterior instrumented posterior spinal fusion. A preoperative kyphosis at one level proximal to the proposed upper instrumented vertebra of greater than 5° was used to predict postoperative proximal kyphosis in this study. This study did not report the effect of PJK on clinical symptoms and patient outcomes. Rhee et al.[20] demonstrated a proximal junctional measurement increase greater than or equal to 10° in 35% of patients treated with posterior instrumented posterior spinal fusion. This study showed that PJK was more commonly associated with posterior instrumentation compared with anterior instrumentation; however, at two years postoperative, no patients were revised for PJK. Yongjung et al.[21] reported that two-year postoperative PJK prevalence in AIS following 3 different posterior segmental spinal instrumentation and fusion surgeries was 27%. A larger preoperative thoracic kyphosis angle, greater immediate postoperative thoracic kyphosis angle decrease, thoracoplasty, and male sex correlated significantly with PJK. There were no significant differences in Scoliosis Research Society Patient Questionnaire-24 outcome scores between the PJK and the non-PJK group.

In our study, 4 patients (11%) had proximal junctional kyphosis. A larger preoperative thoracic kyphosis angle and hybrid construct (proximal hooks and distal pedicle screws) show more correlation with PJK.

All 4 patients were with treated hybrid instrumentation (proximal hooks and distal pedicle screws). Three of 4 patients had a larger preoperative thoracic kyphosis angle (T5-T12 $\geq$ 40°). One of 4 patients reported upper back pain and hardware prominence. During follow-up, the patient still had good clinical symptoms and satisfactory results. All patients had normal physical activity. No patients were revised for PJK. Both constructs achieved success in sagittal correction in patients with AIS. However, a pedicle screws construct gives a better correction and decreases incidences of PJK compared to posterior instrumentation using hooks.

The concept of optimal instrumentation is an interesting point that all orthopedic surgeons in our institution must consider. The international literature shows that nearly all levels of deformity were considered for instrumentation. At our institute, we based the number of implants on necessity. The risks and benefits of implants must be considered. More implants allows for better correction of the deformity**.** In contrast, complications related to screw placement and economic reasons should be considered, especially in the current world economic crisis. Our study revealed satisfactory results of the optimal number of implants.

In addition, hybrid construct was a good alternative choice for correction of the deformity. However, PJK may be considered, especially in patients with large preoperative thoracic kyphosis angle (T5-T12 $\geq$ 40°). In this situation, pedicle screws should be used.

Study limitations

A main limitation of our study is its retrospective design because all the data collected depended on accuracy of documentation. There are relatively small patient numbers after excluding incomplete records and incomplete radiographic data. Another limitation is that clinical evaluation using medical record review is direct interview. This may introduce bias due to different behaviors of interviewers and patients.

Conclusion

The Using posterior instrumentation alone to correct adolescent idiopathic scoliosis (AIS) at Siriraj Hospital had satisfactory results. However, this study needs greater patient numbers and a long-term follow-up period. Our results demonstrated a strong relationship between proximal junctional kyphosis (PJK), hybrid instrumentation (proximal hooks and distal pedicle screws), and

preoperative larger sagittal thoracic Cobb angle (T5-T12 ≥ 40°).

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ผลการรักษาภาวะกระดูกสันหลังคดชนิดไม่ทราบสาเหตุในวัยรุ่นด้วยการผ่าตัดยึดกระดูกทางด้านหลังเพียงอย่างเดียว ในโรงพยาบาลศิริราช

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การศึกษาแบบย้อนหลังในการแก้ไขภาวะกระดูกสันหลังคดชนิดไม่ทราบสาเหตุในวัยรุ่น ด้วยวิธีผ่าตัดทางด้านหลังในผู้ป่วย 37 ราย ซึ่งได้ติดตามผลเป็นเวลาอย่างน้อย 2 ปี แสดงให้เห็นว่าการผ่าตัดทางด้านหลังเป็นวิธีที่ได้ผลดี สามารถแก้ไขภาวะกระดูกสันหลังคดในรายที่มีมุมกระดูกสันหลังคดมากกว่า 90 องศา โดยไม่พบความแตกต่างของการแก้ไขความผิดปกติทั้งใน frontal plane และ sagittal plane ระหว่าง pedicle screw constructs และ hybrid constructs และพบว่าการผ่าตัดให้ผลไม่แตกต่างกันในกลุ่มผู้ป่วยที่มีลักษณะกระดูกสันหลังคดในแต่ละแบบตาม Lenke classitication นอกจากนี้ยังพบความสัมพันธ์อย่างมีนัยสำคัญระหว่าง proximal junctional kyphosis, hybrid instrumentation (proximal hooks and distal pedicle screws) และ preoperative larger sagittal thoracic angle (T5-T12 $\geq 40^0$)