Original Article

Posterior Reduction and Monosegmental Fusion with Intraoperative Three-dimensional Navigation System in the Treatment of High-grade Developmental Spondylolisthesis

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Abstract

Background: The treatment of high-grade developmental spondylolisthesis (HGDS) is still challenging and controversial. In this study, we investigated the efficacy of the posterior reduction and monosegmental fusion assisted by intraoperative three-dimensional (3D) navigation system in managing the HGDS.
Methods: Thirteen consecutive HGDS patients were treated with posterior decompression, reduction and monosegmental fusion of L5/S1, assisted by intraoperative 3D navigation system. The clinical and radiographic outcomes were evaluated, with a minimum follow-up of 2 years. The differences between the pre- and post-operative measures were statistically analyzed using a two-tailed, paired *t*-test.
Results: At most recent follow-up, 12 patients were pain-free. Only 1 patient had moderate pain. There were no permanent neurological complications or pseudarthrosis. The magnetic resonance imaging showed that there was no obvious disc degeneration in the adjacent segment. All radiographic parameters were improved. Mean slippage improved from 63.2% before surgery to 12.2% after surgery and 11.0% at latest follow-up. Lumbar lordosis changed from preoperative 34.9 ± 13.3° to postoperative 50.4 ± 9.9°, and 49.3 ± 7.8° at last follow-up. L5 incidence improved from 71.0 ± 11.3° to 54.0 ± 11.9° and did not change significantly at the last follow-up 53.1 ± 15.4°. While pelvic incidence remained unchanged, sacral slip significantly decreased from preoperative 32.7 ± 12.5° to postoperative 42.6 ± 9.8°and remained constant to the last follow-up 44.4 ± 6.9°. Pelvic tilt significantly decreased from 38.4 ± 12.5° to 30.9 ± 8.1° and remained unchanged at the last follow-up 28.1 ± 11.2°.
Conclusions: Posterior reduction and monosegmental fusion of L5/S1 assisted by intraoperative 3D navigation are an effective technique for managing high-grade dysplastic spondylolisthesis. A complete reduction of local deformity and excellent correction of overall sagittal balance can be achieved.

Key words: High-grade Developmental Spondylolisthesis; Intraoperative Three-dimensional Navigation; Neurological Complication; Reduction; Spondylolisthesis

Introduction

Spondylolisthesis is the term describing forward slip of a vertebra on its caudal neighbor.[1] In this system, the most therapeutically challenging group is the high-grade developmental spondylolisthsis (HGDS), which is characterized by severe anterior slippage of L5, segmental kyphosis L5/S1, and retroversion of the sacrum.[2] The local deformity and dysplasia can result in an abnormal sacro-pelvic orientation as well as to a disturbed global sagittal balance of the spine. The accepted treatment for HGDS is surgery. However, the need for reduction, extent of reduction, and surgical technique are still controversial.[3-6]

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The best way to treat a HGDS is to correct the multidirectional deformity of the lumbosacral junction with minimal neurological risks. Even though there are conflicting reports about the *in situ* fusion for high-grade spondylolisthesis, the instrumented fusion with reduction has a clear advantage like facilitation of full nerve decompression, promotion of bony union, restoration of spinopelvic balance and patient`s ability to stand upright.[6-8] But in the HGDS, the peculiar anatomy of the lumbosacral joint is highly variable. The transverse angles of the pedicle are always bigger than normal, the presence of surrounding iliac spine and neurovascular structures, make the screw fixation and reduction more technically challenging.[2,6] In addition, there is a higher L5 nerve injury during reduction procedure.

The computer-assisted navigation system can provide real-time three-dimensional (3D) images, giving surgeons

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the chance to dynamically select screw entry points and directions, consequently enhancing the accuracy of pedicle screw placement. In addition, it can also reduce radiation exposure during operation as well. The advent of intraoperative 3D navigation systems permit safe and accurate instrumentation and decompression;[9,10] however, there are few report available on its use in the treatment of the HGDS. The purpose of this study is to review a consecutive series of patients with high-grade dysplastic L5/S1 spondylolisthesis, who underwent posterior reduction and monosegmental fusion assisted by the intraoperative 3D navigation system, and to estimate the efficacy of this technique.

Methods

A total of 13 consecutive patients with severe dysplastic spondylolisthesis of L5/S1 were treated with posterior reduction and monosegmental fusion of L5/S1 assisted by intraoperative navigation system. All operations were performed by two senior surgeons at the Department of Spine Surgery, Beijing Jishuitan Hospital, between February 2002 and February 2011.

The subjects provided informed consent before inclusion in the study. The experiment design has been approved by the Ethics Committee Board of Beijing Jishuitan Hospital. Patient data are summarized in Table 1. All patients had radiological parameters of high-grade dysplasia in the lumbosacral junction including the trapezoid shaped L5 vertebra body, dome-shaped sacrum and lumbosacral kyphosis. The average amount of L5 slippage was 63.2% (50–100%). Follow-up examinations were performed after 3 months, 1 and 2 years and a final follow-up visit upon data collection. The average follow-up period was 51 (12–134) months.

Surgical technique

The intraoperative navigation system consists of a modified intraoperative computerized tomography (CT) system (Arcadis Orbic 3D; Siemens Medical Solution, Erlangen, Germany) with a navigation workstation (The Striker Spine Navigation System, St. Louis, MO, USA). First, fixing the tracker at the spinal process of patient [Figure 1a], then the Arcadis acquired 100 multiple successive images as it performed an automated 190 rotation around the patient. The acquired images were transferred to the Stryker navigation workstation to generate axial, sagittal, and coronal reconstruction images and were registered automatically. After registration of bone drill [Figure 1b] and another instrument in the navigation system, we can get the real-time position of instruments in the navigation system.

The lumbosacral junction is exposed from the midline posteriorly. The exposure is continued laterally out to facet joints of L4/L5 and L5/S1. Polyaxial pedicle screws are inserted in L5 and S1 bilaterally assisted by navigation system [Figure 1c]. S1 pedicle screws are placed to the anterior promontory for bicortical purchase. A complete removal of lamina L5 is performed. The L5 roots are thoroughly decompressed and exposed laterally until exiting from the foramen [Figure 1d]. The L5/S1 disc was exposed bilaterally and excised [Figure 1e]. The dome-shaped endplate of S1 is osteotomized to create a flat surface perpendicular to the posterior wall. In some cases, the anterior lip of the lower plate of the L5 vertebra body needs to be osteotomized and excised through the disc space to remodel the trapezoid shape of L5 body. All these osteotomy procedures were performed under the navigation system to identify the position and direction of bone drill. The rods are contoured in lordosis and firmly fixed to the S1 screw first. The L5 screws are reduced to the fixed rods, gradually reducing the slipped L5. L5 roots were continuously visualized to make sure that they were not tightened. It is not necessary to aim for full reduction. Disc spacers (PEEK cage) with resected cancellous bone are inserted into the L5/S1 disc space. Short cages were used to avoid stretching the L5 roots and to allow reconstitution of lordosis [Figure 1f]. Posterolateral intertransverse fusion L5/S1 is performed using cancellous bone from the resected posterior elements. Ambulation of the patients began on the second postoperative day.

Table 1: Clinical data for all patients

Case	Age (years)	Gender	Presentation	Slip (%)	Blood loss (ml)	Operation time (min)	Complications	Follow-up (months)	Outcome
1	8	Female	Back pain	66	800	300	No	12	Normal
2	12	Female	Back pain, cosmesis	55	500	180	No	17	Normal
3	29	Female	Back pain, bilateral buttock pain	83	800	280	No	34	Normal
4	17	Female	Back pain	100	400	150	No	29	Normal
5	16	Female	Back pain	52	400	165	No	45	Normal
6	14	Female	Back pain, radiating to right buttock and thigh	50	400	210	No	41	Normal
7	11	Male	Back pain, paresthesia left L5	59	450	310	No	33	Normal
8	5	Female	Back pain, radiating to both leg	62	400	215	No	51	Normal
9	8	Female	Back pain	66	400	180	No	90	Normal
10	18	Female	Back pain	50	500	195	No	80	Normal
11	23	Female	Back pain, radiating to both buttoms and thigh	58	800	290	Transient L5 nerve impairment	27	Normal
12	18	Female	Back pain, both leg pain	59	400	200	No	134	Normal
13	16	Female	Back pain	62	350	195	No	71	Normal

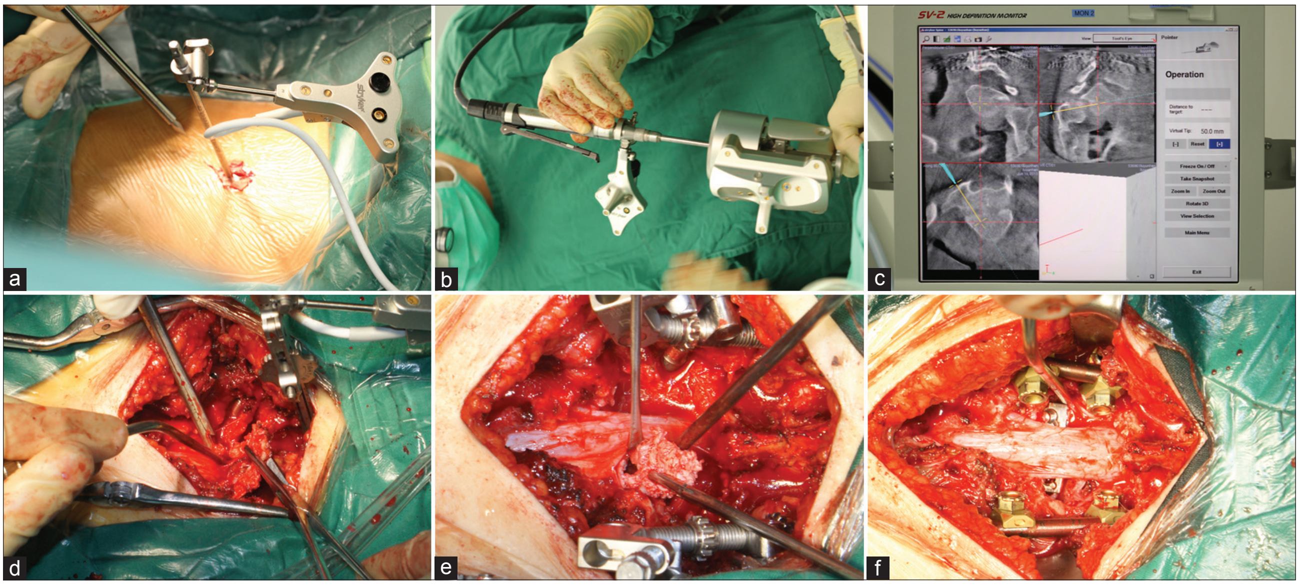

Figure 1: The intraoperative photograph. (a) Fixing the tracker at the spinal process of patient; (b) The high-speed drill is registered by a tracker, allowing the surgeon to directly view the decompression area on the monitor; (c) The intraoperative real-time monitor; (d) Decompression procedure, the plate and facets have been removed; (e) The intervertebral disc decompression; (f) insertion of the cage and fixing the rods.

Clinical outcome measures

At the preoperative, postoperation and latest follow-up the patients were asked to fill in pain and functional outcome score questionnaires. These included the Oswestry Disability Index (ODI), Low Back Outcome Scores (LBOSs), and patient satisfaction questionnaire.

Radiographic parameters

Standing anterior-posterior and lateral radiographs of the entire spine were evaluated before surgery [Figure 2a and 2b], after surgery and at latest follow-up [Figure 3a and 3b] . Two orthopedic surgeons not directly involved with the care of this cohort of patients analyzed each of the radiographs. The severity of spondylolisthesis is measured as a percentage of forward slip of L5 over S1. Lumbar lordosis (LL) is the Cobb angle form the superior endplate of L1-S1. L5 incidence (L5-I) is the angle between a perpendicular line to the L5 superior endplate and a line joining the center of the bicoxo-femoral axis and the center of the superior endplate of L5. The lumbosacral angle (LSA) or slip angle is the angle between the lines on the superior endplates of L5 and S1. Pelvic incidence (PI) is the angle between a line connecting the center of the upper endplate of S1 to the bicoxo-femoral axis and a line perpendicular to the end plate of S1. Pelvic tilt (PT) is the angle between a vertical line and a line connecting the center of the upper endplate of S1 to the bicoxo-femoral axis, and sacral slip (SS) is the angle between a horizontal line and the endplate of S1.[11-13] The preoperative CT scan asseses the detailed information of the deformity [Figure 2c]. The postoperative CT scan assessed the state of fusion [Figure 3c and 3d]. Further, magnetic resonance imaging (MRI) was performed at the last follow-up to assess the adjacent disc state.

Statistical analysis

The difference between the pre- and post-operative measures of Visual Analog Scale (VAS), ODI and LBOS, reduction of slip, LL, LSA, PI, SS and PT were analyzed using a two-tailed, paired *t*-test. $P < 0.05$ was considered to be significant.

Results

Average operating time was 220.7 min (range 160–300) and average blood loss 507 ml (range 300–2000). There was no pseudarthrosis. All patients had a solid bony fusion at latest follow-up, without any progression deformity compared to immediate postoperative radiographs. Eight of 13 patients got the MRI evaluation, and there was no obvious disc degeneration in the adjacent segment.

Clinical outcome

Preoperative VAS improved from 8.4 ± 2.5 to 3.1 ± 2.1 at last follow-up ($P < 0.05$) and LBOS from 22.1 ± 13.2 to 44.2 ± 20.1 ($P < 0.05$). Eleven of 13 patients thought that their expectations had been fully met and would have the surgery again under similar circumstance. In the remaining two cases, their expectation had been partially met but they would still choose to undergo the same surgery again.

Radiographic outcome

Pre- and post-operative radiographs were available for analysis of deformity correction in all patients with a minimum follow-up of 1 year [Table 2]. All radiographic parameters were improved. Mean slippage improved from 63.2% before surgery to 12.2% after surgery and 11.0% at latest follow-up. LL changed from preoperative 34.9 ± 13.3° to 50.4 ± 9.9° postoperatively and 49.3 ± 7.8° at last follow-up. L5-I improved from 71.0 ± 11.3° to 54.0 ± 11.9° and did not change significantly at the last follow-up 53.1 ± 15.4°. While PI remained unchanged, SS significantly decreased from preoperative 32.7 ± 12.5° to postoperative 42.6 ± 9.8° and remained constant to the last follow-up 44.4 ± 6.9°. PT decreased significantly from 38.4 ± 12.5° to 30.9 ± 8.1° and remained unchanged to the last follow-up 28.1 ± 11.2°.

Discussion

Although there is a general consensus on the need for surgical treatment of HGDS patients, the optimal surgical approach and techniques remain controversial.[6,14] While satisfactory clinical outcome has been reported after *in situ* fusion, this procedure is associated with higher rates of pseudarthrosis and slip progression.[6] Without reduction, the lumbosacral alignment does not improve the sagittal spinal imbalance, as well as the cosmetic deformity of the trunk remains. In order to reduce these complication rates after *in situ* fusion, many authors proposed the deformity reduction especially in patients with high-grade spondylolisthesis.[1,5,15-17] Reduction of the slip angle allows direct neural decompression and improves the sagittal lumbosacral orientation. But the reduction was technically challenging and reported to have an excessively high rate of neurological injury. The anterior or posterior approach, the extent of reduction and surgical technique are also controversial.[6,18] In our series, we did anterior fusion by the same posterior approach. Doing such procedure only by posterior approach avoids approach-related complications in the transperitoneal exposure of the lumbosacral junction (presacral veins or nerves injuries and genitourinary dysfunction).

Table 2: Radiographic and clinical improvement after surgical correction (°)

Items	Preoperative	Postoperative	Last follow-up
Slip	64.5 ± 17.0	12.2 ± 13.3*	11.0 ± 13.9*
PI	71.6 ± 10.6	72.3 ± 12.6*	72.1 ± 12.2*
SS	32.7 ± 12.5	42.6 ± 9.8*	44.4 ± 6.9*
PT	38.4 ± 12.5	30.9 ± 8.1*	28.1 ± 11.2*
L5-I	71.7 ± 11.3	54.0 ± 11.9*	53.1 ± 15.4*
LSA	–18.2 ± 13.1	8.1 ± 5.3*	6.8 ± 5.2*
BSA	–41.2 ± 11.9	–18.9 ± 11.7*	–16.7 ± 13.2*
LL	34.9 ± 13.3	50.4 ± 9.9*	49.3 ± 7.8*
VAS	8.4 ± 2.5	3.1 ± 2.1*	2.1 ± 1.6*
LBOS	22.1 ± 13.2	44.2 ± 20.1*	45.3 ± 22.1*

*$P < 0.05$, compared with preoperative. PI: Pelvic incidence; SS: Sacral slip; PT: Pelvic tilt; L5-I: L5 incidence; LSA: Lumbosacral angle; LL: Lumbar lordosis; LBOS: Low Back Outcome Score; BSA: Body surface area; VAS: Visual Analog Scale.

A major concern in any reduction procedure of L5/S1 spondylolisthesis is injury to the L5 nerve root that ranges from 11% to 30% in the posterior reduction of HGDS. In our series, only one patient presented transient postoperative neurological deficits. No persistent deficit was noted at final follow-up. Functional status improved in all cases with no persistent radicular pain or low-back pain at final follow-up. To avoid the associated neurological complication, there are some experiences. First, the wide mobilization of the slipped vertebra must be achieved by the extended posterior decompression, the careful release of the roots far lateral from the foramen, and the complete excision of the disc. Second, as the reduction of a severely slipped L5 is usually associated with elongation of the lumbosacral junction, shortening the lumbosacral spine by performing a sacral dome osteotomy is very important to avoid the neurological complication. In addition to this, the sacral dome resection also results in a complete mobilization of the L5/S1 segment, facilitates complete L5 nerve root release laterally. This procedure can be performed by the navigation that can give the real time information of the instrument and the extent and direction of the osteotomy. Third, the combined movement of rotation and translation is applied to the sacrum and the L5 vertebra. Extensive distraction should be avoided.

Even more important than the reduction of olisthesis is the correction of pelvic retroversion, and consequently the lumbosacral kyphosis. In our technique, correction of pelvic retroversion and L5-S1 kyphosis is achieved by posterior compression against an anterior support. The anterior cages act as a pivot, and the posteriorly applied compression force created lordosis. A further advantage of the cages is that they allow the reduction of the L5 acting as an inclined plane

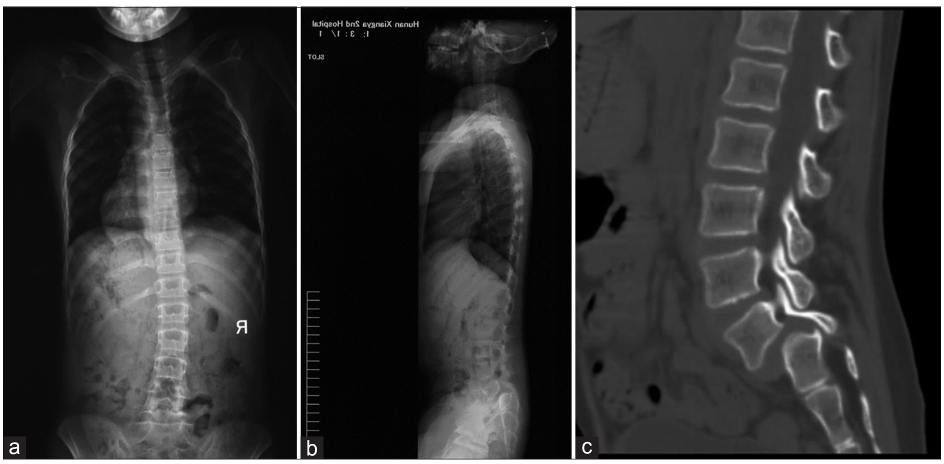

Figure 2: The preoperative radiographs. (a) The anterior-posterior radiography showing high-grade dysplastic spondylolisthesis; (b) The lateral radiography showing the spinal-pelvic imbalance; (c) Computerized tomography showing dome-shaped deformity of sacrum and retroversion of the pelvis.

Figure 3: Postoperative plain radiographs and computerized tomography showing reduction of the slippage. (a) The postoperative anterior-posterior radiography; (b) The lateral radiography showing the reduction of the slippage; (c) and (d) Computerized tomography showing the bone fusion of the L5/S1 joint.

and resist shear forces potentially better than bone on bone. Correction of pelvic retroversion and lumbosacral kyphosis has an enormous effect on the overall sagittal profile. Sacral inclination increases, thereby reducing flexion of the hip joints. L5-I and L5 slope decrease, thereby reducing shear forces at the lower lumbar discs. LL decreases, thoracic kyphosis increases, and gravity line is normalized.

A significant improvement of sagittal lumbosacral alignment is achieved in our series. The L5-I changed form 75° to 50°, there was restoration of the lumbosacral lordosis from 15° kyphosis to 6° lordosis, which in turn improved the preoperative lumbar hyperlordosis. Restoration of lumbosacral alignment not only resulted in a reduction of LL but also in a less anteversion of the pelvis as indicated by the increased PT.

Some authors believe that instrumented fusion from L4 to S1 had the advantage over monosegmental L5/S1 fusion. They believed that fusion from L4 to S1 can avoid the loss of correction and sacral bending, as well as development of spondylolisthesis of L4. In our institute, L5/S1 fusion was performed in order to preserve the motion segment at L4/5. We believe that monosegmental L5/S1 fusion has advantages over L4-S1 fusion because L5/S1 fusion is strong enough in comparison with L4/S1 fusion as Masrumoto reported. Monosegmental fusion of L5/S1 minimizes the functional restriction in this young patient population. Another concern is the further deterioration of the segment L4/5. In our opinion, this segment is not primarily affected and should be preserved whenever possible. In the latest follow-up, we do not see the degeneration of L4/5 disc in the MRI.

To promote the rate of union, firstly we placed S1 pedicle screws bicortically in the anterior promontomy. Secondly, the sacral dome was performed to increase the contact space between the cage and the vertebral body. Thirdly, we improved the alignment between kyphosis and lordosis. All these can be achieved easily using the navigation system. In the last follow-up, all the patients have bone union in the L5/S1 joint.

Since Amiot first described pedicle screw fixation using a computer navigation system in 1995, this technology has dramatically developed in the following years. After the era of CT-based navigation and two-dimensional fluoroscopy-based navigation, the computer assistance system currently used in the spine surgery was mainly the infrared optical navigation with 3D orientation. With the advantages of obtaining intraoperative real-time images, automatic registration, 3D navigation and free of being interrupted by other equipment, 3D fluoroscopy-based navigation is thought to be a very promising technology to improve surgical accuracy and reduce the complication. In the difficult spinal deformity such as HGDS, as there are more spinal structural variation, the operation risk is higher. The computer-assisted navigation system can provide real-time 3D images, giving surgeons the chance to dynamically select screw entry points and directions. In addition, the osteotomy procedures were performed under the navigation system to identify the position and direction of bone drill. All these consequently enhanced the accuracy of pedicle screw placement.

Posterior reduction and monosegmental fusion of L5/S1 assisted by intraoperative 3D navigation are an effective technique for managing high-grade dysplastic spondylolisthesis. A complete reduction of local deformity and excellent correction of overall sagittal balance can be achieved. Fusion of the primarily healthy segment L4/5 can be avoided.

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