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

*Wei Tian, Xiao-Guang Han, Bo Liu, Ya-Jun Liu, Da He, Qiang Yuan, Yun-Feng Xu*

Department of Spine Surgery, Beijing Jishuitan Hospital, Beijing 100035, China

**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 spondylolisthesis (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]

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...
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; 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.

| Case | Age (years) | Gender | Presentation | Slip (%) | Blood loss (ml) | Operation time (min) | Complications | Follow-up (months) | Outcome |
|------|-------------|--------|--------------|----------|----------------|---------------------|--------------|--------------------|---------|
| 12   | 8           | Female | Back pain    | 66       | 800            | 300                 | No           | 12                 | Normal  |
| 13   | 12          | Female | Back pain, cosmesis | 55       | 500            | 180                 | No           | 17                 | Normal  |
| 2     | 12          | Female | Back pain, bilateral buttock pain | 83       | 800            | 280                 | No           | 34                 | Normal  |
| 3     | 29          | Female | Back pain    | 100       | 400            | 165                 | No           | 29                 | Normal  |
| 4     | 17          | Female | Back pain    | 52        | 400            | 150                 | No           | 45                 | Normal  |
| 5     | 16          | Female | Back pain    | 40        | 400            | 210                 | No           | 33                 | Normal  |
| 6     | 14          | Female | Back pain, radiating to right buttock and thigh | 59       | 450            | 215                 | No           | 51                 | Normal  |
| 7     | 11          | Male   | Back pain, paresthesia left L5 | 58       | 800            | 290                 | Transient L5 nerve impairment | 27               | Normal  |
| 8     | 10          | Female | Back pain    | 50        | 500            | 195                 | No           | 80                 | Normal  |
| 9     | 18          | Female | Back pain    | 58        | 800            | 200                 | No           | 134                | Normal  |
| 10    | 16          | Female | Back pain, both leg pain | 62       | 350            | 195                 | No           | 71                 | Normal  |
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 assesses 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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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).

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.

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.

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.
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 from 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 Masumoto 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 promontory. 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.

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.
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.

References

1. Kasliwal MK, Smith JS, Kanter A, Chen CJ, Mummameni PV, Hart RA, et al. Management of high-grade spondylolisthesis. Neurosurg Clin N Am 2013;24:275-91.
2. Vialle R, Benoist M. High-grade lumbosacral spondylolisthesis in children and adolescents: Pathogenesis, morphological analysis, and therapeutic strategy. Joint Bone Spine 2007;74:414-7.
3. Bouyer B, Bachy M, Courvoisier A, Dromzee E, Mary P, Vialle R. High-grade lumbosacral spondylolisthesis reduction and fusion in children using transsacral rod fixation. Childs Nerv Syst 2014;30:505-13.
4. Shedid D, Weil AG, Lieberman I. A novel minimally invasive technique for the treatment of high-grade isthmic spondylolisthesis using a posterior transsacral rod. J Spinal Disord Tech 2014;27:E41-8.
5. Martiniani M, Lamartina C, Specchia N. "In situ" fusion or reduction in high-grade high dysplastic developmental spondylolisthesis (HDSS). Eur Spine J 2012;21 Suppl 1:S134-40.
6. Bridwell KH. Surgical treatment of high-grade spondylolisthesis. Neurosurg Clin N Am 2006;17:331-8, vii.
7. Ruf M, Koch H, Melcher RP, Harms J. Anatomic reduction and monosegmental fusion in high-grade developmental spondylolisthesis. Spine (Phila Pa 1976) 2006;31:269-74.
8. Ruf M, Melcher R, Merk H, Harms J. Anatomic reduction and monosegmental fusion for high-grade developmental spondylolisthesis L5/S1. Z Orthop Ihre Grenzgeb 2006;144:33-9.
9. Tian W, Weng C, Liu B, Li Q, Sun YQ, Yuan Q, et al. Intraoperative 3-dimensional navigation and ultrasonography during posterior decompression with instrumented fusion for ossification of the posterior longitudinal ligament in the thoracic spine. J Spinal Disord Tech 2013;26:E227-34.
10. Tian W, Weng C, Liu B, Li Q, Hu L, Li ZY, et al. Posterior fixation and fusion of unstable Hangman’s fracture by using intraoperative three-dimensional fluoroscopy-based navigation. Eur Spine J 2012;21:863-71.
11. Maciejczak A, Jablonska K, Baczek D, Barnas P, Czternastek M, Dudziak P, et al. Changes in spine-pelvic alignment after surgical treatment of isthmic spondylolisthesis. Neurol Neurochir Pol 2014;48:21-9.
12. Mac-Thiong JM, Wang Z, de Guise JA, Labelle H. Postural model of sagittal spine-pelvic alignment and its relevance for lumbosacral developmental spondylolisthesis. Spine (Phila Pa 1976) 2008;33:2316-25.
13. Labelle H, Roussouly P, Chopin D, Berthonnaud E, Hresko T, O’Brien M. Spine-pelvic alignment after surgical correction for developmental spondylolisthesis. Eur Spine J 2008;17:1170-6.
14. Hensinger RN. Spondylolysis and spondylolisthesis in children and adolescents. J Bone Joint Surg Am 1989;71:1098-107.
15. Kasliwal MK, Smith JS, Shaffrey CI, Saulle D, Lenke LG, Polly DW Jr, et al. Short-term complications associated with surgery for high-grade spondylolisthesis in adults and pediatric patients: A report from the scoliosis research society morbidity and mortality database. Neurosurgery 2012;71:109-16.
16. Min K, Liebscher T, Rothenfluh D. Sacral dome resection and single-stage posterior reduction in the treatment of high-grade high dysplastic spondylolisthesis in adolescents and young adults. Eur Spine J 2012;21 Suppl 6:S785-91.
17. Helenius I, Remes V, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: Long-term outcome. Surgical technique. J Bone Joint Surg Am 2008;90 Suppl 2:145-52.
18. Acosta FL Jr, Ames CP, Chou D. Operative management of adult high-grade lumbosacral spondylolisthesis. Neurosurg Clin N Am 2007;18:249-54.

Received: 06-08-2014 Edited by: Li-Shao Guo
How to cite this article: Tian W, Han XG, Liu B, Liu YJ, He D, Yuan Q, Xu YF. Posterior Reduction and Monosegmental Fusion with Intraoperative Three-dimensional Navigation System in the Treatment of High-grade Developmental Spondylolisthesis. Chin Med J 2015;128:865-70.

Source of Support: Nil. Conflict of Interest: None declared.