



High-grade high-dysplastic lumbosacral spondylolisthesis in children treated with complete reduction and single-level circumferential fusion: A prospective case series



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ABSTRACT

Introduction: Surgical treatment of high-grade developmental spondylolisthesis remains controversial with paucity of data reporting complete reduction of the deformity, especially in pediatric patients.

Research question: To assess efficacy and safety of complete reduction and circumferential L5-S1 fusion in children with high-grade high-dysplastic spondylolisthesis. Emphasis was placed on fusion rates, correction of lumbosacral deformity and long-term clinical outcomes by means of patient-reported outcome measures (PROMs).

Material and methods: Consecutive series of 18 pediatric patients referred to surgery over an 11-years period. Several radiographic variables and PROMs were collected pre- and post-surgery with minimum follow-up of 2-years.

Results: The mean age of cohort was 12.9 years with a mean follow-up of 7.8 years. Postoperatively, the mean slip was reduced from $64.4 \pm 9.8\%$ to $4.5 \pm 5.9\%$ with no loss of correction during follow-up. PROMs significantly improved following the index procedure ($p < 0.0001$). Lumbo-pelvic parameters improved after surgery, including SS, but not PT. Development of adjacent level spondylolisthesis was noted in eight subjects (44%), two of these patients required additional surgery. Posterolateral and anterior fusion was obtained in 100% and 78% of cases, respectively. One patient developed a transient right-sided L5 nerve paresis after surgery that gradually resolved within one year post-surgery. Preoperatively, we recorded three patients with L5 nerve root motor deficit, which resolved completely in two cases and in one patient remained unchanged.

Discussion and conclusion: Complete reduction can safely be accomplished without an increased risk of nerve root injury. Coupled with single-level circumferential fusion, it provides high fusion rates with satisfactory spino-pelvic alignment.

1. Introduction

Most publications dealing with high-grade lumbosacral spondylolisthesis begin with a statement that an optimal technique for their surgical treatment remains controversial. A number of surgical procedures and their modifications have been described in the literature, ranging from a simple non-instrumented in situ posterior fusion up to extensive corrective interventions with sacral dome osteotomies (Agabegi and Fischgrund, 2010; Bodin and Roussouly, 2015; Bourassa-Moreau ÉMac-Thiong et al., 2013; Bradford and Boachie-Adjei, 1990; DeWald et al., 2005; Hart et al., 2014; Jouve et al., 2014; Laursen et al., 1999; Lombardi et al., 2013; Mac-Thiong and Labelle, 2006; Molinari et al., 1999; Sailhan et al., 2006; Vialle et al., 2006). There are several methods

to achieve successful outcome, i.e. a stable lumbosacral junction in a balanced position, without pain and neurological deficit. The argument of supporters of in situ fixation is lower risk of neurological complications (Hart et al., 2014; Jouve et al., 2014), other authors advocate reduction and fixation because of better biomechanical conditions leading to a higher number of fusions and a better cosmetic effect (Bradford and Boachie-Adjei, 1990; Laursen et al., 1999; Molinari et al., 1999; Longo et al., 2014). At our institution, we prefer complete reduction and instrumented single-level circumferential fusion using fixation system with Schanz screws. In this study, we aim to document the long-term clinical and radiological outcome in pediatric patients with high-grade high-dysplastic L5-S1 spondylolisthesis treated with the same surgical technique.

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2. Methods

2.1. Patients

Between November 2007 and January 2018 18 patients were treated for high-grade high-dysplastic (HGHD) spondylolisthesis of the L5-S1 segment. The group included 5 boys and 13 girls with a mean age of 12.9 years (range, 9–18 years) and with a mean follow-up time of 7.8 years (range 2–13 years) after surgery. The study protocol was approved by the ethical committee of our hospital. All patients provided written consent to be enrolled in the study and allowed publication of photographic documentation. Detailed patient characteristics and their corresponding lumbosacral morphology are shown in [Supplementary Table 1](#). All patients underwent preoperative radiographic examination consisting of full spine radiographs in anteroposterior and lateral projection including the pelvis and femoral heads, as well as MRI and CT scans of the lumbosacral junction involving 3D reconstructions. Results of these examinations and patients' clinical status served as the basis for surgical planning.

2.2. Surgical technique

Patients were operated on by a posterior-only approach or combined posterior-anterior approach with complete reduction and L5-S1 interbody fusion. In the first step, all patients were operated from the posterior approach. They were placed in the prone position on the operating table, with the shoulders and pelvis supported with a pediatric frame fixed with adhesive tape. Midline incision was used to expose the lumbosacral junction from L4 to S1, followed by resection of the L5 arch and wide decompression of nerve roots. In seven patients, sacral dome resection and lumbosacral junction release through discectomy and/or outer annulus release was required. Subsequently, 6.5 mm or 5.5 mm Schanz reduction screws were inserted into L5 and standard 6.5 mm screws into S1 bi-cortically (TSRH-3D, Medtronic, USA). In two patients, dysplastic pedicles allowed only extra pedicular screw placement (5.5 mm diameter) into L5 vertebra. Despite that, screw purchase was secure enough not to include the L4 level in the fixation system. After assembling the fixation system with firm anchoring of the screws in S1, anatomical reduction was performed via the “cantilever beam” mechanism using reduction screws and tower reducers (see [Fig. 1](#)). The lumbosacral slip and kyphotic alignment was gradually reduced under visual control of L5 and S1 nerve roots and additional decompression of the nerve roots was performed, where necessary. We noticed that reduction was associated with spontaneous distraction of the lumbosacral junction due to abnormal anatomical relations. However, we compensated for the distraction by simultaneous application of compression, thus avoiding overstretching L5 nerve roots. After achieving satisfactory position, the connecting elements of the fixation system were tightened and reduction screws cut short. The posterior procedure was finalized by applying a posterolateral L5-S1 fusion with autogenous cancellous bone grafts harvested from the iliac crest (14 cases) or allografts (4 cases). In eight subjects, bone grafts were simultaneously applied into the intervertebral space after disc removal and/or sacral dome resection within the same session. The remaining eight patients underwent an anterior discectomy and interbody fusion surgery in a second setting ([Table 1](#)). Intraoperative neuromonitoring (IONM) of lumbar and sacral nerve roots (NIM-Eclipse, Medtronic, USA) was performed throughout the posterior procedure using a standard combination of motor evoked potentials (MEP) and continuous electromyography (EMG) recordings. We did not encounter any adverse events during IONM in any of our patients.

2.3. Clinical and radiographic measurements

Prior to discharge, all patients underwent a post-operative X-ray and CT examination. Standard clinical and radiographic follow-ups were scheduled at 6 and 12 weeks, 6 and 12 months and then annually until

the end of the skeletal growth. Additional follow-up CT evaluation was performed 4–6 months post-operatively to assess bone fusion (see [Figs. 2–3](#)). In addition to regular follow-up assessments, all patients were examined upon completion of the study, i.e. at the mean interval of 93 months (range, 31–162 months) postoperatively. In our study, we evaluated the anatomy of the lumbosacral junction, the course of surgical intervention ([Table 1](#)), correction of deformity, bone fusion, the patient's clinical status, and complications. Measured radiographic parameters included slip percentage, slip angle (SA), lumbosacral angle as described by Dubousset (Dub-LSA) ([Dubousset, 1997](#)), dysplastic lumbosacral angle as described by the Spinal Deformity Study Group (SDSG-LSA) ([Berthonnaud et al., 2008](#)), pelvic tilt (PT), sacral slope (SS) and pelvic incidence (PI). Clinical status was assessed by the Visual Analogue Scale (VAS) and Oswestry Disability Index (ODI).

2.4. Analysis

Descriptive statistics was performed for all clinical and radiographic data. Due to the relatively small sample size, a nonparametric Friedman's test was used for repeated measures analysis across the assessed time points followed by Dunn's multiple comparison post-hoc test. We set the level of significance at 0.05 for all our statistical computations. All statistical calculations were conducted using GraphPad Prism (version 8.3.0 for Windows, GraphPad Software, San Diego, California USA).

3. Results

3.1. Radiographic results

Baseline, preoperative and postoperative radiographic parameters are presented in [Table 2](#). Reduction was expressed by slip percentage, which decreased from a mean (\pm SD) of 64.4% (\pm 9.8) to 4.5% (\pm 5.9) measured immediately after surgery with no loss of reduction at 1 year or the last visit. We found a significant decrease in SA from -21.0 (\pm 15.0) to 5.3 (\pm 6.4). Both Dubousset's and dysplastic SDSG-LSA improved from 77.0 (\pm 17.7) and -5.1 (\pm 16.9) to 101.7 (\pm 12.3) and 16.4 (\pm 14.4), respectively, with no significant deterioration during the follow-up. Concerning pelvic parameters, SS increased from 42.2 (\pm 12.6) to 46.6 (\pm 6.9) that slightly adjusts at the last follow-up 51.0 (\pm 7.3; $p < 0.05$). We observed some changes in PI and PT as well, but were not statistically significant. A CT scan obtained at 6 months post-surgery confirmed a complete posterolateral fusion in all patients (100%) and a solid interbody fusion in 14 cases (78%) ([Table 1](#)).

3.2. Clinical results

[Table 2](#) shows a statistically significant improvement in both PROMs from baseline to 1 year, baseline to last FU and from 6 months to last FU. In 3 cases we found preoperative L5 paresis bilaterally, that in one case resolved within 3 months, and in the other case it got slightly worse after the operation and subsequently significantly improved and returned to normal within 6 months. The neurological deficit of the third patient has remained unchanged up to the last follow-up. One patient, who did not have a neurological dysfunction prior the surgery, developed a transient right-sided L5 paresis (MRC grade 3/5) after the surgery that gradually disappeared within one year post-surgery. All 18 patients gave a positive answer to the question whether in view of their treatment experience they would undergo the same operation again, and pointed out the favorable functional and aesthetic aspects of its outcome.

3.3. Complications

We encountered one intraoperative complication, namely cerebrospinal fluid leak that was addressed by suture of the dural sac. Early postoperative complications included one case of screws loosening inserted bi-cortically into S1 that were replaced by larger diameter

screws and additional insertion of two screws into the sacral alae. The other complication was superficial wound infection found in one patient, treated with revision and re-suturing without the need of instrumentation or bone graft removal. Late postoperative complications included 8 cases (44%) of adjacent segment olisthesis of L4-L5 after successful reduction and fusion of L5-S1. However, only two patients required surgery for instability and clinical deterioration. This was done by extracting the initial instrumentation, complete reduction of L4-L5 and polyaxial screw fixation of L4-L5-S1 with posterolateral fusion. In one patient, the spondylolisthesis progressed from Meyerding grade I to grade II within one year and was indicated for surgical treatment, however, the patient refused the operation for family-related reasons. The other patients remain asymptomatic and all patients continue to be followed-up annually. Although not related to spondylolisthesis treatment, one patient developed a significant scoliotic deformity of the thoracic spine (main curve Th4-Th6-Th10 44°) that was treated with posterior correction and instrumented fusion Th3-Th11. The scoliosis surgery was done 27 months after surgical treatment of the spondylolisthesis.

4. Discussion

In general, reduction has several potential benefits as compared to in situ fusion (Lak et al., 2020). Surgical reduction allows direct decompression of the neural structures in the spinal canal and foramina, as well

as correction of lumbosacral kyphosis (Bradford and Boachie-Adjei, 1990; Lamartina et al., 2009). Of no less importance is the potential to restore normal spino-pelvic alignment (Alzakri et al., 2019; Hresko et al., 2007). Martiniani et al. compared patients with in situ fusion and patients after reduction of spondylolisthesis and recommend in situ fixation only in patients with balanced pelvis, while reduction should be preferred in patients with unbalanced sacro-pelvic complex (Martiniani et al., 2012). Lombardi et al. recommend monosegmental complete reduction in all spondylolistheses greater than 25%, regardless of the type and anatomy (Lombardi et al., 2013). They argue that vertebral body realignment provides a greater fusion surface, increasing the fusion rate by approximating transverse processes closer to each other. Another reason for reduction is releasing the ligamentous and muscular structures at the slipped level and normalizing the load distribution in the adjacent segments, thus possibly limiting the risk of their degeneration. The surgical procedure is associated with good clinical outcomes and a high percentage of the interbody fusion (91%). Longo et al. found better correction of kyphosis and generally better biomechanical relations in patients following reduction as compared to in situ fixation (Longo et al., 2014). Molinari et al. recorded 29% of non-unions and 29% of patients with neurological deficit in patients after stand-alone posterior reduction and fixation. Neurological impairment was transient in all cases (Molinari et al., 1999). In their review, Sailhan et al. detected 11.4% of non-unions, 9.1% of neurological complications and 2.3% of a persistent motor deficit in a series of 44 patients following instrumented posterior

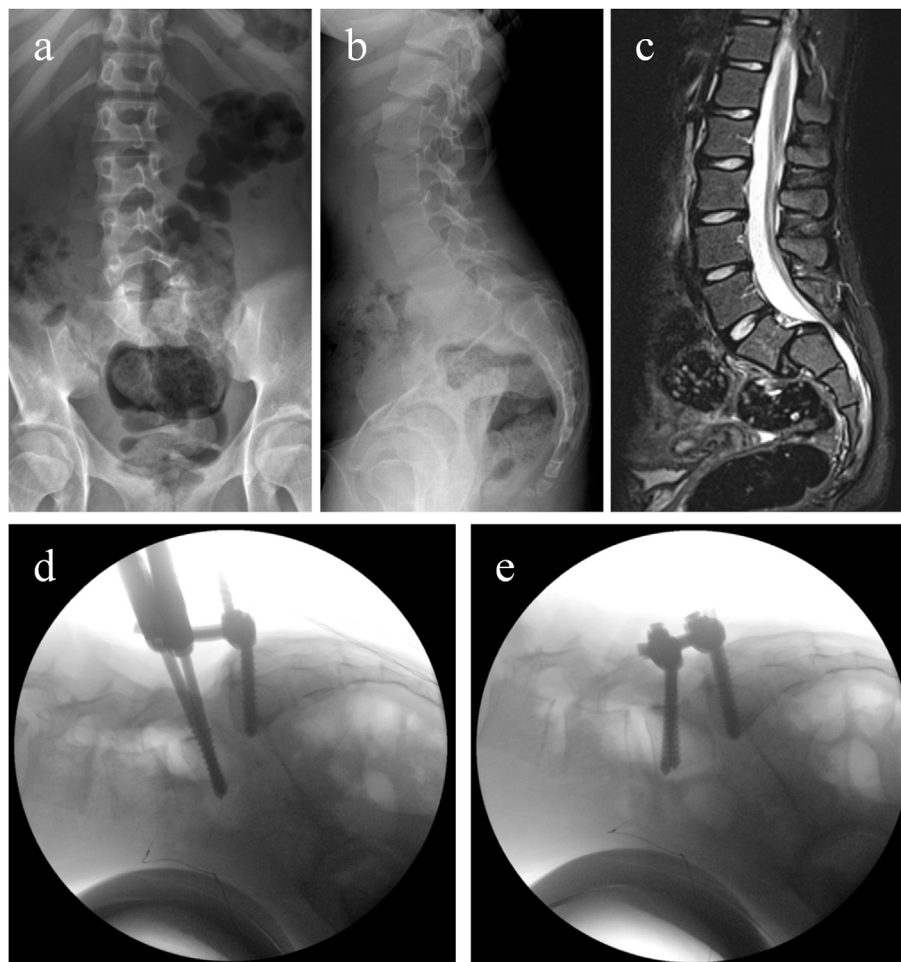


Fig. 1. Preoperative imaging studies of a 14-year old patient. Radiographs in standing position (a, b) show dysplastic changes at the lumbosacral junction. MRI-T2 weighted sagittal image (c) reveals severe L5/S1 stenosis. Perioperative lateral radiograph after screw insertion and posterior release (d). The same image after total reduction (e).

Table 1
Surgical data.

Pt	No. of surgeries	Days between surgeries	Type of surgery	Approach		Surgical time (min)		Blood loss (ml)		X-ray time (s)		Bone graft		Solid fusion (CT 6 m post-op)		
				P	A	P	A	P	A	P	A	Anterior	Postero-lateral			
1	2	8	reduction + decompression	P & A	40	x	200	10	x	24	6	auto	auto	YES	YES	
2	2	9	reduction + decompression	P & A	160	60	x	300	10	x	25	7	auto	auto	YES	YES
3	1	NO	reduction + decompression	PA	x	x	115	x	200	x	24	x	x	alo	YES	YES
4	1	0	reduction + decompression	PA	x	x	120	x	500	x	26	x	x	auto	YES	YES
5	2	45	reduction	P & A	75	50	x	200	10	x	24	6	auto	auto	YES	YES
6	2	12	reduction + decompression	P & A	100	40	x	300	20	x	27	8	alo	x	NO	RIGHT-YES, LEFT-NO
7	2	6	reduction	P & A	80	50	x	500	20	x	24	6	auto	auto	YES	YES
8	2	6	reduction + decompression	P & A	75	70	x	300	10	x	34	12	auto	auto + art	YES	YES
9	1	NO	reduction + decompression	PA	x	x	135	x	300	x	x	36	x	alo	YES	YES
10	1	NO	reduction + decompression	PA	x	x	160	x	500	x	x	45	x	auto	YES	YES
11	1	NO	reduction + decompression	PA	x	x	100	x	200	x	x	34	x	auto	YES	YES
12	2	19	reduction + decompression	P & A	80	60	x	200	10	x	43	12	auto	x	NO	YES
13	1	NO	reduction + decompression	PA	x	x	150	x	500	x	x	42	x	auto	YES	YES
14	1	NO	reduction + decompression	PA	x	x	150	x	200	x	x	44	x	auto	YES	YES
15	1	NO	reduction + decompression	PA	x	x	150	x	500	x	x	40	x	auto	YES	YES
16	1	NO	reduction + decompression	PA	x	x	170	x	100	x	x	32	x	alo	NO	YES
17	2	9	reduction + decompression	P & A	90	35	x	500	20	x	22	4	auto	auto	YES	YES
18	1	NO	reduction + decompression	PA	x	x	180	x	900	x	x	56	x	x	NO	YES
Average					93	51	143	313	13	390	28	8				

Abbreviations: Pt. - patient, P. - posterior approach, A. - anterior approach, PA - 360° treatment from a single posterior approach, auto - autogenous bone grafts harvested from the iliac crest of the same patient, alo - allografts, art - artificial bone graft substitute.

reduction and fusion without decompression. They consider the outcomes acceptable in view of the serious diagnosis (Sailhan et al., 2006). In our study, we aimed for complete reduction in all patients, regardless of their preoperative pelvic balance. We demonstrated that, when coupled with single-level circumferential fusion, complete surgical reduction is a safe and feasible alternative in treatment of HGHD spondylolisthesis resulting in superior clinical outcome at the cost of minimal functional restriction.

Concerning fusion, a number of authors currently prefer circumferential L5-S1 fusion, that will ensure better distribution of the load on the lumbosacral junction, increase the segmental stability and provide greater fusion surface (Laursen et al., 1999; Shufflebarger and Geck, 2005; Ruf et al., 2006; Molinari et al., 2002). Dubousset recommends addition of anterior fusion only with the lumbosacral angle less than 100° following reduction (Dubousset, 1997). Min et al. recommend reduction and fusion from a separate posterior approach after the sacral dome resection; they point out that care should be taken to avoid overstretching L5 nerve roots (Min et al., 2012). Some authors prefer, in case of reduction, to extend the fixation up to L4 or even higher (Laursen et al., 1999; Sailhan et al., 2006; Min et al., 2012; Mehdian et al., 2005), although good results have been reported also with monosegmental L5-S1 instrumentation and fusion (Lombardi et al., 2013; Shufflebarger and Geck, 2005; Ruf et al., 2006).

The importance of reduction in high-grade spondylolistheses has already been emphasized by a number of authors; the issue currently under debate is its scope, i.e. whether it should be partial or complete. Many surgeons prefer partial over complete reduction because incomplete reduction is associated with a lower risk of nerve root injury (Vialle et al., 2006; Petraco et al., 1996). In contrast, Deckey et al. in a recent publication, found no convincing evidence that greater reduction increases rates of neurological deficits, though they acknowledge the shortcomings of the small patient size that exhibited neurological dysfunction (Deckey et al., 2019). Other authors advocating complete reduction reported some neurological complications, but these tended to be transient and negligible (Shufflebarger and Geck, 2005; Ruf et al., 2006). This agrees with our findings where complete reduction is accompanied with low and acceptable rates of neurological injury. Moreover, neurological deficits were observed in patients with already existing sensory-motor dysfunctions, and in accordance with previous reports (Longo et al., 2014; Schär et al., 2017), they persisted only temporarily and normalized ad integrum within one year post-surgery.

Spondylolisthesis of the adjacent segment following high-grade slip reductions has been reported in the literature, yet there is paucity of such clinical reports in regards to pediatric population (Table 3). In the present study, eight patients gradually developed adjacent-level instability above the instrumented L5-S1 fusion. Only two patients required surgery due to clinical and radiographic progression, the other patients remained asymptomatic. An exploration of pre-operative MR images did not reveal any signs of L4-L5 disc degeneration. Therefore, normal disc aging seems unlikely to be the cause. Apart from the loss of the posterior ligamentous complex after laminectomy and wide decompression, we believe that this could be attributed to the failure to address the abnormal spino-pelvic alignment. This, in turn, may negatively modulate lumbosacral biomechanics leading to increased stress at the adjacent level. Accordingly, a biomechanical study conducted by Wang et al. revealed altered biomechanical conditions at the adjacent L4-L5 level following lumbosacral reduction in the terrain of unbalanced pelvis. This study showed that in the unbalanced pelvis, axial loading following surgical reduction and L5-S1 fusion resulted in higher concentration of forces as well as a change of the pattern of these forces at the L4-L5 level in comparison to the balanced pelvis. The authors speculated that this might lead to accelerated disc degeneration, but were unable to support this hypothesis with evidence (Wang et al., 2016). To address this issue, Lamartina et al. described the term „unstable zone” or „unstable square” on standing X-rays of patients with high-grade developmental spondylolisthesis (Lamartina, 2001). The authors recommend to fuse all the vertebrae fitted within the square

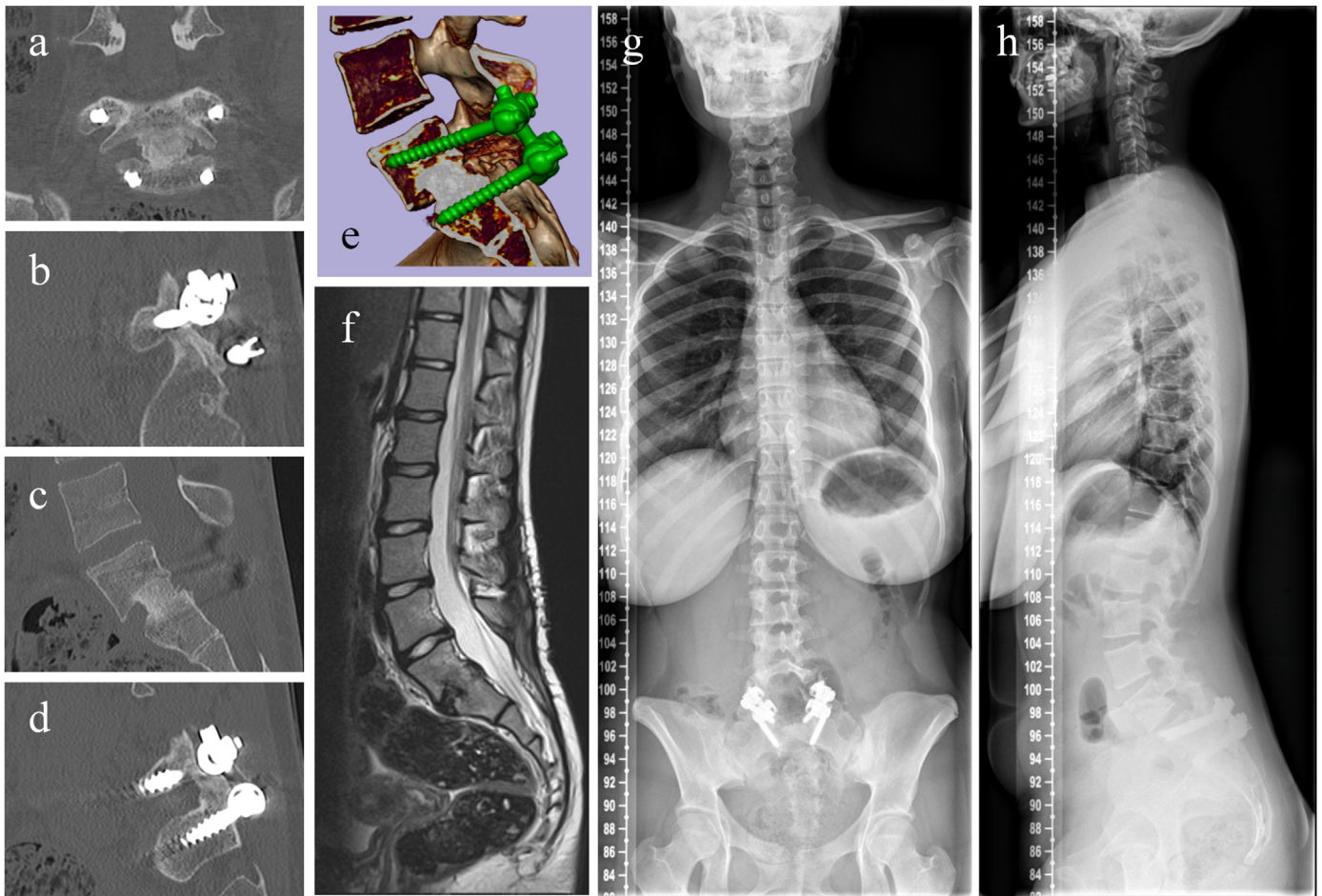


Fig. 2. Imaging studies of the same patient after surgery. CT reconstructions (a–e) show solid anterior and posterolateral fusion 6 months postoperatively. MRI T2-weighted sagittal image (f) obtained at the same visit. Full spine lateral (g) and anteroposterior (h) radiographs obtained 4 years after surgery demonstrate a slight kyphotic decompenstation at the L4/L5 level.

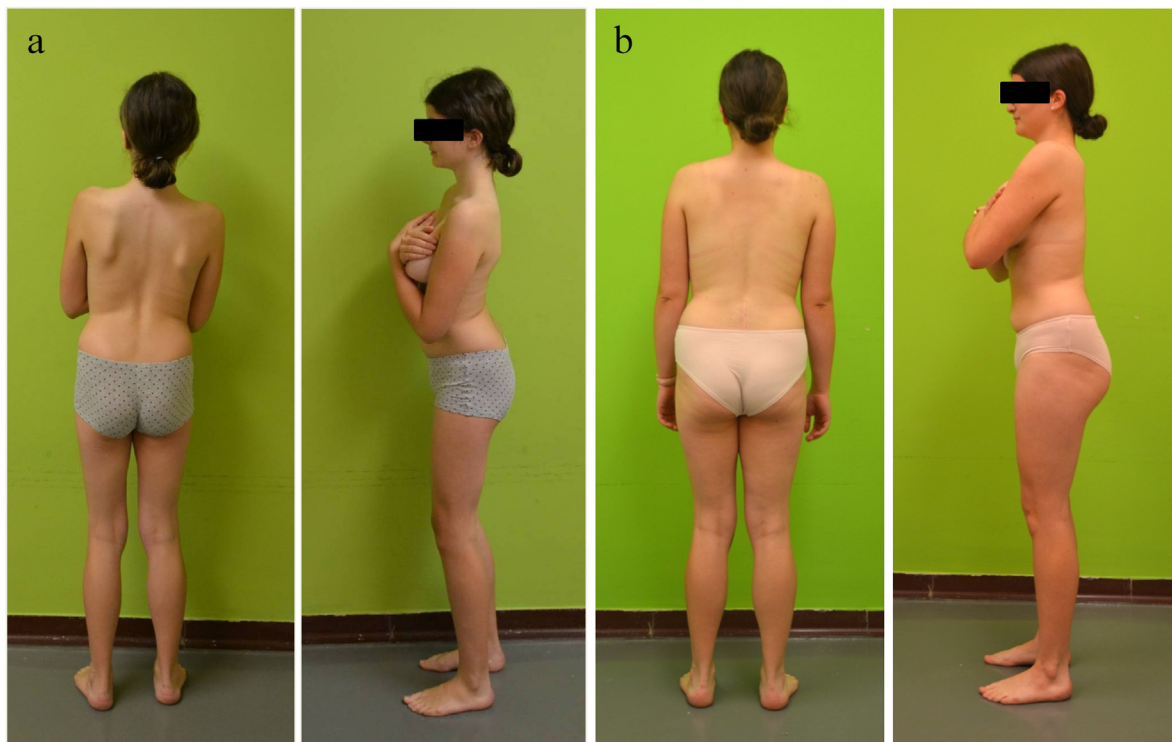


Fig. 3. Clinical photographs of the same patient before surgery (a) and 4 years after instrumented reduction and fusion (b).

Table 2
Summary of clinical and radiological data before and after intervention.

Variable	Baseline	Post-op	6 months	Last FU	p-value
Slip %	64.4 ± 9.8	4.5 ± 5.9 ^b	4.5 ± 5.9 ^b	4.5 ± 5.9 ^b	<0.0001
Slip angle	-21.0 ± 15.0	5.3 ± 6.4 ^b	5.4 ± 6.3 ^b	4.3 ± 7.1 ^b	<0.0001
Dub-LSA	77.0 ± 17.7	101.7 ± 12.3 ^b	102.0 ± 11.9 ^b	101.2 ± 12.3 ^b	<0.0001
SDSG-LSA ^a	-5.1 ± 16.9	16.4 ± 14.4 ^b	16.3 ± 14.2 ^b	17.8 ± 12.2 ^b	<0.0001
PI	77.6 ± 8.3	72.0 ± 10.9	73.3 ± 9.3	78.2 ± 10.8	ns
SS	42.2 ± 12.6	46.7 ± 6.9	46.6 ± 6.9	51.0 ± 7.3 ^c	0.0016
PT	35.4 ± 11.7	24.7 ± 8.7	26.3 ± 7.0	27.2 ± 9.1	ns
Variable	Baseline	6 months	1 year	Last FU	p-value
VAS	6 ± 2	2 ± 2	1 ± 2	1 ± 1	<0.0001
ODI	40 ± 16	14 ± 12	8 ± 9	4 ± 6	<0.0001

Values are shown as the mean ± standard deviation. P-value: Friedman's test. Post hoc analysis of clinical variables (Dunn's post hoc test, P < 0.05) revealed a statistically significant difference between values baseline vs 1 year, baseline vs last FU, 6 months vs last FU.

^a Refers to dysplastic LSA as has been described by the Spinal Deformity Study Group (Berthonnaud et al., 2008).

^b Denotes statistical significance vs. baseline values (Dunn's post hoc test, P < 0.05).

^c Denotes statistical significance vs. baseline and post-op values (Dunn's post hoc test, P < 0.05).

whenever L5 reduction is performed in these patients and proper correction of pelvic retroversion and lumbar lordosis cannot be maintained. In retrospect, we looked at Lamartina's unstable square, four of the eight patients with radiological adjacent segment instability would potentially benefit from fusion extending from L4 to sacrum at the time of primary surgery. Out of the two patients, who underwent revision surgery for

Table 3
Comparison of relevant reports on surgical reduction of high-grade spondylolisthesis in children and young adults.

Author, year	No. Of patients	Mean FU time (years)	Listhesis type (M-B)	Levels fused	Slip % (Pre/Post)	SS (Pre/Post)	PT (Pre/Post)	ASD	New neurological injury (transient/permanent)	Complications (without neurology or ASD)
Shufflebarger et al., 2005 (Shufflebarger and Geck, 2005)	18	3.3	isthmic and dysplastic	L5-S1	77/13	NR	NR	1 ^a	0/0	2
Ruf et al., 2006 (Ruf et al., 2006)	27	3.8	high-dysplastic	L5-S1	74/10	NR	NR	4	5/1	1
Lamartina et al., 2009 (Lamartina et al., 2009)	25	>3	high-dysplastic	L4-S1 (3) L5-S1 (22)	73.2/13.6	NR	NR	NR	1/0	1
Karampalis et al., 2012 (Karampalis et al., 2012)	9	11	NR	L5-S1	NR	NR	NR	1	2/0	4
Bouyer et al., 2014 (Bouyer et al., 2014)	12	3.6	dysplastic?	L4-S1	72/19	38/47	37/30	0	5/0	8
Hart et al., 2014 (Hart et al., 2014)	16	6.5	dysplastic, isthmic, traumatic	L4-S1 (10) L5-S1 (6)	62.1/36.7	NR	NR	NR	1/1	7
Thomas et al., 2015 (Thomas et al., 2015)	15	2-7	dysplastic	L4-S1	73/17	44.9/46.5	30.7/25.1	NR	5/0	5
Our series	18	7.8	high-dysplastic	L5-S1	64.4/4.5	42.2/51	35.4/27.2	8	1/0	3

M-B = Marchetti and Bartolozzi classification; ASD = adjacent segment degeneration; NR = not recorded.

^a Sacral bending was reported.

adjacent level instability, only one patient fell in to the “unstable square” criteria. Finally, inadequate reconstruction of segmental lordosis at the L5-S1 level might further contribute to development of ASD. Interbody fusion with cages of sufficient dimension and shape can with proper placement, facilitate the re-creation of a more lordotic alignment following surgery. Its effect on restoring appropriate focal sagittal alignment is well established in the literature in various indications, including low-grade isthmic spondylolisthesis (Boissiere et al., 2013). In our experience, however, dysplastic changes at the lumbosacral junction often preclude use of such cages in developmental spondylolisthesis, especially in HGHD spondylolisthesis, as in our presented cohort of patients. Taken together, these findings suggest that the etiology of ASD is most likely multi-factorial. To address this, we suggest that the L4-L5 segment might be considered in the index procedure in unbalanced patients while balanced patients may still benefit from a limited, single-level fusion.

4.1. Limitations

The key limitations of this study arise from the case-series design and the absence of control-arm treatment. Given that high-grade spondylolisthesis is a rare condition, there remains a lack of high-level evidence-based data, as the majority of published studies are case-series of limited sample size. Although our patient sample size is also limited, it represents one of the larger published studies documented in the literature when considering complete anatomical reduction treatment in the pediatric population. Nevertheless, we acknowledge the lack of power analysis inherent to our patient number. Other limitations included the variability of PROM responses during follow-ups or recall bias, where participants may fail to reflect their previous state of health after a certain amount of time. A potential caveat is the failure to address the sagittal balance of the whole spine, but such detailed analysis was beyond the scope of this study. In the near future, however, we plan to validate our findings with further investigation involving all patients with a high-grade slip, including an overall alignment analysis of the spine.

5. Conclusions

The technique of complete reduction and single-level circumferential fusion is a suitable alternative for surgical treatment of high-grade high dysplastic spondylolisthesis in children. It provides high fusion rates and favorable clinical results, including satisfactory aesthetic effect. Complications associated with complete reduction do not significantly exceed their number compared to other surgical techniques.

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Authors contributions

Jan Štulík and Zdeněk Klézl contributed to the study conception and design. Gábor Geri and Michal Barna collected radiographic and clinical data. All authors contributed to the analysis and interpretation of acquired data. Jan Štulík obtained administrative and technical support necessary for successful completion of the project. Jan Štulík and Gábor Geri were responsible for drafting of the first version of the manuscript. Finally, all authors read, reviewed and approved the final version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.bas.2022.100871>.

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