European Spine Journal (2019) 28:2087–2094
https://doi.org/10.1007/s00586-019-05973-8

ORIGINAL ARTICLE

Restoration of normal pelvic balance from surgical reduction in high-grade spondylolisthesis

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Received: 26 September 2018 / Revised: 24 March 2019 / Accepted: 5 April 2019 / Published online: 15 April 2019

Abstract

Purpose To investigate the effectiveness of surgical reduction in high-grade spondylolisthesis in maintaining or restoring a normal pelvic balance, as related to the QoL.

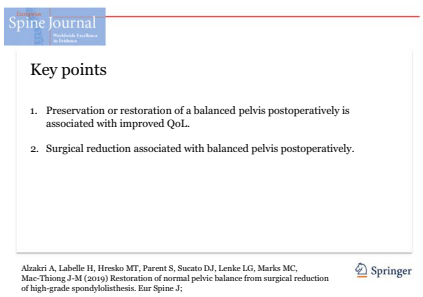
Methods It is a retrospective analysis of prospectively collected data of 60 patients (17 males, 43 females) aged 15 ± 3.1 years who underwent surgery for high-grade spondylolisthesis and were followed for a minimum of 2 years after surgery. Patients with a residual high-grade slip following surgery were referred to the postoperative high-grade (PHG) group, while patients with a residual low-grade slip were referred to the postoperative low-grade (PLG) group. Pelvic balance was assessed from pelvic tilt and sacral slope, in order to identify patients with a balanced pelvis or unbalanced pelvis. The SRS-22 questionnaire was completed before surgery and at last follow-up.

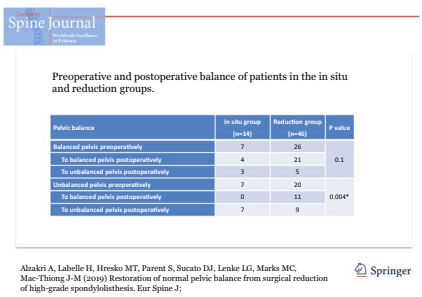
Results Postoperatively, there were 36 patients with a balanced pelvis and 24 patients with an unbalanced pelvis. The improvement in QoL was better in patients with a postoperative balanced pelvis. There were 14 patients in the PHG group and 46 patients in the PLG group. Four of seven patients (57%) in the PHG group and 21 of 26 patients (81%) in the PLG group with a preoperative balanced pelvis maintained a balanced pelvis postoperatively ($P = 0.1$). None of the patients in the PHG group and 11 of 20 patients (55%) in the PLG group improved from an unbalanced to a balanced pelvis postoperatively ($P < 0.05$).

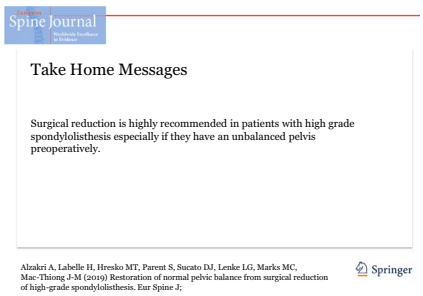
Conclusions Surgical reduction in high- to low-grade slip is more effective in maintaining and restoring a normal pelvic balance postoperatively.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Quality of life · Spine · High-grade spondylolisthesis · Pelvic balance · Surgery

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-05973-8) contains supplementary material, which is available to authorized users.

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Introduction

It has been demonstrated in high-grade spondylolisthesis patients that sacro-pelvic morphology is abnormal [1–4]. In addition to the local lumbosacral deformity, abnormal sacro-pelvic orientation and morphology as well as disturbed global sagittal balance of the spine can also be found [5]. In particular, Hresko et al. [6] have distinguished two subsets of patients using cluster analysis. A first group involved a balanced pelvis with a high sacral slope (SS) and a low pelvic tilt (PT). The second group involved an unbalanced pelvis, as indicated by a retroverted pelvis and a vertical sacrum, with a low sacral slope (SS) and a high pelvic tilt (PT). Hresko et al. [6] suggested that surgical reduction might be considered for patients with an unbalanced pelvis but unfortunately there is still no evidence supporting this concept in the literature.

Surgical reduction in high-grade spondylolisthesis remains debated [7–9]. It is a challenging procedure and can be associated with high risk of complications [10]. Petraco et al. [11] reported that reduction in high grade to low grade was associated with increase in strain of L5 nerve root, especially during the second half of reduction. However, when lumbosacral kyphosis decreased, the tension on L5 nerve root also decreased. Poussa et al. [12] reviewed 22 adolescents with severe (more than 60%) slip and reported that patients in the fusion in situ group had better quality of life (QoL) outcomes than the reduction group. Unfortunately, their small cohort and the failure to assess QoL prior to surgery limit the extent of their conclusions. In addition, their reduction technique was limited, as mean percentage of slip in the reduction group remained 57% postoperatively. Bourassa-Moreau et al. [13] reported that QoL tended to improve after surgical intervention for high-grade spondylolisthesis but they did not assess the influence of surgical reduction in their results. On the basis of the current literature, the reduction in high-grade spondylolisthesis potentially improves overall spine biomechanics by correcting the local kyphotic deformity and reducing vertebral slippage [14]. Reduction was not typically associated with a greater risk of developing neurological deficits compared with arthrodesis in situ [15, 16]. There is level III evidence that instrumentation and reduction lower the risk of nonunion, and that circumferential fusion is superior to posterior-only or anterior-only fusion [17, 18].

However, there is no study that specifically evaluated the effect of surgical reduction in restoration or preservation of pelvic and sagittal balance in relationship with the QoL. Considering that pelvic balance can also impact on global sagittal balance and posture [19], optimizing postoperative pelvic balance could be important in improving the QoL. Therefore, the objective of this study is to assess the impact of surgical reduction in pelvic balance and QoL in high-grade spondylolisthesis patients.

Materials and methods

A retrospective analysis of a prospective database comprising information on patients with lumbosacral spondylolisthesis recruited between January 1, 2002, and December 31, 2011, at four pediatric hospitals was performed. All patients accepted and signed the consent form approved by each institutional review board.

There were 60 patients (17 males, 43 females) aged 15 ± 3.1 years (range 10–21 years) who underwent surgery for high-grade spondylolisthesis of L5-S1 and were followed for a minimum of 2 years after surgery.

Inclusion criteria for this study were the following:

- High-grade lumbosacral spondylolisthesis.
- Age between 10 and 21 years at surgery.
- Standing postero-anterior and lateral radiographs of the full spine at baseline (prior to surgery) and at last follow-up.
- SRS-22 questionnaires completed at baseline and at last follow-up.
- A minimum of 24-month follow-up was required for all patients (maximum FU 48-month, mean 28-month, SD 5.4-month, median 25-month).

Patients with a residual high-grade slip (> 50%) following surgery were referred to the postoperative high-grade (PHG) group, while patients with a residual low-grade slip (< 50%) were referred to the postoperative low-grade (PLG) group. Slip percentage was measured according to the technique described by Bourassa-Moreau et al. [20], in which the slip percentage is measured from the position of the postero-inferior corner of L5 vertebral body with respect to the perpendicular line drawn from the upper sacral endplate.

Pelvic balance was assessed from the PT and SS, in order to identify patients with a balanced or unbalanced pelvis, as described previously by Hresko et al.; as he performed a K-means procedure to produce two clusters based on mean SS and mean PT, balanced pelvis when SS is high, PT is low and unbalanced pelvis when SS is low, PT is high. After measuring PT and SS, these measurements were reported on the nomogram provided by Hresko et al. [6] to determine pelvic balance. The slip percentage, the lumbosacral angle (LSA) measured between the upper endplate of L5 vertebral body and the posterior border of S1 vertebral body and the position of the C7 plumbline with respect to the hip axis (midpoint of the line joining the center of the femoral heads) were also measured from the standing lateral

radiograph before surgery and at 2-year follow-up. All radiograph measurements were performed by a single observer. The fusion levels, the presence of anterior column support and complications were assessed.

Patients were divided into two groups according to their postoperative pelvic balance:

(a) Balanced post-op group: patients with balanced pelvis after surgery.
(b) Unbalanced post-op group: patients with unbalanced pelvis after surgery.

QoL was assessed using the SRS-22 questionnaire. Subscales measuring pain, self-image, mental health and function and the total score were calculated before and after surgery.

L5–S1 transforaminal lumbar interbody fusion (TLIF) cage was used for 28 patients (60%) in the PLG group and two patients (13%) in the PHG group. The fusion level among the PLG group was at L5-Sacrum in 23 patients, at L4-Sacrum in 14 patients, at L4-Pelvis in six patients, at L3-Pelvis in two patients and at L5-Pelvis in one patient, whereas in the PHG group was at L4-Sacrum in six patients, at L4-Pelvis in five patients and at L5-Sacrum in three patients.

Pelvic balance, slip percentage, LSA and QoL scores were compared for all patients before and after surgery using paired Wilcoxon tests. Mann–Whitney U tests were performed to analyze differences in pelvic balance, slip percentage, LSA and QoL between the PHG and PLG groups, as well as between balanced and unbalanced post-op groups. Associations between postoperative balance and surgical reduction were quantified using Pearson Chi Square tests among all patients. The level of significance was set at 0.05 for all statistical tests.

Results

Baseline preoperative and postoperative SRS-22 scores for all patients are shown in Table 1, showing significant improvement in all QoL scores after surgery. Pre- and postoperative radiological measures are shown in Table 1. Slip percentage and LSA were significantly improved after surgery, while mean PI, PT and SS remained similar when considering the entire cohort. Postoperatively, four patients had slip percentage more than 75%, 10 patients between 50 and 75%, 17 patients between 25 and 49% and 29 patients < 25%.

At baseline, 27 patients had an unbalanced pelvis, with 16 patients remaining unbalanced and 11 becoming balanced postoperatively. At baseline, 33 patients had a balanced pelvis, while 25 patients remained balanced and eight patients were unbalanced at the last follow-up. Preoperative and postoperative QoL in patients who had already balanced pelvis preoperatively are shown in Table 2. Although the mean improvement in QoL was increased for all SRS-22 scores in the balanced post-op group, it reached statistical significance only for the self-image domain and the total score. The change in slip percentage and LSA were similar between the two groups, but the PT and SS were improved

Table 1 Quality of life scores and radiographic measurements for all 60 patients

	Baseline (Mean ± SD)	Last follow-up (Mean ± SD)	*P* value
Quality of life scores			
Pain	2.9 ± 0.9	4.0 ± 0.8	< 0.05
Self-image	3.3 ± 0.7	4.2 ± 0.8	< 0.05
Function	3.5 ± 0.6	4.3 ± 0.5	< 0.05
Mental health	3.7 ± 0.8	4.3 ± 0.7	< 0.05
Total	3.4 ± 0.6	4.2 ± 0.6	< 0.05
Radiographic measurements			
Slip percentage (%)	75 ± 22	33 ± 24	< 0.05
Lumbosacral angle (°)	71 ± 38	92 ± 48	< 0.05
Pelvic tilt (°)	32 ± 11	30 ± 9	0.06
Sacral slope (°) (IR, M)	49 ± 10 (41.8–57, 49)	52 ± 9 (46.8–58, 52)	0.06
	First follow-up (Mean ± SD)	Last follow-up (Mean ± SD)	*P* value
Slip percentage (%)	32 ± 25	33 ± 24	< 0.05
Lumbosacral angle (°)	92 ± 47	92 ± 48	< 0.05
Pelvic tilt (°)	30 ± 9	30 ± 9	< 0.05
Sacral slope (°)	52 ± 9	52 ± 9	< 0.05
Pelvic incidence (°)	83 ± 9.6	84 ± 9.2	< 0.05

Table 2 Preoperative and postoperative QoL in patients who had already balanced pelvis preoperatively

Domain	Baseline (Mean ± SD)	Last follow-up (Mean ± SD)	*P* value pre-op, last FU
Pain	2.7846 ± 0.9	3.8769 ± 0.8	< 0.05
Self-image	3.1654 ± 0.8	4.1154 ± 0.9	< 0.05
Function	3.3615 ± 0.5	4.3135 ± 0.5	< 0.05
Mental Health	3.4769 ± 0.9	4.2231 ± 0.8	< 0.05
Total	3.2177 ± 0.6	4.1488 ± 0.6	< 0.05

significantly after surgery in the balanced post-op group. The SRS-22 scores and radiographic measurements are shown in Table 3. At baseline, the C7 plumbline was in front of the femoral heads in five patients with unbalanced pelvis and in four patients with balanced pelvis. At follow-up, the C7 plumbline was normal in all patients.

There were 46 patients in the PLG group and 14 patients in the PHG group. The QoL scores and radiographic measurements are shown in Table 4. Slip percentage and LSA were both improved by surgery in both groups, but to a greater extent in the PLG group. In the PLG group, PT decreased, and SS increased postoperatively, while in the PHG group, PT increased, and SS decreased postoperatively.

As shown in Table 5, the proportion of patients improving from an unbalanced pelvis preoperatively to a balanced pelvis postoperatively was significantly improved in the PLG group (55% vs. 0%, $P = 0.004$). Conversely, the proportion of patients with a preoperative balanced pelvis that remained balanced postoperatively was increased in the PLG group (81% vs. 57%) but it did not reach statistical significance ($P = 0.1$).

Of the 26 patients in the PLG group with a preoperative balanced pelvis, 21 remained balanced while five became unbalanced (Table 5). These two subgroups of patients with a preoperative balanced pelvis undergoing reduction were similar with regard to age as well as preoperative radiographic measurements (slip percentage, LSA, PT, SS). Postoperatively, PT was significantly increased ($P = 0.001$) in the five patients who became unbalanced (mean: 38.6° ± 8.0°; median: 36.7°; interquartile range 32.5°–45.6°), when compared to the 21 patients who remained balanced (mean: 23.1° ± 7.4°; median: 24.0°; interquartile range 17.7°–29.4°).

The mean improvement in QoL was increased in the PLG group for all SRS-22 scores, but it did not reach statistical significance (Table 4). When only considering the PLG group of 46 patients, the improvement in QoL with respect to pain, self-image, function, mental health and total score was, respectively, 1.2 ± 0.9, 1.1 ± 0.8, 1.0 ± 0.7, 0.7 ± 0.9, 1 ± 0.7 for patients with a postoperative balanced pelvis ($n = 32$), and 0.8 ± 0.7, 0.5 ± 0.9, 0.5 ± 0.5, 0.4 ± 0.4, 0.6 ± 0.6 among patients with a postoperative unbalanced pelvis ($n = 14$). However, the differences between these two subgroups did not reach statistical significance. When looking specifically at the 26 patients with a preoperative

Table 3 Quality of life scores and radiographic measurements in patients with postoperative balanced and unbalanced pelvis

	Balanced post-op group ($n = 36$) (Mean ± SD)			Unbalanced post-op group ($n = 24$) (Mean ± SD)			Change in balanced versus unbalanced post-op groups (*P* value)
	Preoperative	Postoperative	Change	Preoperative	Postoperative	Change	
Quality of life scores							
Pain	2.7 ± 0.8	4 ± 0.6	1.2 ± 0.9	3.3 ± 0.9	4.2 ± 0.9	0.9 ± 0.7	0.2
Self-image	3.2 ± 0.6	4.4 ± 0.5	1.1 ± 0.9	3.4 ± 0.7	4.0 ± 0.9	0.6 ± 0.8	0.05*
Function	3.4 ± 0.6	4.4 ± 0.4	1.0 ± 0.7	3.5 ± 0.6	4.1 ± 0.5	0.4 ± 0.6	0.1
Mental health	3.6 ± 0.8	4.3 ± 0.7	0.7 ± 1.0	3.8 ± 0.7	4.2 ± 0.7	0.4 ± 0.6	0.3
Total	3.2 ± 0.5	4.3 ± 0.4	1.1 ± 0.6	3.5 ± 0.6	4.1 ± 0.7	0.6 ± 0.5	0.05*
Radiographic measurements							
Slip percentage (%)	70 ± 24	28 ± 22	42 ± 20	84 ± 21	39 ± 26	45 ± 30	0.6
Lumbosacral angle (°)	79 ± 22	96 ± 16	17 ± 12	64 ± 13	81 ± 12	17 ± 14	0.8
Pelvic tilt (°)	27 ± 10	24 ± 6	−4 ± 8	37 ± 9	40 ± 6	2 ± 7	0.004*
Sacral slope (°) (IR, M)	52 ± 10 (44–58.5, 51)	56 ± 9 (50.9–60, 57.5)	4 ± 8	48 ± 11 (41–52, 47)	46 ± 8 (38–52, 47)	−2 ± 9	0.01*
Pelvic incidence (°)	83 ± 10.3	84 ± 9.6	0 ± 1.6	83 ± 8.8	84 ± 8.9	0 ± 2.2	0.9

PLG postoperative low grade, *PHG* postoperative high grade, *IR* interquartile range, *M* Median

*Statistically significant with $P < 0.05$

Table 4 Quality of life scores and radiographic measurements for patients in the PLG and PHG groups

	PLG group ($n=46$) (Mean ± SD)			PHG ($n=14$) (Mean ± SD)			Change in PLG versus PHG groups (P value)
	Preoperative	Postoperative	Change	Preoperative	Postoperative	Change	
Quality of life scores							
Pain	3.0 ± 0.9	4.2 ± 0.8	1.1 ± 0.8	2.7 ± 0.9	3.7 ± 0.6	0.9 ± 0.8	0.4
Self-image	3.3 ± 0.7	4.4 ± 0.7	1.0 ± 0.9	3.0 ± 0.7	3.8 ± 0.9	0.7 ± 0.8	0.3
Function	3.4 ± 0.7	4.4 ± 0.4	0.8 ± 0.7	3.3 ± 0.4	4.0 ± 0.5	0.7 ± 0.4	0.8
Mental health	3.8 ± 0.8	4.4 ± 0.7	0.6 ± 0.8	3.3 ± 0.7	3.8 ± 0.9	0.4 ± 0.8	0.6
Total	3.4 ± 0.6	4.4 ± 0.5	0.9 ± 0.6	3.1 ± 0.5	3.8 ± 0.6	0.7 ± 0.6	0.5
Radiographic measurements							
Slip percentage (%)	70 ± 16	22 ± 12	48 ± 21	94 ± 31	70 ± 18	23 ± 24	0.001*
Lumbosacral angle (°)	75 ± 40	97 ± 50	18 ± 12	60 ± 31	77 ± 40	14 ± 14	0.5
Pelvic tilt (°)	31 ± 11	28 ± 8	− 3 ± 8	34 ± 11	36 ± 9	2 ± 7	0.06
Sacral slope (°) (IR, M)	50 ± 11(36.7–62.3, 49)	53 ± 8 (42–54, 50)	3 ± 9.9	50 ± 11(30.3–70.3, 53)	49 ± 10 (32.7–64.7, 49)	− 2 ± 6.9	0.03*

PLG postoperative low grade, *PHG* postoperative high grade, *IR* interquartile range, *M* Median

*Statistically significant with $P<0.05$

Table 5 Preoperative and postoperative balance of patients in the PHG and PLG groups

Pelvic balance	PHG group ($n=14$)	PLG group ($n=46$)	P value
Balanced pelvis preoperatively	7	26	
To balanced pelvis postoperatively	4	21	0.1
To unbalanced pelvis postoperatively	3	5	
Unbalanced pelvis preoperatively	7	20	
To balanced pelvis postoperatively	0	11	0.004*
To unbalanced pelvis postoperatively	7	9	

*Statistically significant with $P<0.05$

balanced pelvis undergoing reduction, there was no difference in preoperative or postoperative QoL scores between the 21 who remained balanced postoperatively and the five who became unbalanced postoperatively. However, the improvement in QoL was greater—although not statistically significant—for all scores in the subgroup remaining balanced after reduction.

Among patients in the PLG group, three had intraoperative dural tear repaired immediately without any evidence of postoperative cerebrospinal fluid (CSF) leak. One patient was reoperated for replacement of right S1-L5 screws due to possible L5-S1 neural foramen impingement. Another patient had revision surgery to partly release the reduction in the presence of severe lumbar neuropathy and fusion extension up to L4 1 year after the index surgery for supra-adjacent spondylolisthesis. Of note, this patient had a balanced pelvis prior to surgery that became unbalanced after the index surgery, and that remained unbalanced at last follow-up after fusion extension up to L4. One patient had central intravenous line infection treated by catheter removal and intravenous antibiotics. One patient had a meralgia paresthetica that did not require any additional intervention. One patient was diagnosed with proximal deep-vein thrombosis in the left lower limb. This patient was treated with inferior vena cava filter placement.

Postoperatively among the PHG group, one patient had prominent instrumentation needing removal, and another patient had a postoperative CSF leak and underwent dural repair. No nonunion or hardware failure was documented among all patients.

Discussion

This study is the first to specifically present the variation in the QoL in relationship with pelvic and sagittal balance before and after surgery with a minimum follow-up of 2 years for high-grade spondylolisthesis managed surgically. A follow-up of 2 years was used because it is a time frame commonly used in the literature to describe the outcome of treatment; a longer follow-up would also be interesting to fully evaluate the outcome of these patients. We used the SRS-22 questionnaire, which has been validated in adolescent's population with spondylolisthesis [21], in order to assess the QoL preoperatively and postoperatively.

This study highlights the importance of pelvic balance because it has been shown to regulate the overall sagittal balance in both normal and spondylolisthesis subjects [14, 19, 22]. While obtaining postoperative pelvic balance was significantly associated with improvement in self-image and SRS-22 total score, the failure to reach statistical significance in other domains is most likely due to the small sample size, particularly in the unbalanced post-op group.

While we have shown that achieving normal pelvic balance postoperatively is associated with better improvement in QoL, it is also important to determine how to preserve or restore a balanced pelvis when planning surgery for high-grade spondylolisthesis. Surgical reduction—as opposed to in situ fusion—was proposed by Hresko et al. [6] to restore pelvic balance, but they did not provide data to support this hypothesis. In our study, we have shown that surgical reduction in a low-grade slip $<50\%$ was more likely associated with restoration or maintenance of normal pelvic balance postoperatively. With a reduction in the slip percentage to $<50\%$—and the concomitant improvement in LSA—we believe that this maneuver will tend to decrease the PT and increase the SS, thereby favoring a balanced pelvis (Fig. 1). Therefore, PT decreased, and SS increased in the PLG group, while PT increased, and SS decreased in the PHG group. By improving pelvic balance, surgical reduction will therefore facilitate restoration of the normal correlations that are observed between adjacent segments of the spine and pelvis, thereby leading to normal global sagittal alignment [14]. Accordingly, Gussous et al. [23] have observed that there is a negative correlation between PT and QoL in adult patients with lumbosacral spondylolisthesis.

The average slip percent at the last FU were $22.2\% \pm 12\%$ (minimum 1%, maximum 47%, median 21%, interquartile range 11–30%) and $70.3\% \pm 18.4\%$ (minimum 51%, maximum 109%, median 64%, interquartile range 57–85%) among the PLG and PHG groups, respectively. In addition, the results have shown that surgical reduction tends to improve QoL although the differences did not reach statistical significance. The failure to reach statistical significance could be due to three reasons. First, the limited number of patients in the PHG group suggests that further study with a larger cohort should be performed to determine if there are specific thresholds for reduction that is associated with improved QoL. Second, we hypothesize that the improvement in QoL is mainly associated with pelvic balance, such that the impact of surgical reduction in QoL is mostly associated with the capability to achieve normal postoperative balance. Accordingly, in the PLG group, there was a tendency for better improvement in QoL among patients with a normal postoperative pelvic balance. Last, analysis of the PLG group is limited by the fact that the techniques and results of reduction varied within the group, while the optimal technique and criteria/goals for reduction are yet to be defined. Indeed, the surgical technique for reducing high-grade spondylolisthesis is not standardized, as surgeons use different concepts, techniques, instruments and implants to perform reduction, as in the current study.

Fig. 1 Pre- and post-op full spine X-Ray. Pelvic incidence 86, Pre-op pelvic tilt 65, pre-op sacral slope 21, post-op PT 32, post-op SS 54. The patient changed his unbalanced pelvis preoperatively to balanced pelvis postoperatively

Gandhoke et al. have shown in a series of 25 adult patients with high-grade spondylolisthesis who had a surgical reduction and arthrodesis, the mean visual analog scale (VAS) pain score improved after surgery from 7.7 to 2.4 ($P<0.01$). The mean ODI and Prolo score at last follow-up were 20 and 8.2, respectively, which reflects relatively minimal disability and good functional status [16]. Maciejczak et al. [24] reported that radiological improvement of pelvic balance after surgical correction of mid- and low-grade isthmic spondylolisthesis in adult patients did not correlate with clinical outcomes. These articles deal with adult patients while our cohort was mainly composed of adolescents. In addition, these articles only analyzed postoperative quality of life without considering the preoperative quality of life of patients, while this is one of the main features of our study.

The compensatory mechanisms involved in spondylolisthesis represent an attempt to maintain a global alignment, to

escape from pain or to control body posture [25]. The pelvic balance, orientation, alignment and compensation mechanisms are complex in spondylolisthesis, and future studies should assess these issues in sagittal, coronal and axial planes. In addition, the conclusions are limited by the absence of a criterion in the literature for defining the minimum clinically important difference (MCID) in QoL in young patients with spondylolisthesis. Although criteria for MCID have been proposed in other populations with spinal disorders, these criteria cannot be used in the current study because they are disease-specific. While the current study evaluates the overall (and statistical) changes in QoL in different subgroups, future analyses using a defined criterion for MCID would instead allow comparing different subgroups based on the proportion of individuals reaching a clinically significant improvement in QoL due to surgery. Also, our analyses were primarily based on the relationship between pelvic balance and QoL, but the authors acknowledge that study of the entire sagittal balance is needed in the future to evaluate the importance of the global sagittal balance on the quality of life after surgery in adolescent patients with high-grade spondylolisthesis.

Shortening procedure such as sacral dome osteotomy should be evaluated in the future as a potential factor improving quality of life, in relationship with possible decrease in the risk of adjacent segment disease and L5 nerve root injury.

Posterior spinal fusion of spondylolisthesis in the adolescent population was associated with a 46% reoperation rate [26]. The overall complication rate was 17% in our cohort, and the most common complication was a dural tear. This complication rate was slightly higher than the 10% complication rate reported through the mortality and morbidity database of the Scoliosis Research Society for 605 patients with pediatric spondylolisthesis [15, 25]. Our higher complication's rate can be explained by the prospective design of our data collection on complications, and by the inclusion of only high-grade slips in the current study. The overall rate of complications was similar between the PLG (17%) and the PHG (14%) groups. However, the occurrence of two neurological complications in the PLG group and none in the PHG group is in line with previous findings, suggesting that surgical reduction in spondylolisthesis can be associated with a higher risk of neurological complication [15].

Acknowledgements This work was supported by a Standard Investigator Research Grant from the Scoliosis Research Society. This study is approved by Hospital's Research Ethics Committee.

Compliance with ethical standards

Conflict of interest J-M Mac-Thiong, H Labelle and S Parent are a co-founders, board members and shareholders of Spinologics Inc. J-M Mac-Thiong receives research support from Medtronic and Depuy-Synthes. S Parent receives research support from DePuy-Synthes. LG Lenke receives royalties from Medtronic and Quality Medical Publishing, is a consultant for Medtronic, and receives research support from EOS Imaging. DJ Sucato is a consultant from Globus.

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