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ORIGINAL ARTICLE

Single segment of posterior lumbar interbody fusion for adult isthmic spondylolisthesis: reduction or fusion in situ

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Abstract
Objective We prospectively compared surgical reduction or fusion in situ with posterior lumbar interbody fusion (PLIF) for adult isthmic spondylolisthesis in terms of surgical invasiveness, clinical and radiographical outcomes, and complications.
Methods From January 2006 to June 2008, 88 adult patients with isthmic spondylolisthesis who underwent surgical treatment in our unit were randomized to reduced group (group 1, $n = 45$) and in situ group (group 2, $n = 43$), and followed up for average 32.5 months (range 24–54 months). The clinical and radiographical outcomes were compared between the two groups.
Results The average operative time and blood loss during surgery showed insignificant difference ($p > 0.05$) between two groups. The radiological outcomes were significantly better in group 1, but there was no significant difference between two groups of clinical outcomes, depicting as VAS, ODI, JOA and patients' satisfaction surveys. Incident rate of surgical complications was similar in two groups, but in group 1 the complication seemed more severe because of two patients with neurological symptoms.
Conclusions For the adult isthmic spondylolisthesis without degenerative disease in adjacent level, single segment of PLIF with pedicle screw fixation is an effective and safe surgical procedure regardless of whether additional reduction had been conducted or not. Better radiological outcome does not mean better clinical outcome.

Keywords Isthmic spondylolisthesis · Surgical reduction · Single segment · Sagittal balance · PLIF

Introduction

It has been widely accepted that the primary goal of surgery for lumbar isthmic spondylolisthesis is neurological decompression and stability reconstruction. Regarding the optimal surgical treatment procedures for the disease, it still remains controversial whether it is essential to reduce the slippage of vertebrae [1–3]. Modern surgical techniques and instrumentation have permitted the reduction of the slipped lumbar vertebra even in severe spondylolisthesis [4–7]. However, these operations could result in an increased risk of neurological complications from the screws and also the possibility of distracting neurological elements during the corrective procedure [2]. The neurological complication of reduction procedure is found to be very low and not significantly different from the in situ fusion [1, 2, 5, 8]. Thus, correcting associated deformity and restoring sagittal spinal balance become very important and have attracted much attention in the past few years [5, 9, 10]. Recently, we have developed a drawing-back technique with pedicle screw to reduce the slippage of vertebra combined with posterior lumbar interbody fusion

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(PLIF) during the surgical treatment of adult isthmic spondylolisthesis. By comparing this reduction technique with fusion in situ in a prospective and randomized manner, we have investigated the effectiveness and security of this reduction technique for adult lumbar isthmic spondylolisthesis.

Materials and methods

A total of 94 adult patients with isthmic spondylolisthesis were enrolled in this study between January 2006 and June 2008. The inclusion criterion was that the patient had single-level isthmic spondylolisthesis without degenerative disease in adjacent level. The exclusion criteria were multilevel isthmic spondylolisthesis and previous lumbar spine surgery.

Every patient was given a serial number according to the consecutive sequence of hospitalization, and randomly organized to group 1 or group 2 according to the serial number. Written consent to participate in this study was obtained from all patients. In the follow-up period, six patients were lost within 6 months postoperatively. Of the remaining 88 patients (93.6 %) included in the entire study, there were 33 males and 55 females, aged from 28 to 65 years (mean, 45.2 years) at the time of the surgery. The levels of spondylolisthesis were diagnosed at L4 in 61 cases and L5 in 27 cases (Table 1). All patients considered for surgical treatment had low back pain, lower extremity pain, or neurological intermittent claudication that were refractory to conservative treatment for no less than 3 months.

Table 1 Clinical data for 88 patients undergoing PLIF with reduction or fusion in situ

Category	Group 1	Group 2
Total patients	45	43
Sex		
Male	17	16
Female	28	27
Mean age in years (range)	45.5 (30–65)	44.9 (28–64)
Level of spondylolisthesis		
L4	32	29
L5	13	14
Meyerding grade		
I	15	16
II	25	23
III	5	4
Operative time (min)	119 (100–160)	125 (100–180)
Blood loss (ml)	475 (180–1,030)	490 (250–840)

Data were collected prospectively by independent observers using standardized data collection forms.

Radiological measurements

All patients were examined by standing plain radiograph including anterior–posterior and lateral views, computed tomography scanning (CT) and magnetic resonance imaging (MRI) before surgery. The amount of vertebral slip was measured from standing lateral radiograph and calculated according to the Taillard technique [11] and Meyerding grade [12]. Focal lordosis was measured using the Cobb's technique [13]. Disk space height was normalized as the percentage of the superior endplate over the rostral vertebral body [14]. For Meyerding grade, 31 cases were grade I, 48 were grade II and 9 were grade III.

Surgical technique

All patients underwent complete removal of the bilateral floating laminae and decompression of nerve root far distally and laterally. In group 1, pedicle screw instrumentation (Tenor, Medtronic Sofamor Danek, USA; Click'X, Synthes, Switzerland) was used to correct the deformity. After insertion of pedicle screws, lateral fluoroscopy was used to confirm the screw placement and assess the slippage reduction. The rods were contoured and provisionally secured to the caudal screws, which were used with standard screws, leaving a gap between the cephalad pedicle screws and rods that reflected the spondylolisthesis (Fig. 1a). By bilaterally and simultaneously drawing back the cephalad pedicle screws with reduction system and tightening the nuts over the rods and down onto the screw shanks (Fig. 1b), the cephalad screws were drawn back onto the rods, achieving the correction of the olisthesis (Fig. 1c). Then, the pedicle screws were distracted to increase the interbody disk height and clear out the disk space contents bilaterally, with cartilaginous end plates removed (Fig. 1d). Two PEEK cages (SCIENT'X Company, France), filled with bone chops taken from posterior elements, were inserted to the disk space for interbody fusion. Finally, the pedicle screws were compressed to restore the lumbar lordosis (Fig. 1e).

In group 2, after insertion of pedicle screws, blunt-tipped distractors of increasing diameter were used to achieve distraction of the disk space. A radical discectomy was then performed and two cages were inserted to the disk space bilaterally for interbody fusion. For four patients with grade III spondylolisthesis, a single cage was inserted obliquely as described by Zhao's method [15]. Finally, the pedicle screws were compressed and fastened to restore the

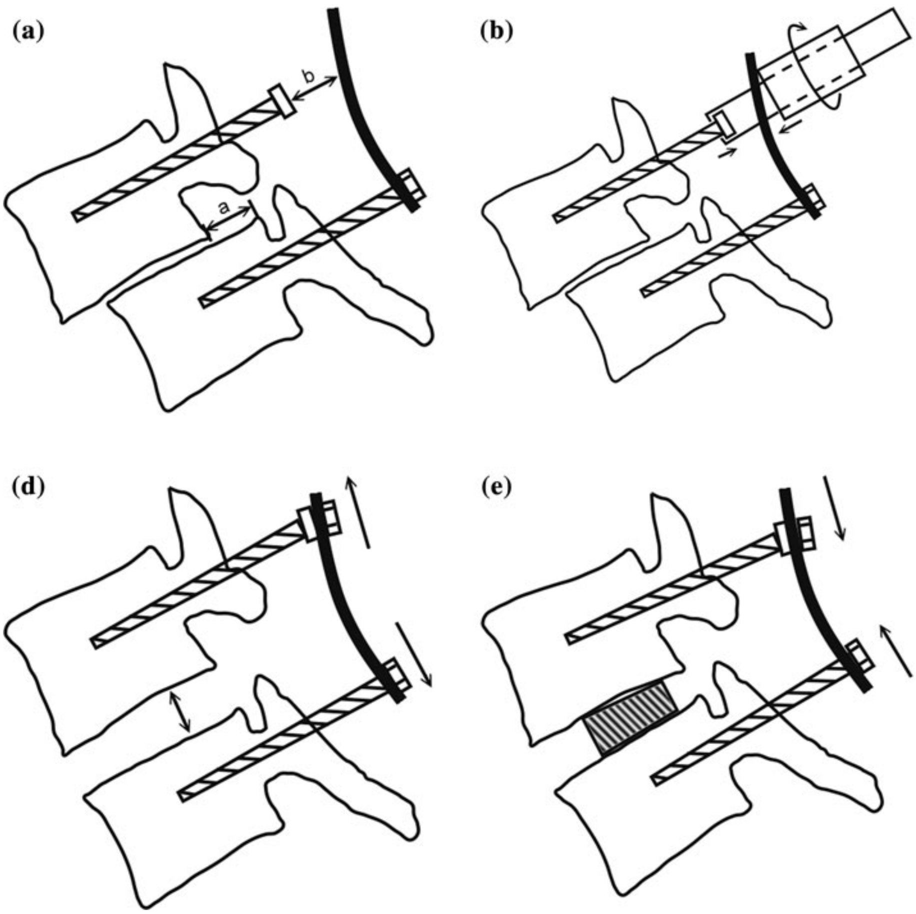

Fig. 1 **a** After insertion of pedicle screws, the rods were contoured and provisionally secured to the caudal screws, leaving a gap between the cephalad pedicle screws and rods that reflected the spondylolisthesis. **b**, **c** Drawing back the cephalad pedicle screws with reduction system and tightening the nuts over the rods and down onto the screw shanks, the cephalad screws were drawn back onto the rods, achieving the correction of the olisthesis. **d** Distracting the pedicle screws to increase the interbody disk height and clear out the disk space contents. **e** PEEK cages were inserted to the disk space for interbody fusion and the pedicle screws were compressed to restore the lumbar lordosis

lumbar lordosis. In this group, intentional surgical reduction was not performed, and therefore, this operation was referred to as "fusion in situ".

Outcome measures

Clinical status was evaluated pre- and postoperatively using visual analog scale (VAS; 0 mm = no pain, 100 mm = worst imaginable pain), Oswestry Disability Index (ODI) and Japanese Orthopedic Association (JOA) scores. Functional improvement was expressed by the recovery rate of JOA [16]. Patient satisfaction surveys recorded five-point Patient Subjective Outcome scores (excellent, good, fair, unchanged, worse) [17].

Radiographs were taken in neutral laterally 1 day postoperatively and additional extension–flexion positions at 3, 6, 12, 24 months and final follow-up to evaluate the sagittal alignment of lumbar spine and the bony fusion after surgery. If it was difficult to decide whether bony fusion was obtained from radiograph, two-dimensional CT was taken additionally. Radiograph fusion criteria included the presence of bony trabeculation bridging the fusion area and the absence of bony lucency at the area [2, 15], while two-dimensional CT studies additionally demonstrated ingrowth of bone into the cage and bony graft emanating from the vertebrae. Radiograph and two-dimensional CT studies were independently evaluated by 2 spine surgeons and 1 radiologist.

Follow-up data were collected by an independent observer.

Statistical analysis

SPSS statistical program (version 17.0) was used for the statistical analysis. The results are given as mean and SD or range. The *T* test was used to perform statistical comparisons. *p* values less than 0.05 were considered "statistically significant".

Results

All the 88 patients were followed up for 24–54 months (mean 32.5 months). Of the 88 patients, 45 were in the group 1 and 43 were in the group 2. There were no significant differences between two groups with regard to patient gender, age and spondylolisthesis level (Table 1). The average operative time was 119 min in group 1 and 125 min in group 2, the difference between two groups was insignificant ($p > 0.05$). The average blood loss during surgery was 475 ml in group 1 and 490 ml in group 2, with insignificant difference ($p > 0.05$, see Table 1).

Clinical outcomes

After surgery, all patients in both groups could sit up and walk to lavatory for urination assisted by medical worker within 1 week. The mean VAS score was 42.5 in group 1 and 44.1 in group 2 before surgery. Three months after surgery, it decreased to 17.7 ($p < 0.001$) in group 1 and 18.0 ($p < 0.001$) in group 2. And at final follow-up, it improved to 11.7 ($p < 0.001$) in group 1 and 11.9 ($p < 0.001$) in group 2 (see Table 2). For each data collection time, the difference between two groups was insignificant. The mean preoperative ODI score in group 1 was 50.2, compared with 20.4 ($p < 0.001$) at the 3-month follow-up and 16.2 ($p < 0.001$) at final follow-up. The mean preoperative ODI score in group 2 was 51.1, compared with 19.8 ($p < 0.001$) at 3 months postoperatively and 15.9 ($p < 0.001$) at final follow-up (see Table 2). At every follow-up time point, there was no significant difference between the two groups. JOA score was 15.4 in group 1 and 15.3 in group 2 before surgery, 18.9 and 19.1 at 3 months after surgery, and 24.1 and 23.9 at final follow-up, respectively (see Table 2). There was no significant difference between the two groups. The postoperative recovery rate was 64.4 % in group 1 and 65.2 % in group 2 at the final check, without significant difference ($p = 0.565$).

At final follow-up, 39 patients (86.7 %) considered their outcome to be excellent or good, 4 patients fair and 2 patients unchanged in group 1. And in group 2, 38 patients (88.4 %) excellent or good, 3 patients fair and 2 patients unchanged. The difference between both groups was not statistically significant.

Radiological outcomes

All the 88 patients achieved spinal fusion without cage extrusion in the final follow-up. The average of slippage was 28.1 % in group 1 and 27.9 % in group 2 preoperatively, both significantly decreased to 6.1 and 17.5 % in the initial postoperatively, and 6.3 and 17.7 % in the final follow-up (see Table 3). At every follow-up time point after surgery, the slippage in group 1 was significantly less than that in group 2. The olisthesis and reduction were not significantly altered between the initial postoperative to the final postoperative follow-up in both groups. The average disk height was 14.9 % in group 1 and 14.3 % in group 2 preoperatively ($p = 0.583$), and increased to 28.6 and 25.7 % on the initial postoperatively ($p < 0.001$ respectively), which in group 1 was significantly higher than that in group 2 ($p < 0.05$). On the final follow-up, it was 28.3 % in group 1 and 25.5 % in group 2, with no significant loss of intervertebral space seen in both groups (see Table 3).

Focal lordosis was 11.4° in group 1 and 11.5 in group 2 before surgery, both increased significantly to 20.4 ($p < 0.001$) degrees and 15.7 ($p < 0.001$) postoperatively.

Table 2 VAS, ODI and JOA of the two groups

	Group 1	Group 2	*p*
VAS			
Pre-op	42.5 ± 17.5	44.1 ± 18.9	NS
3 m post-op	17.7 ± 9.6	18.0 ± 10.1	NS
Final follow-up	11.7 ± 7.6	11.9 ± 7.8	NS
ODI			
Pre-op	50.2 ± 16.1	51.1 ± 13.8	NS
3 m post-op	20.4 ± 10.7	19.8 ± 10.1	NS
Final follow-up	16.2 ± 10.2	15.9 ± 9.6	NS
JOA			
Pre-op	15.4 ± 3.0	15.3 ± 3.0	NS
3 m post-op	18.9 ± 3.4	19.1 ± 3.5	NS
Final follow-up	24.1 ± 2.6	23.9 ± 2.8	NS

Values are mean ± SD

NS not significant

Table 3 Radiological outcomes of the two groups

	Group 1	Group 2	*p*
Amount of slippage (%)			
Preoperatively	28.1 ± 11.4	27.9 ± 12.0	NS
Postoperatively	6.2 ± 6.0	17.5 ± 9.2	<0.001
Final follow-up	6.3 ± 6.0	17.7 ± 9.3	<0.001
Disk height (%)			
Preoperatively	14.9 ± 6.2	14.3 ± 6.5	NS
Postoperatively	28.6 ± 5.3	25.7 ± 5.3	<0.05
Final follow-up	28.3 ± 5.1	25.5 ± 5.2	<0.05
Local lordosis (degree)			
Preoperatively	11.4 ± 6.0	11.5 ± 5.9	NS
Postoperatively	20.4 ± 6.3	15.7 ± 6.2	<0.005

Values are mean ± SD

NS not significant

And in group 1, the focal lordosis improved significantly better than that in group 2 ($p < 0.005$, see Table 3).

Surgical complications

Surgical complications were seen in nine patients in this series, five in group 1 and four in group 2. In two patients of group 1, the pedicle screws in slipping vertebra were pulled out when reducing was made intraoperatively. Bone cement was put into pedicles to enhance the screws, and then reduction was accomplished. Two patients developed incision infection after operation, one in group 1 and the other in group 2, which resolved with a re-operation of debridement and drainage. In group 1, two patients complained of neuropathic pain postoperatively. In a 45-year-old male patient, who underwent a reduction from 38 % of L5/S1 slippage to 5 %, developed burning pain in low back and extensively in two lower limbs until 2 months later. In the other patient, the constant pain and numbness in the right leg had persisted for 3 months, and partially resolved with conservative treatment. In group 2, three patients had a small dural tear and repaired intraoperatively, and two patients developed cerebrospinal fluid leakage after surgery until the second postoperative week, without re-operation.

There were no hard ware-related or direct PLIF complications. No adjacent disk degeneration was needed to be reoperated in both groups.

Discussion

The optimal surgical approach, especially for reduction or not, to the management of adult lumbar isthmic spondylolisthesis has not been resolved yet. The basic principle of surgical treatment is decompression and stabilization. In previous studies, some authors [2, 3] showed that fusion in situ obtained better results than reduction in the long term for severe spondylolisthesis. However, fusion in situ was usually performed to extend one or two levels above the slipped vertebrae, fusing normal motion segments [2, 3, 18]. DeWald et al. [19] suggested that the goals of surgical treatment of spondylolisthesis were fusion of as few motion segments as possible, restoration of the sagittal balance of lumbar spine, and fusion of the disk space if it is not competent.

In this series of isthmic spondylolisthesis, without degeneration or stenosis in adjacent segment, it does not seem essential to extend fusion more than the spondylolisthesis segment. Therefore, we adopted single segment of PLIF for these adult isthmic spondylolisthesis. To investigate effectiveness and security of surgical reduction for olisthesis, two surgical techniques were compared with prospective randomized modality.

A number of authors have developed many surgical techniques to achieve reduction and fusion of spondylolisthetic deformity [3, 5, 20–23]. With a new three-stage spinal shortening procedure for reduction of severe adolescent isthmic spondylolisthesis, Mehdian and Arun [23] reported that the mean degree of slip improved from 86 % preoperatively to 5 % postoperatively. Using insert-and-rotate technique, Sears [5] reported that a 79 % mean reduction of the olisthetic component of the deformity and mean focal lordosis increased by 71 % from 10.6° to 18.1°. Spruit et al. [21] performed posterior reduction and second-staged anterior lumbar interbody fusion in adult isthmic spondylolisthesis, and reported that the mean spondylolisthetic slip was reduced from 21 % preoperatively to 7 % postoperatively. Posterior distraction reduction techniques were popular but necessitated fusion to the upper lumbar spine. Kaneda et al. [24] reported that there was only modest improvement (5 %) in the slippage with distraction technique and worsening of the slip angle by 7° as would be expected by this kyphogenic technique. In group 1 of this study, the slippage was reduced by transpedicle screws with drawing-back technique, the mean degree of slip reduced from 28.1 % preoperatively to 6.1 % postoperatively (Figs. 2, 3). However, in group 2, the slippage was also significantly reduced from 27.9 % preoperatively to 17.5 % postoperatively without intentional reduction procedure. When we performed PLIF in this group, distractors of increasing diameter were used to distract the disk space, and spontaneous reduction was obtained in these procedures, as “insert and rotate” technique in some degrees [5]. So, using for adult isthmic spondylolisthesis, PLIF technique enables partial correction of sagittal deformity (Fig. 4).

PLIF was first attempted by Cloward in 1950s and later modified and extensively used. The interbody fusion immediately produces a biomechanically stable postoperative spine, thus enhancing the opportunity for arthrodesis [25]. Two studies have been performed comparing PLIF to posterolateral fusion (PLF), which reported similar outcomes for both techniques with 2 years follow-up period [26, 27]. But in a long-term prospective study, Edward Cunningham et al. [28] found that patients who underwent a PLIF performed much better than patients who had undergone a PLF. Note that this difference was most evident in the long-term follow-up results. This may explain why previous two studies have not shown a difference [26, 27]. The reasons for the better outcomes may be due to improved sagittal alignment or fusion rate. And within the single-level fusion group, the difference between PLF and PLIF was more pronounced [28]. As in our series, after reduction procedure in group 1, PLIF can be accomplished through the same posterior approach. And the sagittal alignment of lumbar spine can be restored with

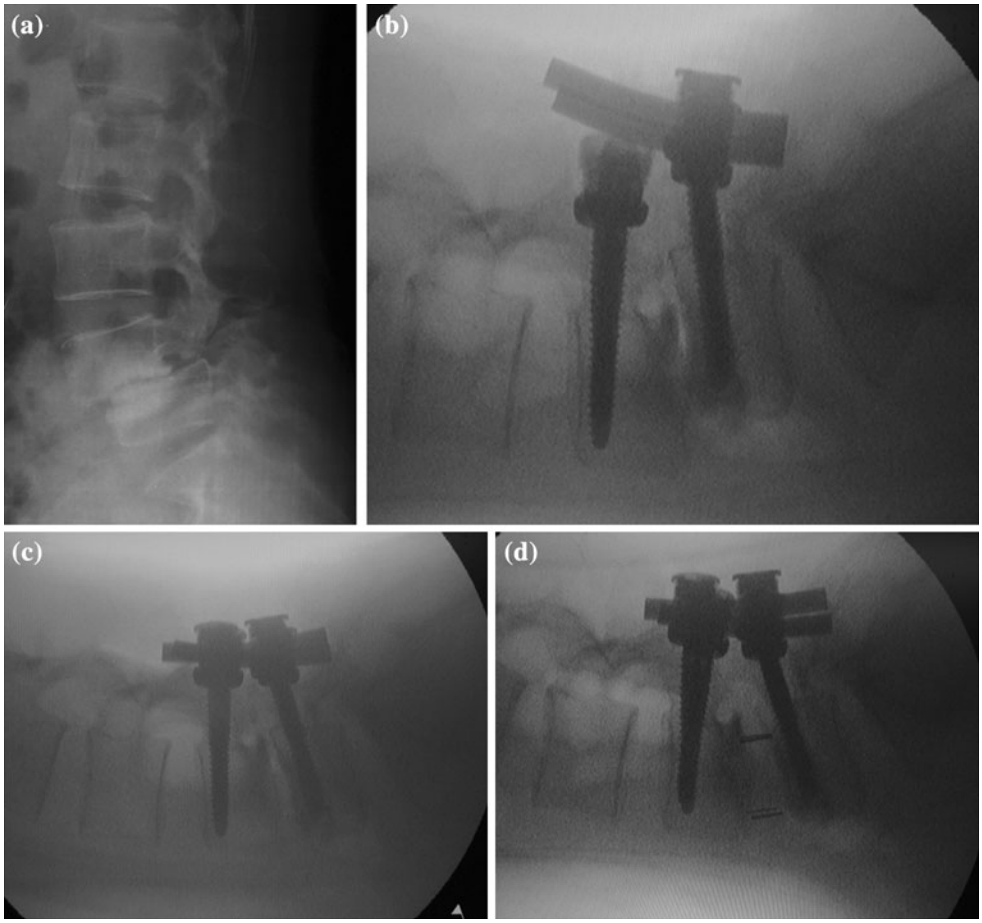

Fig. 2 Surgical procedure performed intraoperatively in a 51-year-old woman with grade II isthmic spondylolisthesis at L4–5. **a** Preoperative lateral X-ray showed grade II slippage and interbody space collapse. **b** Pedicle screws were inserted at L4–5, the rods were contoured and provisionally secured to the L5 screws, leaving a gap to draw back L4. **c** With reduction system, L4 was drawn back and reduction completed. **d** PLIF was performed and focal lordosis was restored

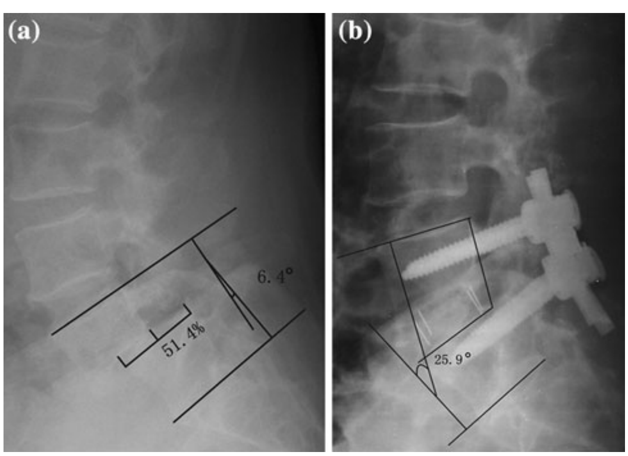

Fig. 3 Surgical reduction and PLIF performed in a 52-year-old woman with grade III isthmic spondylolisthesis. Preoperative lateral X-ray showed that slippage was 51.4 % and focal lordosis was 6.4° (**a**). Postoperative X-ray showed that complete reduction of the spondylolisthesis was obtained and focal lordosis increased to 25.9° (**b**)

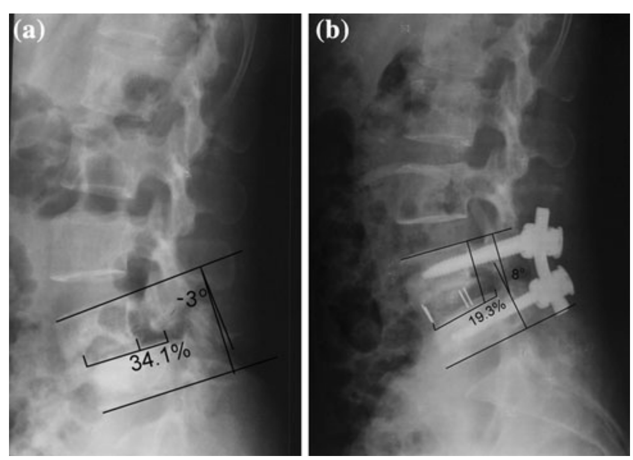

Fig. 4 A 53-year-old woman with grade II isthmic spondylolisthesis was surgically treated with PLIF in situ. Preoperative lateral X-ray showed that slippage was 34.1 % and focal lordosis was −3.0° (**a**). Postoperative X-ray showed that disk space distracted with olisthesis partially reduced to 19.3 % and focal lordosis increased to 8° (**b**)

compression of the pedicle screws (Fig. 1e). In group 2, even without reduction procedure, PLIF technique gained spontaneous partial reduction and restoration of sagittal balance. It was because of distraction of disk space when performing PLIF and spontaneous partial reduction could be accomplished, such as "insert and rotate" technique [5]. In both groups, with PLIF technique 100 % fusion rate was obtained in our study.

The potential benefits of reduction had been advocated by many authors [5, 29, 30]. In our present series, the slippage, focal lordosis and intervertebral disk height in group 1 were corrected better than that in group 2. However, the clinical outcomes in two groups showed no significant differences. It proved that the clinical outcomes were almost similar in patients who underwent instrumented PLIF whether intentional reduction was performed or not for the spondylolisthesis. A limitation of this study is that a large part of the patients were low-grade spondylolisthesis. Only 9 patients (10.2 %) were grade III, 5 in group 1 and 4 in group 2. It was difficult to contain two cages for high-grade spondylolisthesis because of decreasing contact area of adjacent vertebrae. As in group 2, only one cage was used in the four patients with grade III spondylolisthesis. Our on-going study is to compare these two techniques for high-grade spondylolisthesis. Because gross spinal imbalance is rare in low-grade spondylolisthesis, the measurements of long sagittal alignment were not included in this study. And this is a significant weakness of the study as it will not allow an understanding of the relationship of overall sagittal balance and outcomes.

The total complications of this series were seen in 9 cases (10.2 %), similar in two groups. When the decision was taken to correct a spondylolisthetic deformity, the risk of causing neurological deficit is the principal concern. In many previous studies, reduction of spondylolisthesis, even in high grade, the complications of neurological deficit were few and relatively minor [5, 20, 21, 31–33]. Among 18 patients of Sear's series [5], a patient with grade IV spondylolisthesis who underwent surgical reduction and PLIF developed a delayed L5 radiculopathy with partial foot drop and radicular dysaesthesia postoperatively. Another patient complained of persistent and apparently neuropathic leg pain postoperatively. And three patients required re-operation, one with nonunion and the other two with adjacent segment disease. Spruit et al. [21] performed posterior reduction and second-staged ALIF in 12 adult patients with isthmic spondylolisthesis. They found no nerve root deficits postoperatively, but one patient had a persistent warm left leg due to sympathic nerve chain injury. Morelos et al. [6] reduced slippage of vertebra surgically in 32 patients with isthmic spondylolisthesis at L5–S1 with non-fusion technique using selective instrumentation. No nerve root injury was found, but two patients required surgical re-intervention with PLF of L5–S1 because of loss of deformity correction. In our series, to avoid neurological complications, we routinely decompressed the spinal canal and nerve roots far distally and laterally before slip reduction, permitting complete visualization of the roots at all times during the reduction procedure. With this procedure, no severe nerve root injury was found in this series besides 2 patients (4.4 %) complaining of neuropathic pain postoperatively in group 1, both resolved within 3 months after surgery. Because of these two patients with neurological symptoms, the complications in group 1 seemed more severe than that in group 2. In group 1, a potential risk of screws pulling out could occur when reducing was made intraoperatively. Enhancing the screws with bone cement may prevent screws from pulling out. In group 2, without reduction of slippage, it was often difficult to deal with disk contents. And the main complication was dural tear, which could result in cerebrospinal fluid leakage after surgery.

In conclusion, for the adult isthmic spondylolisthesis without degenerative disease in adjacent level, single segment of PLIF with pedicle screws fixation is an effective and safe surgical procedure regardless of whether reduction had been conducted or not. Better radiological outcome does not mean better clinical outcome. However, the long-term outcomes should be further studied to get an understanding between the benefits of these two techniques. And the results of these two techniques for high-grade isthmic spondylolisthesis should be further studied too.

Conflict of interest None.

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