ORIGINAL ARTICLE

High-grade child spondylolisthesis: A custom-made canulated screw to treat the so-called double instability


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KEYWORDS
Spondylolisthesis; High grade; Circumferential fusion; Child; Spine; Surgery

Summary
Study objectives: Describing and assessing of a new surgical procedure to achieve circumferential fusion and translumbosacral fixation using a custom-made canulated screw.

Patients and methods: Seven patients aged 13–18 years old underwent surgery with this technique (mean age: 15). All patients had high-grade spondylolisthesis (Meyerding stage III or IV). There were five girls and two boys. A posterior surgical approach alone was used in all cases. The posterior neural arch of L5 was removed and a sacral laminectomy, extending to S2, was performed. Sacral nerve roots S2 and S3 were carefully dissected and transposed. A K-wire was placed medially across the vertebrae from the posterior edge of S2 extending to the antero-superior corner of L5. Fluoroscopic perioperative fluoroscopic control confirmed correct K-wire placement. The custom-made 10 mm diameter canulated screw was then inserted along the K-wire as a guide. Screw fixation was obtained by placing a specific large diameter screw head to obtain compression by a lag screw effect. Once fixation was obtained, the sacral dome was excised and interbody fusion was performed (tricorticocancellous graft on each side of the screw). Additional bilateral posterolateral fusion was then performed. A half body custom fit thoracolumbar orthosis brace was prescribed 3 months postoperatively, followed by a Lombostat flexible lumbar support for an additional 3 months period.

Results: One neurological complication occurred. A dural tear occurred during dissection requiring simple repair. All of the patients were on their feet on the fifth postoperative day and began walking. The half body brace was worn for 4 months in four patients and 2 months in the three others. At final follow-up patients had no residual pain.

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Introduction

Spondylolisthesis is defined as the slipping of one vertebra over the vertebra below either due to a problem of continuity of the isthmus or dysplasia of the pars interarticularis. In children and adolescents these anomalies, which result in spinal instability, are usually found in the lumbosacral joint.

Although numerous hypotheses have been proposed for the pathogenesis of spondylolisthesis since it was first described by Herbiniaux [1], the exact mechanisms of these malformations are still unknown. This is also true for the many therapeutic strategies, which have been described with various results. The most frequently used classification of spondylolisthesis is that of Meyerding [2], which describes four grades depending on the degree of slipping. Spondylolisthesis with high-grade slippage (grades 3 and 4) is rare in children and treatment strategies remain controversial. Indeed, in symptomatic forms of this grade of displacement, the goal is to obtain definitive lumbosacral fusion, but opinions differ on how it should be obtained.

We believe that there is a dual instability in these high-grade spondylolstheses. The first is general and the cause of slipping due to isthmic rupture or lengthening in dysplastic forms. The second is locoregional, due to mobility in the L5-S1 space resulting in pain and possible radiculalgia as well as significant symptomatic thoracolumbar lordosis with forward projection of the trunk.

This study reports a continuous series of seven patients treated for high-grade spondylolisthesis according to the Meyerding classification [2]. All of these patients underwent surgery with a new technique including a posterior approach alone, circumferential fusion and transsacral fixation with a custom-made screw with an original design.

Patients and methods

Seven patients were included in the prospective study, five girls and two boys, mean age: 14.5 years old [range 12–18]. All patients had high-grade spondylolisthesis, three grade 3 and four grade 4 on the Meyerding scale.

The preoperative assessment included a clinical evaluation, a complete radiological work-up with AP and lateral view X-rays of the entire spine as well as MRI to search for any associated malformations of the medullary canal. The degree of slipping was measured on a standing lateral X-ray and on MRI with the patient lying on his/her back.

The radiographic assessment evaluated deformation of the superior endplate of S1, anomalies of the posterior neural arch of L5 and isthmic defects as well as classifying the degree of slipping. The angle of lumbosacral kyphosis was also measured according to the method described by Boxall et al. [3] and sagittal balance was evaluated according to the parameters of Duval-Beaupère et al. [4]. Blondel et al. have shown that measurement of pelvic incidence is not reliable in the presence of deformation in the superior endplate of S1 [5]. Modified pelvic incidence angles were determined between the right angle created by the middle of the superior endplate of L4 and L5 and the center of the femoral heads to look for any significant variations.

Planning for the length of the translumbosacral screw was based on preoperative X-rays. The surgical procedure was identical in all seven cases and was performed under general anesthesia with the patient in the decubitus ventral position with blocks to create lumbosacral lordosis and partial reduction by external manoeuvres on the lumbosacral slipping.

The approach was median and centered on the L5-S1 space with placement of an orthostatic separator. First the spinal canal was opened by ablation of the L5 and S1/S2 posterior neural arches allowing dissection of neural roots L5 and S1. Sacral roots S2 and S3 were then carefully dissected to have access to the posterior side of S2 where the guide wire was inserted under fluoroscopic control, medially from the posterior side of S2 to reach the anterosuperior angle of L5 before drilling with an appropriate cannulated drill (Figs. 1 and 2). The 10 mm cannulated screw (Medicalex, Bagneux, France) was inserted without the lag screw head. The sacral dome was then corrected with a chisel and an L5-S1 discectomy was performed including scraping the inferior endplate of L5 and the superior endplate of S1.

Interbody fusion was performed with corticocancellous iliac grafts and compression of the interbody space with a larger lag screw head (Fig. 3). Finally a bilateral posterolateral graft was performed to obtain circumferential fusion. A patient-controlled morphine pump was systematically provided to control postoperative pain and the patient was

Discussion: The lumbar spine in children with high-grade spondylolisthesis adapts to the new mechanical conditions after surgery. Therefore the principal goal of treatment is to obtain stable osseous fusion. Our treatment philosophy is based on the concept of a dual instability. We believe that a general instability exists which causes the development of spondylolisthesis; this must be respected by not attempting to correct the displacement beyond what can be obtained on the operating table with complete muscle release. The other, locoregional instability, must be stabilized during circumferential fusion. The custom-made, 10 mm screw has been shown to be effective in neutralizing the mechanical stress during circumferential fusion with a posterior approach alone, thus avoiding the risks of an anterior approach. Long-term results show that the preoperative posture is not the sole mechanical determinant in children and adolescents but that this posture is largely a reaction to pain.

Level of evidence: Level IV. Retrospective study.
immobilized in a half body corset for 3 months, followed by a lombostat lumbar belt for 3 months.

Postoperative radiographic follow-up confirmed correct positioning of the graft as well as the degree of correction of lumbosacral slipping. All patients then underwent radiographic and clinical controls until radiographic fusion was obtained. Once fusion was obtained, AP and lateral X-rays of the entire spine were obtained to measure sagittal spinal balance under these new postural conditions.

**Results**

Clinical data with the Meyerding grades are summarized in Table 1.

Seven patients (five girls and two boys) were included in the study, mean age: 14.5 years old [range 12–18]. The preoperative assessment showed severe lumbalgia, which had not responded to at least 1 year of appropriate medical treatment. Three patients had sciatica-type radiculalgia symptoms. All patients had severe spondylolisthesis. Three patients had grade 3 and four grade 4 spondylolisthesis on the Meyerderling scale on lateral X-ray. During MRI with the patient in the decubitus dorsal position, the degree of slipping was also evaluated and it was systematically a grade less than that measured with the patient standing: four grade 3 and three grade 2 when lying down.

The main preoperative radiological sagittal results are provided in Table 2. The mean preoperative lumbosacral kyphosis angle was 73.6° (42°–92°). Deformation of the supe-

<table>
<thead>
<tr>
<th>No. cases</th>
<th>Sex</th>
<th>Age</th>
<th>Preoperative radiological grade</th>
<th>Preoperative MRI grade</th>
<th>Postoperative grade</th>
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<tr>
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<td>F</td>
<td>12</td>
<td>IV</td>
<td>III</td>
<td>III</td>
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<td>16</td>
<td>IV</td>
<td>III</td>
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</table>
rior endplate of S1 made it impossible to obtain a reliable measurement of pelvic incidence. The modified mean incidence in relation to the superior endplate of L5 was 63.6° (30—90°). The mean measurement in relation to the superior endplate of L4 was 33.8° (15—50°). Mean sacral slope was 40.3° (26—50°). Evaluation of lumbar lordosis showed long thoracolumbar lordosis (mean 31.8°) with loss of thoracic kyphosis (mean 14°), a neutral vertebrae usually at L1 and an inflection point at T11. Four patients presented with isthmic lysis, which was visible on X-ray.

During circumferential fusion, one case of dural tear occurred during dissection, requiring simple repair and with no clinical consequences. Moreover, one neurological complication occurred in a patient presenting with a severe form of spondylolisthesis without isthmic lysis and with progressive bilateral S1 nerve root deformation, which had flattened to form bands because of the progressive vertebral slipping. The morphological change in the right neural root (quadrilateral shape, adhering to the lamina and with no reaction to stimulation) was the reason that it was not recognized resulting in a permanent postoperative neurological deficit.

Surgery lasted a mean 285 minutes (240—370 min), with slight blood loss which did not necessitate any peri- or postoperative blood transfusions. The mean length of the screw used was 69 mm (50—85 mm). Postoperative immobilization with a half body corset was used in seven cases.

Patients were allowed to get up 5 days after surgery wearing the corset, which was worn for 3 months then replaced by a lumbar belt for three more months. The mean hospital stay was 11 days (6—16 days).

Correct positioning of the graft material was confirmed on early postoperative control X-rays (Fig. 4). In seven cases radiological fusion was obtained 6 months after surgery. Postoperative sagittal radiological results are summarized in Table 3. Once consolidation of fusion had been obtained, mean lumbosacral kyphosis was 75.5° (55—90°). The mean incidence in relation to the superior endplate of L5 was 63° (46—90°). The mean measurement in relation to the upper endplate of L4 was 33.6° (22—56°). Mean sacral slope was 41° (30—48°). Evaluation of sagittal curves showed harmonization of curves with lumbalisation of lordosis (mean 42°) with one neutral vertebra, usually at L2 and an inflection point at T12-L1. Thoracic kyphosis was also more pronounced (mean 25°). Moreover, hip flexion had regressed (Figs. 5 and 6) and forward translation of the trunk in relation to the pelvis (uncompensated sagittal balance) had disappeared with a mean change in sagittal inclination at T9 from −4° preoperatively (−8—0) to 9° at the final follow-up (4—12).

Table 2  Preoperative sagittal radiological evaluation.

<table>
<thead>
<tr>
<th>No. cases</th>
<th>Lumbosacral kyphosis</th>
<th>Lordosis L1-L4</th>
<th>Kyphosis T4-T12</th>
<th>Sagittal slope T9</th>
<th>Neutral vertebra</th>
<th>Inflection point</th>
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<td>30</td>
<td>18</td>
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<td>T11</td>
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<td>32</td>
<td>22</td>
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<td>T11</td>
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<tr>
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<td>L1</td>
<td>T11</td>
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<tr>
<td>5</td>
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<td>36</td>
<td>6</td>
<td>−6</td>
<td>L1</td>
<td>T11</td>
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<tr>
<td>6</td>
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<td>28</td>
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<td>69</td>
<td>32</td>
<td>18</td>
<td>−6</td>
<td>L1</td>
<td>T11</td>
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</table>

Figure 4 Pre- and postoperative X-rays showing lumbosacral fixation by the custom screw.

Figure 5 Preoperative X-rays showing sagittal spine balance with a long thoracolumbar lordosis associated with hip flexion.
Table 3  Postoperative sagittal radiological evaluation.

<table>
<thead>
<tr>
<th>No. cases</th>
<th>Lumbosacral kyphosis angle</th>
<th>Lordosis L1-L4</th>
<th>Kyphosis T4-T12</th>
<th>Sagittal slope T9</th>
<th>Neutral vertebra</th>
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<td>44</td>
<td>26</td>
<td>10</td>
<td>L2</td>
<td>T12</td>
</tr>
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</table>

Patients had regular follow-up visits for a mean 30 months (12–44 months). No case of infection occurred. One patient with successful fusion required revision surgery for ablation of the screw head, which was causing subcutaneous pain. During revision surgery, there were no adhesions to the screw that could have complicated easy dural manoeuvres.

During clinical follow-up and until the last follow-up visit, none of the patients except one (neural root sectioned) had any radiculalgia or neurological complications. Patients’ preoperative radiculalgia had disappeared.

Discussion

Management of high-grade spondylolisthesis has been controversial for decades, resulting in numerous treatment strategies that may be more or less combined. Moreover, all severe forms do not necessarily require surgical treatment. For example Harris and Weinstein [6] described a series of 11 cases who did not undergo surgery including 10 patients with mild or no symptoms and 18 years of follow-up.

Nevertheless, in the presence of radiculalgia or persistent lumbalgia that does not respond to medical treatment, or if the risk of progression to spondyloptosis is high, lumbosacral fusion should be considered because in these cases the intervertebral L5-S1 disc is necessarily injured [7]. The aim of treatment is to obtain limited but solid fusion while restoring satisfactory spinal balance with a minimum of surgical risk. There have been numerous debates on instrumented or non-instrumented fusion, on the necessity of reducing the slipping and performing neural decompression.

We believe that there is a dual instability in these cases. The general instability is the cause of spondylolisthesis, whether it involves pars interarticularis fractures or elongation (dysplastic form). The mechanical and/or biological factors causing this slipping have not yet been clearly elucidated except to note that spondylolisthesis mainly involves patients whose pelvic incidence is high. In our opinion, there is no indication for correcting the slipping beyond what can be obtained on the operating table during complete muscle release. Forcing correction of the slipping would produce significant stress on the graft and a risk of failure.

The second instability is locoregional. There is mobility in the L5-S1 disc space, which varies but is always present. This mobility is the source of pain and possible radiculalgia. Pain and radiculalgia are the symptoms of severe thoracolumbar lordosis with forward projection of the trunk (uncompensated sagittal balance).

Partial reduction of slipping is obtained on the operating table because of the viscoelastic nature of the degenerated L5-S1 disc. This is clearly shown in our series by the results of the Meyerding grade on preoperative MRI in the decubitus dorsal position, which was systematically less than that measured on standing X-rays. Lumbosacral kyphosis is not reduced during surgery with this technique because we have shown that part of the significant underlying thoracolumbar lordosis with forward projection of the trunk is corrected after correction of painful locoregional instability. Indeed the pelvic vertebra should be thought of as a sesamoid bone that joins the extensors of the trunk above and the hamstrings below. These two systems fight together against locoregional instability by contracting. Thus progression of the disease results in retraction of these muscles. Once locoregional instability has been neutralized, the symptoms of significant thoracolumbar lordosis are improved. Both the hamstring syndrome and the forward translation of the trunk are resolved (Fig. 7).

We systematically performed decompression of the vertebral canal and the L5-S1 foramens by resection of the posterior neural arch and the compressive elements of the foramens according to the technique described by Gill et al. [8]. Because these manoeuvres increase instability, they...
techniques which are always associated with neurological disorders. There are many instrumented reduction including eight children requiring anterior complementary formed [9]. Vialle et al. [10] reported a series of 20 patients, through which non-instrumented lumbosacral fusion is performed extemporaneously by placing the patient in the decubitus ventral position and extending the hips during surgery. Partial reduction of slipping in high-grade spondylolisthesis in children is also controversial. There is a difference between reduction of slipping and that of lumbosacral kyphosis. The goal of the latter is to place the sacrum in a horizontal position. Partial reduction of slipping is obtained by viscoelastic changes from gravity and from the relative mobility of the L5-S1 disc in children. In our series the preoperative Meyerderg grade on MRI with the patient in the decubitus dorsal position was systematically one grade lower than that of the grade in standing X-rays. On the other hand, reduction of lumbosacral kyphosis can only be obtained by instrumented surgical manoeuvres because of bone incongruence, in particular, deformation of the sacral dome. In this study, simple reduction by placement on the operating table followed by sacral dome resection were used with the main advantage being a relatively lower neurological risk.

Partial reduction by external manoeuvres can be performed extemporaneously by placing the patient in the decubitus ventral position and extending the hips during surgery. It can also be progressive using a hamac and creating lordosis then building a windowed cast during surgery through which non-instrumented lumbosacral fusion is performed [9]. Vialle et al. [10] reported a series of 20 patients, including eight children requiring anterior complementary fusion and six patients with regressive postoperative neurological disorders. There are many instrumented reduction techniques [11—14] which are always associated with neural decompression and sometimes resection of a prominent sacral dome and in others with a dual posterior and anterior approach. The results of these different techniques are generally good but are associated with a risk of postoperative neurological deficits.

This technique of vertebral fusion can be instrumented or non-instrumented and by a posterior, anterior or combined approach. Grzegorzezki and Kumar [15] reported good results in their study of 21 children and adolescents who underwent in situ non-instrumented fusion. However there is a risk of pseudarthrosis with non-instrumented fusion and progression of slipping in the year following surgery has been reported. The few existing series of anterior fusion for spondylolisthesis in children and adolescents reported visceral, vascular and sexual complications so that this approach is rarely used alone as a first-line treatment. Other authors have proposed posterior interbody fusion, which results in decompression and good fusion but with an estimated risk of neurological deficits of between 4 and 5% [16,17].

Other therapeutic strategies of instrumented lumbosacral fusion have also been described. This includes wide opening of the canal, allowing some reduction of slipping associated with an improvement in the static saggital spine. Smith et al. [18] reported good results with partial reduction of lumbosacral kyphosis by associating transsacral interbody fusion and pedicular screws until L4. Another variant was reported by Boachie-Adjei et al. [19] with a low rate of complications and satisfactory results after more than 2 years of follow-up. Nevertheless, these techniques require sacrificing L4-L5 and are not without a risk of neurological deficits. More recently, Ruf et al. [20] proposed a technique which allowed anatomical reduction of slipping by circumferential L5-S1 fusion using temporary screws in L4. This strategy provides solid fusion with correction of lumbosacral kyphosis but was accompanied by neural deficits in six out of 27 cases as well as decompression on the adjacent level in 15% of cases.

The procedure used in that study was derived from the technique by Smith and Bohlman [21] which includes circumferential fusion with transacral peg fixation by posterior approach alone. Functional results with anterior and posterior fusion are better after 17.2 years of follow-up in the series by Lamberg et al. [22]. In our experience we first used a fibular graft then "hollow screws" and noted graft fracture or deformation of the hollow screws. We then began using larger screws to neutralize the physiological slipping between the decubitus dorsal position and standing due to the viscoelasticity of the "soft" intervertebral tissues, thus protecting the graft when the patient was in the standing position.

A custom-made 10 mm diameter screw with a larger head was therefore designed and produced, making it possible to obtain intervertebral compression. By a posterior approach alone and after simple reduction by positioning on the table, circumferential fusion was performed and obtained in seven of the treated cases. Postoperative radiographic analyses showed that once fusion was obtained sagittal alignment curves were modified with disappearance of significant dorolumbar lordosis and the development of lower lumbar lordosis and more marked thoracic kyphosis. Thus, for us, the goal is not to obtain perfect reduction of slipping, but to place the spine in a favorable position to obtain solid osseous fusion while limiting as much as possible the risk of neurological deficits. The neurological complication reported in this case involved a grade IV listhesis without ischemic lysis.
The complication was not directly related to the technique but had more to do with the very unusual appearance of the S1 nerve root.

In these young patients without degenerative injuries and with flexible spines, the mechanisms of compensation to restore sagittal alignment seem to occur by themselves once fusion is obtained. These changes in sagittal balance also emphasize the importance of the perispinal tissue, which can be assimilated to a veritable lever of muscular contraction once fusion is obtained, as shown by the restoration of sagittal alignment and the decrease in hip flexion after fusion. In our opinion, this is mainly correction of trunk imbalance rather than an intrinsic change in lumbar lordosis, as shown by the lack of significant variation between pre- and postoperative modified incidence angles.

These results support the notion of dual instability in high-grade forms of this disease, making it essential, in our opinion, to surgically correct locoregional instability.

Further follow-up of these patients is necessary to confirm that the persistent and in certain cases significant lumbosacral kyphosis will not result in long-term problems in older adults, as well as the outcome of the L4-L5 disc. This circumferential fusion screw is therefore an additional technique in the therapeutic arsenal for the management of high-grade spondylolisthesis. It has the advantage of using a single surgical approach for spinal stabilization but like any new technique it requires a learning curve, whose main difficulties include identifying the pulled neural roots from high-grade slipping and the necessity of wearing a brace after surgery.

Conflict of interest statement

None.

References