Although the vast majority of spinal deformity surgeries are still done in adults and in the adolescents who are past the growth spurt, an increasing number of surgeries are being performed on younger patients with spinal deformities, and this is due to the better understanding of the natural history of spinal diseases and the improved surgical techniques. While the main goal of surgical intervention in these younger patients remains the same, i.e., the cessation of the deforming progress, modern surgical techniques tend to put an emphasis on actively correcting the existing deformity to restore the spinal balance and the biomechanics, in addition to stabilizing the deformity via a solid arthrodesis.

To fulfill these objectives, the use of internal fixation has become an integral part of the deformity surgery, and this similar to surgical correction that is performed in the older patient population. However, due to the biological characteristics that are unique to the pediatric population, there has been much debate concerning the necessity of employing internal fixation as the most suitable fixation devices for the pediatric population.

Spinal pedicle screws were first introduced by Boucher\textsuperscript{1} in the 1950s and they were popularized by Roy-Camille\textsuperscript{10} in the 1960s. They offer a secure vertebral grip that achieves improved control of the instrumented segments and rigid internal immobilization. Due to these advantages, spinal pedicle screws are gaining increasing popularity for the management of spinal deformities. However, for the younger pedi-
atic population, there has been few studies that have docu-
mented the long term results regarding the effectiveness and
safety of the pedicle screw fixation and the potential complica-
tions of employing pedicle screws in the immature spines that
have continued vertebral growth\(^4\) and small, plastic pedicles,
i.e., iatrogenic spinal stenosis and the crankshaft phenomenon\(^3\).

This retrospective study was carried out to determine the
efficacy of performing pedicle screw fixation for correcting
spinal deformity correction in the younger pediatric popula-
tion, and to evaluate the long-term effects of pedicle screw
fixation on the growing spine.

**MATERIAL AND METHOD**

Three-hundred-fifty pediatric spinal deformity patients
(the patients were less than 18 years old) underwent posterior
pedicle screw instrumentation, and 38 consecutive patients
who were less than 10 years of age at the time of surgery were
analyzed after a minimum follow up of 2 years (range: 2 to
7 years) to determine the effect of pedicle screw fixation on
the actively growing spinal column.

There were 16 males and 22 females with a mean age of
6.9 years (range: 2.7 to 10 years) at the time of their surgical
treatment. The triradiate cartilage was open in all the patients.
The etiologic diagnosis was congenital scoliosis/kyphosis in
25 patients, idiopathic scoliosis in 9 patients, neuromuscular
scoliosis from the postnatal form of cerebral palsy in 1 patient,
neurofibromatosis in 1 patient, postinfectious deformity in
1 patient and postlaminectomy kyphosis that has occurred
following resection of neuroblastoma in 1 patient. The pa-
tients with congenital deformities had an average of 5.7 years
(range: 2.7 to 10.0 years) at the time of the surgery. The pa-
thology of congenital spinal deformities were single hemiver-
tebra in 20 patients, double hemivertebrae in 1 patient, but-
terfly vertebra in 1 patient, hemivertebra with an unsegment-
ed bar in 1 patient, block vertebra in 1 patient and hemivertebra
with block vertebra in 1 patient (Table 1). The patients
with idiopathic deformities had an average of 9.7 years (range:
9.1 to 10.0 years) at the time of the surgery. Three of these
patients with idiopathic deformities were diagnosed with
juvenile form and 6 of them were diagnosed with adolescent
form.

The patients were reviewed using the medical records, the
preoperative and postoperative standing AP radiographs, and
the lateral radiographs; these were all taken at 2 weeks, 6
months, 12 months, 24 months and at the final follow-up
for the determination of the spinal maturity, the deformity
correction and the spinal balance in the coronal and the sagit-
tal planes. The deformity was measured on all the radiographs
by the Cobb’s method with using the end vertebrae that was
determined on the preoperative standing radiographs. Trunk
balance was determined by the distance of the T1 plumb line
from the center sacral line on the standing AP radiographs.
A deviation greater than 20 mm was considered decompen-
sation.

The crankshaft phenomenon was evaluated at the final fol-
low-up for the patients who were treated with only posterior
fusion and had Risser 4 or 5. This phenomenon was defined
as the progression of the Cobb angle of more than 10\(^°\) during
postoperative follow-up if no other specific cause of progres-
sion (pseudoarthrosis or adding-on) was found.

The position of the screws was checked on postoperative
radiographs at first postoperative exam and this was confir-
mmed with the CT scans if possible. The occurrence of screw-
induced iatrogenic stenosis was evaluated using the thin slice
CT scans that were taken during the first postoperative week
and at the last follow up. The spinal canal was considered
stenotic when there was a visible constriction of the dura in
the instrumented area with obliteration of the epidural fat
or when the anteroposterior or interpedicular distance of the
instrumented vertebrae was significantly less than those of
the uninstrumented vertebrae that lay above or below the
instrumented area.

All radiographic evaluations were carried out in a double
blind fashion by the third and the fourth authors, and the

<table>
<thead>
<tr>
<th>Table 1. Etiologic diagnosis</th>
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<tbody>
<tr>
<td>Etiology</td>
</tr>
<tr>
<td>Congenital kyphoscoliosis</td>
</tr>
<tr>
<td>Single HV(^*)</td>
</tr>
<tr>
<td>Double HV(^*)</td>
</tr>
<tr>
<td>Butterfly</td>
</tr>
<tr>
<td>Block V(^1)</td>
</tr>
<tr>
<td>HV(^*) with unseg. bar</td>
</tr>
<tr>
<td>HV(^*) with block V(^1)</td>
</tr>
<tr>
<td>Idiopathic scoliosis</td>
</tr>
<tr>
<td>Juvenile</td>
</tr>
<tr>
<td>Adolescent</td>
</tr>
<tr>
<td>Neuromuscular scoliosis</td>
</tr>
<tr>
<td>Neurofibromatosis</td>
</tr>
<tr>
<td>Others</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

HV\(^*\), hemivertebra; V\(^1\), vertebra.
mean values of the measurement were used for the analysis.

**Surgical techniques**

All the surgeries were done by the second author (SI Suk). The pedicle screw instrumentation was carried out by the following technique.

The spine was approached via a posterior midline incision that exposed the tip of the transverse processes. Following bilateral facetectomy and removal of the cartilages, the presumed pedicle entry points were decorticated with a rongeur. Guide pins were then inserted into the exposed cancellous bone, and the intraoperative PA and lateral radiographs were taken to determine the position of the guide pins relative to the ideal pedicle entry points. When the entry points were determined, a low speed drill was used to enter the pedicle. A safe entry was determined when the hole was surrounded by bone and resistance was met in all direction on probing. When a sound entry was confirmed, the hole was sequentially enlarged with larger drill bits until the hole assumed the size equal to the minor diameter of the inserted screw. Following a second probing to confirm the bony containment of the pedicle path, the pedicle screw was inserted.

With the pedicle screws in position, they were connected to the longitudinal members and instrumental correction of the deformity was carried out as planned.

Following the completion of the correction, all the screws were tightly locked to the rods and the constructs were stabilized by cross-linking of the longitudinal members by means of transfixators.

**RESULT**

For congenital deformities, the mean preoperative primary curve was $43^\circ$ (range: $35^\circ$ to $75^\circ$) in the coronal plane with a mean preoperative coronal imbalance of $13$ mm (range: $0$ to $25$ mm) and $28^\circ$ (range: $7^\circ$ to $60^\circ$) in the sagittal plane with a mean sagittal imbalance of $12$ mm (range: $0$ to $25$ mm). For the idiopathic scoliosis, the curve pattern was King type II in 3 patients, type IV in 2 patients and type V double thoracic in 4 patients. The mean preoperative major thoracic curve was $61^\circ$ (range: $43^\circ$ to $85^\circ$) in the coronal plane with a mean preoperative coronal imbalance of $18$ mm (range: $5$ to $25$ mm) and sagittal imbalance of $17$ mm (range: $3$ to $45$ mm). Four patients had a significant hypokyphosis. The mean magnitude of the proximal thoracic curve in patients diagnosed as King type V was $38^\circ$ (range: $30^\circ$ to $52^\circ$) with flexibility of $42.2\%$.

The treatment was comprised of posterior fusion with segmental pedicle screw fixation in 21 patients, vertebral column resection combined with segmental pedicle screw fixation in 16 patients (15 for the congenital deformities and 1 for a postlaminectomy kyphoscoliosis), and combined anterior and posterior correction was done in 1 patient (one case of juvenile idiopathic scoliosis). An average of 5.2 levels (range: 1 to 15) were fused with a mean of 8.9 screws per patient (range: 4 to 25 screws).

1. Deformity correction

In the posterior fusion group, the deformity was corrected to $16^\circ$ (range: $3^\circ$ to $41^\circ$) in the coronal plane, which showed...
In the sagittal plane the mean kyphosis was 13° (range: 2° to 42°), which showed a correction of 19° following the surgery. At the final follow up, the deformity in the coronal plane was 18° (range: 3° to 45°), which showed a loss of correction of 7.2%. In the sagittal plane, the deformity was 15° (range: 4° to 58°), which showed a loss of correction of 2°. The spine was balanced in all the patients. There was no significant progression of the deformity (Fig. 1, Table 2). For this study group, 12 patients (8 idiopathic deformities and 4 congenital deformities) was evaluated as Risser 4 or 5 at the final follow up. None of the patients showed aggravation of the deformity that was attributable to the crankshaft phenomenon.

In the posterior vertebral resection group, the mean preoperative coronal deformity of 45° (range: 36° to 75°) was corrected to 13° (range: 3° to 34°), which showed a correction of 71.5%. The mean preoperative kyphosis of 35° (range: 25° to 70°) was corrected to 11° (range: 2° to 42°), which showed a correction of 24° following the surgery. At the final follow up, the deformity in the coronal plane was 15° (range: 3° to 39°), which showed a loss of correction of 9.2%. In the sagittal plane, the deformity was 14° (range 4° to 58°), which showed a loss of correction of 3°. The spine was balanced in all the patients. There was no significant progression of the deformity (Fig. 2, Table 2).

For the patient treated by combined anterior release and posterior instrumentation, the preoperative scoliosis of 85° was corrected to 30°, which showed a correction of 64.7%. At the final follow up, the curve was 38° with 9.4% loss of correction. There was no significant progression of the deformity (Table 2).

### Table 2. Deformity correction

<table>
<thead>
<tr>
<th>Group</th>
<th>Preop</th>
<th>IMPO</th>
<th>IM corr</th>
<th>Final FU</th>
<th>LOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF* group (n=21)</td>
<td>49</td>
<td>32</td>
<td>45</td>
<td>35</td>
<td>85</td>
</tr>
<tr>
<td>PVCR group (n=16)</td>
<td>16</td>
<td>13</td>
<td>13</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td>Ant+Pi group (n=1)</td>
<td>18</td>
<td>15</td>
<td>15</td>
<td>14</td>
<td>38</td>
</tr>
<tr>
<td>PVCR (Total n=38)</td>
<td>72%</td>
<td>2°</td>
<td>9.2%</td>
<td>3°</td>
<td>9.4%</td>
</tr>
</tbody>
</table>

PF*, posterior fusion; PVCR, posterior vertebral column resection; Ant+Pi, anterior release and posterior instrumentation; Preop, preoperative; IMPO, immediate postoperative (2 weeks postoperation); IM corr, immediate postoperative correction; Final FU, final follow-up; LOC, loss of correction.

### Table 3. Complications

<table>
<thead>
<tr>
<th>Complication</th>
<th>Patients</th>
<th>Screws (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw malposition</td>
<td>5</td>
<td>7 (2.1)</td>
</tr>
<tr>
<td>Lateral</td>
<td>3 (0.9)</td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>2 (0.6)</td>
<td></td>
</tr>
<tr>
<td>Inferior</td>
<td>2 (0.6)</td>
<td></td>
</tr>
<tr>
<td>Medial</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pedicle fracture</td>
<td>4</td>
<td>6 (1.8)</td>
</tr>
<tr>
<td>Screw fixation failure</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Defority recurrence</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. (A, B) A 5.4 year-old female with a congenital kyphoscoliosis due to hemivertebra at L1. The magnitude of the coronal and sagittal angle was 40° and 34°, respectively. This patient was treated by posterior vertebral column resection with monosegmental fusion. (C, D) The postoperative 2-year follow-up standing radiographs. The coronal and sagittal angles were corrected to 17° and 5°, respectively.
were inserted with a mean of 8.9 screws per patient (range: 4 to 25). The diameter of the screws ranged from 4.0 to 5.0 mm (86 were 4.0 mm, 188 were 4.5 mm, 64 were 5.0 mm and 4 were 6.0 mm). There were 7 screw malpositions (2.1%) in 5 patients. The malpositions were lateral for 3 screws (0.9%), superior for 2 screws (0.6%) and inferior for 2 screws (0.6%) (Table 3). There were no medial malpositions. The screw malpositions were more common in the congenital deformities than in the other types of deformities.

Intraoperative fractures of the pedicle-lamina occurred in 6 pedicles (1.8%). All but 2 were detected intraoperatively. Those detected fractures occurred during the final stage of inserting the pedicle screws, but none of them caused gross intraoperative loosening that necessitated removal of the screws. Those intraoperatively undetected fractures occurred during the course of applying compression over the screws and they were recognized on a postoperative CT scan.

There were no major neurological or visceral complications that were attributable to the pedicle screws. There was 1 fixation failure in a congenital kyphoscoliosis patient who was treated by posterior vertebral column resection. In this patient, the intraoperative pedicle fracture occurred in the upper most instrumented vertebra during the course of applying compression over the pedicle screws. As the patient was very obese, the screw cutout was detected only on the postoperative CT scan that was performed several days later. Because there were no neurological symptoms, she was immobilized in a plaster of Paris body jacket for 3 months. However, on removal of the body jacket, the deformity recurred with pull-out of the proximal screws. Revision was carried out by performing proximal extension of the fusion and replacing the pulled out pedicle screws with larger diameter screws. There was 1 recurrence of deformity in a congenital kyphoscoliosis patient who was treated by posterior fusion due to an inappropriately short fusion. It was revised by performing proximal and distal extension of the fusion. A superficial infection occurred in a congenital scoliosis patient who was treated by posterior vertebral column resection, and the infection was treated by incision and drainage. The wound healed uneventfully in 2 weeks.

3. Iatrogenic spinal stenosis

A thin slice CT scan was performed at the last follow up for 27 patients (72%). Compared to the CT scans taken during the preoperative period and the CT scans taken during the immediate postoperative period, the shape of the spinal canal at the last follow up was neither deformed nor narrow. The AP and transverse diameters were 18 mm (range: 16 to 20 mm) and 20 mm (range: 18 to 21 mm), respectively, in the immediate postoperative period, and AP and transverse diameters were 19 mm (range: 17 to 20 mm) and 22 mm (range: 20 to 23 mm), respectively, at the last follow up and there was no statistically significant difference. The AP and transverse diameters of the uninstrumented areas were similar to the levels in the adjacent instrumented areas. There was no patient displaying indentation of the dura due to the screws or any patient who showed symptoms of neurogenic claudication that would be suggestive of spinal stenosis.

DISCUSSION

The spinal pedicle screws are a penetrating type anchor with resistance that spans to the middle and anterior column, and this enables a cantilever beam fixation in various force application modes and it offers a rigid bony grip that enables control of all three vertebral columns. Due to these biomechanical advantages, it has become more popular to use for correcting spinal deformities, both in adults and in the pediatric population.

Nevertheless, the pedicle screws are not as popular to use in the pediatric population before the growth spurt as in adults or in adolescents due to the fear of technical difficulties that might be encountered in placing the screws into small, immature pedicles, and there is also the potential of causing an iatrogenic stenosis of the spinal canal by transfixation of the neurocentral junction located at the posterior third of the vertebral bodies. The ability of the posterior pedicle screw fixation to resist the crankshaft phenomenon is also undetermined, and this is thought to be the main cause of deformity progression in the immature spine that is treated without an anterior growth arrest procedure. This retrospective review was performed to shed some light on these controversies.

As a whole, the reported risk of pedicle screw misplacement ranges from 3 to 40% with 0 to 41% of the neurological complications being attributable to the misplaced screws in surgeries that involve pedicle screw instrumentation. The reported incidence of screw misplacement in the pediatric population ranges from 0.3 to 25% with screw related
neurological complication being noted in 0 to 0.9%.

Though there has never been a study specifically reporting on the complications of pedicle screw placement in patients before the onset of their growth spurt, it is not too difficult to imagine a higher rate of misplacement-related complications, when considering the small size of the pedicles and the higher proportion of congenital deformities that occurs for the surgical candidates in this age group. However, our study revealed that screw misplacement in this age group is not more common than in the older age group. This may be attributed to our screw insertion technique that employs intraoperative radiographic control to determine the exact entry point, and also the gradual enlargement of the pilot hole with sequential drilling. The other factor that reduced malposition of the screws was that the pedicle screws were inserted into the normal vertebra after the resection of the deformed vertebra (resection of the hemivertebra during posterior column resection).

Intraoperative fracture of the pedicle in this age group is mainly caused by the gross discrepancy between the diameter of the pedicle and the diameter of the inserted screws. Although screws with diameters up to 115% of the pedicle diameter may be inserted without causing a fracture of the pedicle in the immature spine, fractures may occur even with the smallest diameter screws that are commercially available (4.0 mm) due to the small size of the immature pedicles. However, due to the plasticity of the immature cortical bone in young patients that allows significant deformation, comminuted fracture of the pedicle that renders the screw grossly unstable is a very rare event in this age group. In addition, the pedicle screws offer significant pull-out strength even with the split fracture of the pedicle by their grip into the vertebral body. These fractures mostly occur during the insertion process of the pedicle screws, especially during the final drive into the pedicles, and the fracture may be prevented by performing generous deconcentration of the entry points and enlarging the proximal portion of the pedicle path with using a drill slightly larger than the minor diameter of the employed screw. As the screws are quite stable, it is not necessary to remove them unless there is gross instability. Nevertheless, fractures of the pedicles will render the screws unstable to longitudinally directed forces (e.g. compression and distraction) and it may necessitate extending the fusion level if the fractures occur bilaterally at the end of the pedicle screw construct. Fracture of the pedicles may also occur during the course of applying a compressive or distractive force to the spinal column via the inserted screws, and this occurred for one patient in the study. This complication is more prone to occur in the smaller pedicles when using oversized pedicle screws that are greater than 80% of the pedicle diameter and this may be attributed to the microfractures of the pedicle cortex that occurs during the plastic deformation, which weakens the pedicle wall. As these cutouts significantly reduce the holding power of the pedicle screws, extending the instrumentation/fusion to secure additional points of fixation often necessary, as was done in our patient.

The neurocentral junctions are two obliquely oriented cartilage plates that lay between the anterior and posterior ossification centers of the vertebral body, and these plates are responsible for the growth of the spinal canal. Hence, spinal stenosis may result from premature closure of the synchondrosis or from premature osseous fusion of the anterior and the posterior elements. Although the neurocentral junctions usually close at the age of 3 to 6 years, the time for the spinal canal to reach its adult size seems to have regional variation. The proximal part of the vertebral column tends to mature before the caudal parts do.

The spinal canal at L3, 4 is 70% of the adult size at birth and it reaches the fully mature adult size by one year of age, while the canal of L5 is about 50% of the adult size at this age and reaches the adult size by 5 years.

Being a penetrating type anchor that spans all three columns of the spine, the pedicle screws essentially cross the neurocentral junction that is located at the posterior third of the vertebral body and may cause closure of the synchondrosis. However, iatrogenic fusion of the neurocentral junction does not invariably result in retardation of the canal growth or iatrogenic stenosis as the development of any stenosis is mainly dependant upon the size of the spinal canal at the time of the violation. The absence of iatrogenic spinal stenosis in our series may be attributable to the patient’s age at the time of operation being greater than 2 years which is when the spinal canal has nearly reached its adult size, and to the fact that most of the screws were inserted in the upper lumbar spine and the thoracic spine, which both mature relatively earlier than the lower lumbar spine.

Another potential complication of lengthy fusion in the immature patients, the crankshaft phenomenon, is attributed
to the continued growth of the anterior column in the presence of a posterior tether, which causes rotation of the fused segments. It mainly occurs in the immature patients below the age of 10 years who have open triradiate cartilage.

Though the standard method of preventing such a complication is adding an anterior arthrodesis at the time of posterior instrumentation, there have been suggestions, via animal studies, that using a stiff pedicle anchored construct may prevent the crankshaft phenomenon by overpowering the deforming force of the remaining anterior growth centers.

There was no progression of deformity that could attributed to crankshaft phenomenon in our series of patients who underwent posterior instrumentation, and this confirms the view of Asher et al. This may be attributed to the biomechanical characteristics of the pedicle screws that served as a cantilever beam fixation, and this offered resistance to the longitudinally directed forces that were evenly applied along its entire length through the posterior, middle and the anterior column.

CONCLUSION

In conclusion, pedicle screw fixation may be used in the young pediatric population below the age of 10 years with a safety that is comparable to that in patients of the older age group, this is without the hazard of causing iatrogenic spinal stenosis in most of the patients.

Pedicle screw fixation also has more advantages than the other forms of fixation e.g. hooks or wires, as pedicle screw fixation is able to prevent the crankshaft phenomenon and it eliminates the need of an additional anterior procedure.

REFERENCE

목적: 척추 변형 수술에서 3차원 교정이 가능한 척추경 나사못의 사용은 증가하고 있으나 10세 이하의 소아에서의 임상적 결과에 대한 보고는 드물어, 10세 이하의 소아에서 변형 교정을 위해 사용한 척추경 나사못의 유용성을 판단하고, 성장하는 추체에 척추경 나사못이 미치는 임상적 문제들을 알아보고자 하였다.

대상 및 방법: 수술을 시행할 때 10세 이하인 38명 환자를 대상으로 하였으며, 원인 질환으로는 25명의 선천성 척추 측만증, 9명의 특발성 척추 측만증, 기타 원인으로 인한 척추 변형 4명이었으며 최소 2년 이상(2-7년) 추시 가능한 환자를 대상으로 하였으며, 성장중인 추체에 척추경 나사못의 효과를 알아 보기 위해 27명(72%)에서 전산화 단층 촬영을 시행하였다. 수술 방법으로 후방 고정을 시행한 환자는 21명, 후방도달 척추 절제술을 시행한 환자는 16예, 전-후방 교정을 시행한 1예였다. 결과: 관상면에서 교정도를 살펴 보면 후방 고정을 시행한 경우는 67.2%의 교정을 보였으며, 후방 도달 척추 절제술을 시행한 경우는 71.5%, 전-후방 고정을 시행한 경우는 64.7%의 교정도를 보였다. 시상면에서는 평균 교정도는 20'였다. 전체적으로 341개의 척추경 나사못을 사용하였으며 환자 평균 8.9개의 나사못을 사용하였다. 합병증으로는 7개의 나사못이 정상 위치에 삽입되지 않았으며 (2.1%), 1명의 환자에서 고정의 상실이 있었으며, 1명에서 변형이 다시 진행하였으며, 1명에서 천부 염증이 관찰되었다. 그러나 모든 환자에서 심각한 신경학적 합병증은 발생하지 않았다. 또한 척추경 나사못 삽입으로 인한 척추관 협착 소견은 방사선학적으로 관찰되지 않았다. 결론: 척추경 나사못은 10세 이하의 척추 변형이 있는 소아에서도 성인과 같은 유용한 효과를 관찰할 수 있으며 어린 소아에서 척추경 나사못 삽입 후에 척추관 협착 소견은 관찰되지 않았다.

목록 단어: 척추 변형, 소아, 척추경 나사못 고정술

소아 척추 변형 수술시 척추경 나사못 고정술의 유용성
-10세 이하 환자에서의 임상적 결과-

김진혁ㆍ석세일ㆍ정의룡ㆍ김성수ㆍ오유민ㆍ전재민ㆍ최윤석
인제대학교 의과대학 상계백병원 서울 척추센터