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Health-related quality of life and sagittal balance at two to 25 years after posterior transfixation for high-grade dysplastic spondylolisthesis

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Aims

High-grade dysplastic spondylolisthesis is a disabling disorder for which many different operative techniques have been described. The aim of this study is to evaluate Scoliosis Research Society 22-item (SRS-22r) scores, global balance, and regional spino-pelvic alignment from two to 25 years after surgery for high-grade dysplastic spondylolisthesis using an all-posterior partial reduction, transfixation technique.

Methods

SRS-22r and full-spine lateral radiographs were collected for the 28 young patients (age 13.4 years (SD 2.6) who underwent surgery for high-grade dysplastic spondylolisthesis in our centre (Scottish National Spinal Deformity Service) between 1995 and 2018. The mean follow-up was nine years (2 to 25), and one patient was lost to follow-up. The standard surgical technique was an all-posterior, partial reduction, and S1 to L5 transfixation screw technique without direct decompression. Parameters for segmental (slip percentage, Dubousset's lumbosacral angle) and regional alignment (pelvic tilt, sacral slope, L5 incidence, lumbar lordosis, and thoracic kyphosis) and global balance (T1 spino-pelvic inclination) were measured. SRS-22r scores were compared between patients with a balanced and unbalanced pelvis at final follow-up.

Results

SRS-22r domain and total scores improved significantly from preoperative to final follow-up, except for the mental health domain that remained the same. Slip percentage improved from 75% (SD 15) to 48% (SD 19) and lumbosacral angle from 70° (SD 11) to 101° (SD 11). Preoperatively, 35% had global imbalance, and at follow-up all were balanced. Preoperatively, 63% had an unbalanced pelvis, and at final follow-up this was 32%. SRS-22r scores were not different in patients with a balanced or unbalanced pelvis. However, postoperative pelvic imbalance as measured by L5 incidence was associated with lower SRS-22r self-image and total scores (p = 0.029).

Conclusion

In young patients with HGDS, partial reduction and transfixation improves local lumbosacral alignment, restores pelvic, and global balance and provides satisfactory long-term clinical outcomes. Higher SRS-22r self-image and total scores were observed in the patients that had a balanced pelvis (L5I < 60°) at two to 25 years follow-up.

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Introduction

L5 to S1 spondylolisthesis that develops at a young age can be progressive and is a common cause of low back pain in the adolescent population.[1] High-grade dysplastic spondylolisthesis (HGDS) is defined as a deformity of the lumbosacral junction in which L5 has slipped forward more than 50% on S1 with dysplastic features.[2-4] Dysplastic features are dysplasia of the posterior arch

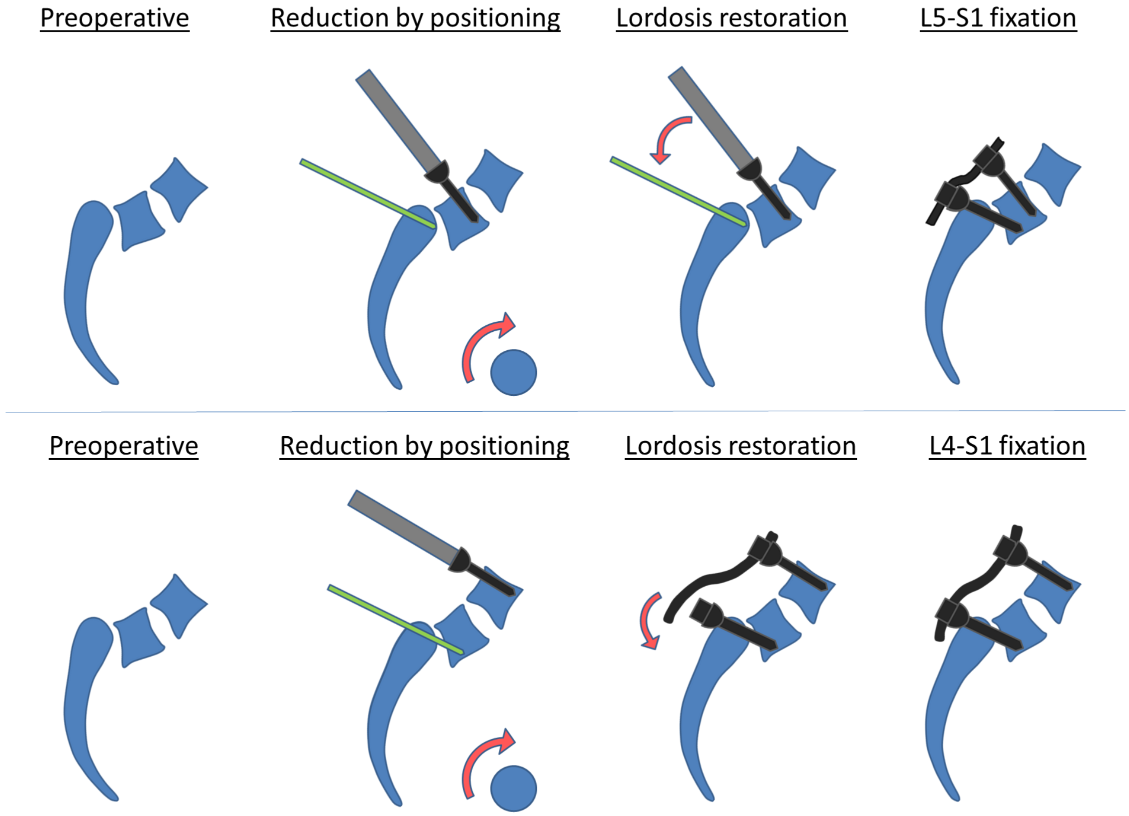

Fig. 1

Angular correction of lumbosacral kyphosis and improvement of the anterolisthesis of L5 over the sacrum by one Meyerding grade[2] is mostly achieved through prone patient positioning over the Montreal mattress. Transfixation from S1 into L5 is supplemented by stabilization to L5 (top) or L4 (bottom) to allow lordosis restoration and a solid fusion with the use of iliac crest bone.

of L5 or the sacrum, sacral doming, trapezoidal shape of L5, and high pelvic incidence.[5] Children with HGDS can present with symptomatic postural decompensation, scoliosis, back pain and/or lower-extremity radicular symptoms.[1]

The generally accepted goals of high-grade spondylolisthesis surgery in paediatrics are to relieve pain, resolve neurologic dysfunction, avoid olisthesis progression, restore postural balance, and improve self-image. Mac-Thiong et al[4,6,7] and the Spinal Deformity Study Group (SDSG) proposed a functional classification that intends to guide surgical treatment based on regional pelvic and global sagittal balance.[4,6,7] Complete restoration of pelvic balance has been advocated as the most important factor for optimal long-term health-related quality of life (HRQoL).[8]

Multiple spinal fusion techniques, as well as methods of reduction and restoration of alignment, have been described in the literature for surgical treatment of high-grade spondylolisthesis. The main differences are the approach used, degree of reduction, techniques used for stabilization (e.g. bone graft only, pedicle screws, transdiscal fibular allograft, interbody cages), and whether direct decompression of nerve roots was performed.[9] There is a need to evaluate the long-term HRQoL and spinal balance after specific techniques of corrective surgery for high-grade spondylolisthesis with limited risk of iatrogenic neurologic injury.

Since 1995, we have performed a partial angular correction technique, indirect decompression and bilateral transfixation pedicle screws via a posterior approach in young patients with HGDS. The aim of this study was to evaluate Scoliosis Research Society 22-item (SRS-22r) scores in relation to global, regional and local spino-pelvic sagittal balance at long-term follow-up after surgery for high-grade dysplastic spondylolisthesis using partial reduction, transfixation technique in a single paediatric institution.

Methods

Study population. This is a cohort of consecutive patients that were treated in the Scottish National Spine Deformity Service that covers all paediatric surgeries for high-grade spondylolisthesis. From 1995 to 2018, 28 patients aged between nine and 20 years (mean 13.3) underwent surgery for HGDS. Informed consent was obtained from all participants. All patients were invited for completing SRS-22r questionnaires and patients operated on before 2012 were also invited for lateral full-spine radiographs. Preoperative clinical charts were reviewed for presence/

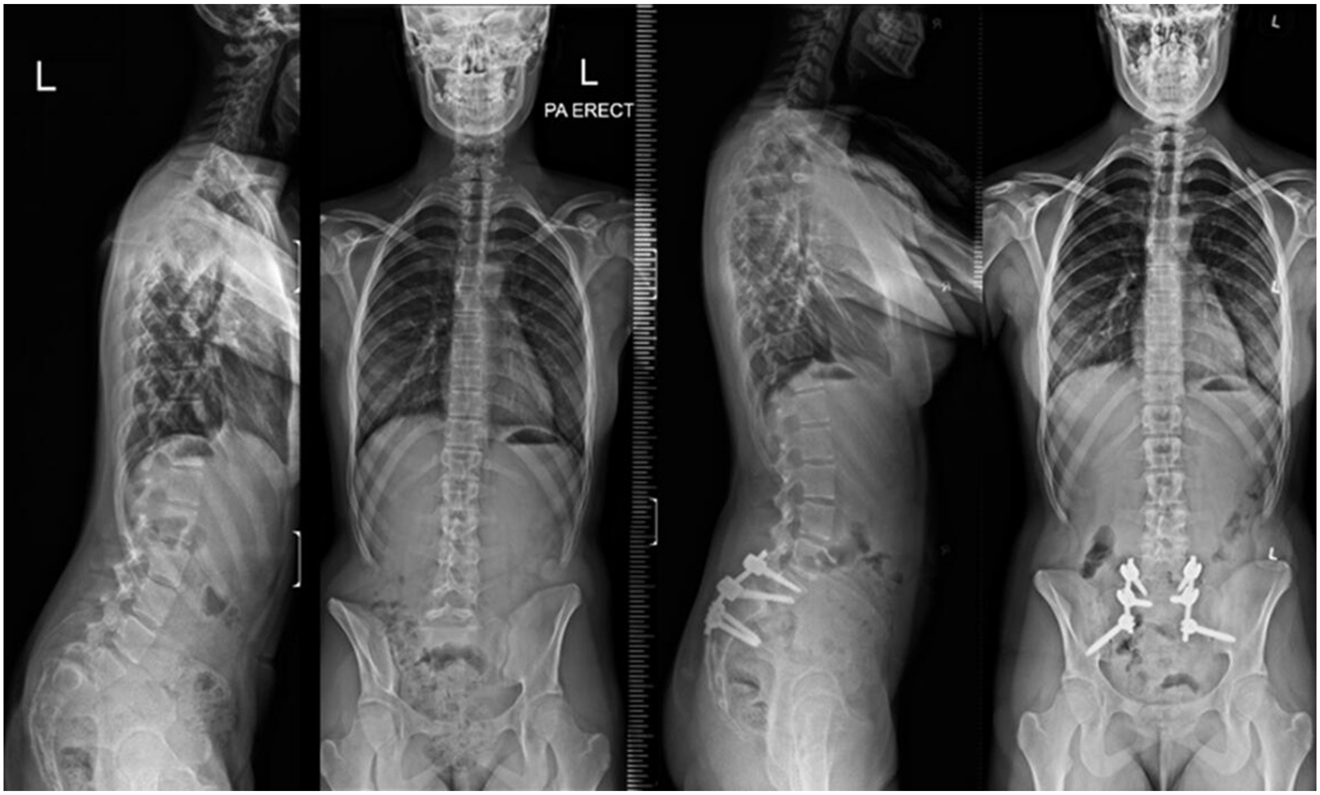

Fig. 2

Preoperative and postoperative full-spine radiographs of a 14-year-old girl who underwent partial reduction, transfixation and additional stabilization of the rods from L5 to the pelvis for a grade 3 dysplastic spondylolisthesis with preoperative global imbalance which was corrected after surgery.

absence of back or thigh pain, radicular pain, hamstring tightness, Phalen-Dickson gait, or forward stoop and abnormal neurological examination. Hamstring tightness was defined as documentation of presence or absence of tightness or a straight-leg-raise test < 60°. Presence of scoliosis, pars lysis, sacral doming, trapezoidal L5 morphology (anterior-posterior vertebral height index < 0.8), and laminar defects was analyzed.

Surgical technique. All patients underwent a posterior transfixation pedicle screw stabilization, which was our standard technique for paediatric and young adults with HGDS. Patients were positioned prone on a Montreal mattress with the hips in extension in order to antevert the sacrum and pelvis to indirectly reduce the lumbosacral kyphosis. The knees were flexed in order to reduce tension on the sciatic nerve. A Gill's type decompression was not performed in any of the patients.[10] Two patients underwent a hemilaminectomy for S1 nerve root compression due to central intrusion of a bifid lamina. Overall, 17 patients were instrumented proximally to L4, one to L3, and ten to L5 with the use of pedicle screws. When L5 pedicle screws were used, attention was taken to place them high in the pedicle to avoid breach into the foramina. Dissection anterior to the ala of the sacrum is essential to visualize the key landmark of the transverse process of L5. Further improvement of the lumbar lordosis was achieved through angular correction of the upper instrumented vertebra (UIV), by a cantilever of the L4 or L5 screws (Figures 1–3). 3.2 mm Steinmann's pins were placed converging approximately 20° via the S1 pedicles across the L5 to S1 disc space and into the anteroinferior body of L5. The starting point of the Steinmann pin has to be chosen as low as possible to avoid encroachment into the L5 foramen and allow firm purchase of the L5 vertebral body. The Steinmann's pins were then sequentially replaced by 60 mm to 70 mm long and 7 mm diameter transfixation screws. The indirect reduction by positioning and lordosis restoration maneuver were performed under fluoroscopic imaging. Care was taken not to over-distract the L5 to S1 disc space during final transfixation screw insertion as this can affect the already stretched L5 nerve roots.

Eight patients were additionally instrumented to the pelvis with traditional iliac screws. This was decided during surgery in order to secure distal stability of the construct. No interbody bone graft was placed. A bone gauge was used to lift a thin plate of bone from the sacral ala on both sides and this was hinged towards the transverse processes of L5 to create a bony bed for placement of the bone grafts. The decorticated posterolateral gutter was filled with cancellous iliac crest bone graft. Since 2008, patients with high-grade spondylolisthesis

Fig. 3

Preoperative and postoperative full-spine radiographs of a 14-year-old boy who underwent partial reduction, transfixation and proximal fixation of the rods to L4 for a grade 4 dysplastic spondylolisthesis with a globally balanced spine preoperative and at final follow-up.

were operated under intraoperative neuromonitoring (somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs), and electromyogram span (EMG) of the gastrocnemius and anal sphincter). Patients were mobilized from postoperative day one and received a soft lumbar brace at discharge for three months. Sports activities were restricted for six months to allow bone healing.

Health-related quality of life and clinical follow-up. All patients were invited to complete SRS-22r questionnaires. Furthermore, clinical charts were screened for complications during hospital stay or follow-up, the normalization of posture and resolution or development of new neurological symptoms post-surgery.

Radiological outcome parameters. Preoperative and most recent postoperative upright full-spine radiographs were collected and imported in Surgimap (Nemaris, USA) for further analyses by two of the authors (TS, EG). For four patients (14%), full-spine lateral radiographs were not available at follow-up, so their lateral lumbar radiographs were included instead. The radiological outcome parameters were:

- Segmental spino-pelvic alignment: Meyerding grade,[2] slip percentage, Dubousset lumbosacral angle (Dub-LSA).[11]
- Regional spino-pelvic alignment: pelvic tilt (PT), sacral slope (SS), pelvic incidence (PI), and L5 incidence (L5I).
- Global balance: T1 spinopelvic inclination (TISPI) and sagittal vertical axis (cm).
- Compensatory thoracolumbar mechanisms: level of apex of lordosis, level of inflection point between kyphosis and lordosis, lumbar lordosis (S1-inflection point and L1 to L5), and thoracic kyphosis (T4 to T12).

Patients were classified into pelvic and global balance/unbalance based on the criteria described by Hresko et al[4] and Seebaly et al;[12] Hresko et al differentiates pelvic balance based on the formula SS < or> 0.84*PT + 25, whereas Sebaaly et al[12] differentiate based on L5I < or> 60°.

Statistical analysis. SPSS 20.0 (SPSS, USA) was used for data analysis. Continues parameters were analyzed using mean and standard deviations. Mann-Whitney U test and Wilcoxon signed rank test were used to compare SRS-22r scores between preoperative and final follow-up and between patients with pelvic balance/unbalance at follow-up, respectively.

Results

Mean follow-up was 8.9 years (2 to 25). Demographics, as well as preoperative clinical and radiological characteristics, are shown in Table I. SRS-22r was introduced in 2012 and therefore was available for 12 patients

Table I. Patient demographics.

Variable	Data (n = 28)
Age, years, mean (SD); range	13 (3); 9 to 20
Females, %	75
Preoperative clinical status (n = 24 to 27), %	
Back or thigh pain	100
Radicular pain	30
Incontinence (anamnestic)	0
Thight hamstrings	75
Phalen-Dickson gait or forward stoop	63
Sensory deficit (numbness, anamnestic)	12
Motor deficit (objective, examination)	15
Abnormal Achilles tendon reflex	23
Preoperative radiological characteristics (n = 26), %	
Risser 0 or 1	64
Scoliosis	54
Preoperative supine CT (n = 14), %	
Bilateral lysis/bilateral intact pars	86/14
Sacral doming	100
L5 lumbar index < 0.8	100
Laminar defect L5 or S1	86
Slip percentage, n (SD)	46 (12)

SD, standard deviation.

Table II. Scoliosis Research Society 22-item domain scores preoperative and at final follow-up.

SRS-22r score	Preoperative, mean (SD)	Follow-up, mean (SD)	p-value†
Function	3.5 (0.8)	4.4 (0.6)	0.003*
Pain	3.2 (0.9)	4.2 (0.7)	0.002*
Self-image	3.5 (0.7)	4.2 (0.8)	0.002*
Mental health	4.2 (0.6)	4.1 (1.0)	0.530
Satisfaction	4.2 (0.8)	4.7 (0.6)	0.043*
Total	3.7 (0.6)	4.3 (0.6)	0.002*

*Statistical significance p < 0.05.
†Mann-Whitney U test.
SD, standard deviation; SSr2, Scoliosis Research Society 22-item score.

preoperatively, and 27 patients at final follow-up. One patient was lost to follow-up.

Clinical outcomes. Preoperative and follow-up SRS-22r domain and total scores are shown in Table II. SRS-22r domain and total scores improved significantly from preoperative to final follow-up, except for the mental health domain. Hamstring contracture resolved and a normal gait was established up to 12 months post-surgery. Two patients (7%) had an early wound infection and were treated with oral antibiotics. For all patients with preoperative radicular symptoms, their symptoms resolved postoperatively. Three patients (10%) developed a transient unilateral L5 radiculopathy (one motor (EHL weakness MRC 3/5), two sensory) after surgery that resolved within six weeks. One (4%) 15-year-old girl with spondyloptosis and radicular pain that was severely disabled and wheelchair bound by pain underwent an initial L4/S1 transfixation. She developed acute pain and urinary retention on postoperative day four. Urgent CT and MRI demonstrated a horizontal sacral fracture (insufficiency fracture), for which she underwent an emergency midline and foraminal decompression L5-S1, as well as extension of the instrumentation to the pelvis. She recovered to normal neurological and bladder function after urinary diversion for five months. The same patient underwent repeat posterorolateral bone grafting (4%) two years postoperative to reinforce the fusion mass. There were no detected nonunions. Eight patients underwent spinal CT during follow-up. All demonstrated adequate posterolateral fusion, and six (75%) also showed extensive anterior interbody fusion around the transfixation screws (Figure 4). One (4%) patient underwent revision for iliac screw malposition. Five (18%) patients underwent implant removal during follow-up due to symptoms caused by local prominence of the transfixation (n = 3) or iliac screws (n = 2). None of the scolioses required treatment.

Radiological outcomes. All local, regional, and global alignment parameters improved significantly from preoperative to final follow-up, except for the lumbar lordosis (Table III). Lumbar lordosis improved from 64° (SD 19) to 77° (SD 10) but this did not reach statistical significance. The inflection point and apex of lumbar lordosis shifted to more caudal levels (from T9 to T11 and from L2 to L3 respectively), and the compensatory thoracic hypokyphosis corrected from 13° (SD 13) to 27° (SD 12). 63% of patients had a preoperative unbalanced pelvis using PT/SS ratio and 79% using L5I; at final follow-up 32% and 24% were unbalanced, respectively. Only 65% of patients had global balance preoperative with all being globally balanced at follow-up. There were no significant differences in correction of slip percentage and Dubousset lumbosacral kyphosis (Dub-LSK), as well as SRS-22r scores between patients with different ages, follow-up duration, or fused to L4 compared to L5. Comparison of SRS-22r scores between patients with a balanced and unbalanced pelvis at follow-up according to the criteria of Hresko et al,[4] showed no significant differences for any of the SRS-22r domains (Table IV). Comparison of SRS-22r scores according to the L5I, showed significantly higher self-image and total SRS-22r scores for patients with a balanced pelvis at follow-up (p = 0.029, Wilcoxon signed rank test, Table IV).[12] Additional correlation analysis between L5I, PT, and the other sagittal parameters are shown in Table V.

Discussion

While there are various surgical techniques for treatment of high-grade spondylolisthesis, their effectiveness in terms of restoring sagittal balance, as well as improving quality-of-life remain largely unknown. In this study, we investigated the impact of pelvic and global balance on HRQoL after HGDS surgery using a transfixation technique.[13,14] We presented a consecutive

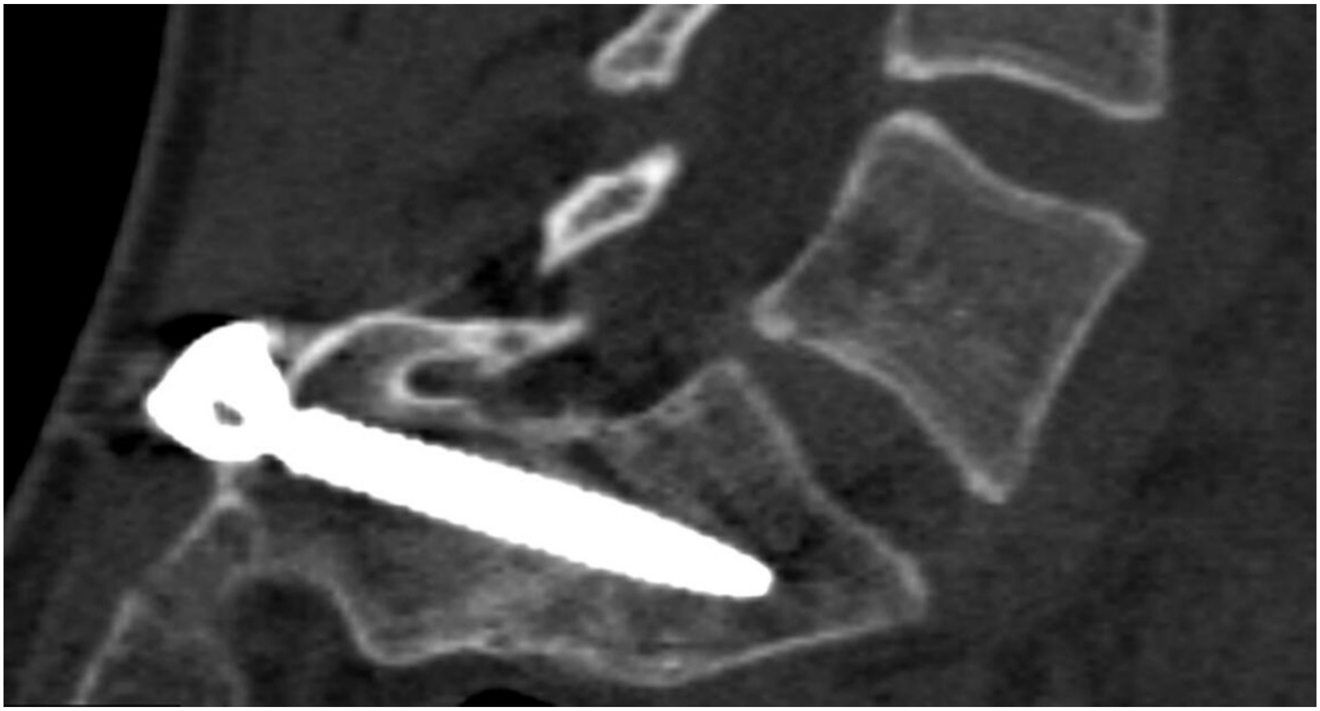

Fig. 4
Sagittal CT reconstruction showing anterior interbody fusion around a S1-L5 transfixation screw.

Table III. Local, regional, and global sagittal parameters preoperative and at follow-up.

Variable	Preoperative, mean (SD); range	Follow-up, mean (SD); range	p-value*
Lumbosacral parameters			
Slip percentage	75 (15); 50 to 100	48 (19); 9 to 81	< 0.001
Dub-LSA,°[11]	70 (11); 50 to 88	101 (11); 84 to 125	0.004
Regional spinopelvic parameters			
Pelvic tilt, percentage	32 (8); 17 to 51	28 (7);13 to 43	0.023
Sacral slope	43 (10); 26 to 60	55 (10); 28 to 73	< 0.001
Pelvic incidence	76 (9); 50 to 92	84 (SD 9); 67 to 101	0.006
L5 incidence[12]	70 (14); 42 to 95	52 (15); 27 to 86	< 0.001
Level of inflection point	T9 (1.4); T6 to T12	T11 (1.0); T9 to T12	< 0.001
Level of apex of lordosis	L2 (1.24); T10 to L3	L3 (0.6); L2 to L4	0.001
Lumbar lordosis (L1 to L5),°	66 (SD 16); 35 to 94	62 (SD 11); 46 to 84	0.300
Lordosis (S1-inflection point)	64 (SD 19); 34 to 105	77 (SD 10); 59 to 93	0.641
Thoracic kyphosis (T4 to T12)	13 (SD 13); 9 to 48	27 (SD 12); 0 to 44	0.001
Pelvis balanced (PT/SS ratio) %[4]	37	68	
Pelvis balanced (L5 incidence), %[12]	21	76	
Global spinopelvic parameters			
T1 spinopelvic angle	-2 (7); -13- to +15)	-6 (3); -10 to 0	0.039
Sagittal vertical axis, cm	+ 4.9 (6.4); -4.8 to +20	0.7 (1.6); -1.5 to 4	0.009
Global spinal balance, %[4]	65	100	

*Mann-Whitney U test.
Dub-LSA, Dubousset lumbosacral angle; SD, standard deviation.

series of 28 patients with HGDS over a study period of 25 years treated at a national centre, in which only the transfixation technique was used for all patients. While there are previous studies on the results of uninstrumented techniques or mixed instrumentation techniques (Table VI), this is the first series that describes the radiological results, as well as SRS outcome scores of a single instrumentation technique performed for HGDS in adolescent and young adults treated over the last 25 years in a national spinal deformity service. The limitations, however, are that preoperative full-spine radiographs and SRS-22r scores were only available from

Table IV. Scoliosis Research Society 22-item domain scores preoperative and at follow-up for patients with a balanced and unbalanced pelvis at follow-up, according to Hresko et al[4] and Seebaly et al.[12]

	PT/SS ratio			L5 incidence		
Measure	Balanced pelvis (n = 17), mean (SD)	Unbalanced pelvis (n = 8), mean (SD)	p-value†	Balanced pelvis (n = 19), mean (SD)	Unbalanced pelvis (n = 6), mean (SD)	p-value†
Function	4.3 (0.7)	4.5 (0.6)	0.60	4.3 (0.7)	4.5 (0.4)	0.640
Pain	4.2 (0.8)	4.2 (0.6)	0.63	4.2 (0.8)	4.1 (0.6)	0.500
Self-image	4.2 (0.9)	4.3 ± 0.7	0.97	4.4 (0.8)	3.7 (0.5)	0.029*
Mental health	3.9 (1.0)	4.4 (0.6)	0.43	4.2 (0.8)	3.7 (1.2)	0.401
Satisfaction	4.7 (0.8)	4.8 (0.3)	0.72	4.7 (0.8)	4.7 (0.3)	0.316
Total	4.2 (0.7)	4.3 (0.5)	0.65	4.3 (0.7)	4.1 (0.4)	0.029*

*Statistical signficance p < 0.05.
†Wilcoxon signed rank test.
PT, pelvic tilt; SD, standard deviation; SS, sacral slope.

Table V. Correlations between the L5 incidence, pelvic tilt, and the other local and regional sagittal parameters of the spine and pelvis.

Parameter	L5 incidence,°	p-value†	Pelvic tilt,°	p-value†
Slip percentage	0.30	N/S	0.23	N/S
Dub-LSA, °[11]	-0.27	N/S	-0.34	N/S
Pelvic tilt	0.51	0.009*	N/A	N/A
Sacral slope	0.35	N/S	-0.31	N/A
Pelvic incidence	0.71	< 0.001*	0.49	0.014*
L5 incidence[12]	N/A	N/A	0.51	0.009*
Level of inflection point	-0.41	0.047*	0.19	N/S
Level of apex of lordosis	-0.60	0.002*	-0.32	N/S
Lordosis (S1 to inflection point)	0.35	N/S	0.09	N/S
Thoracic kyphosis (T4 to T12)	-0.46	0.019*	0.17	N/S

**Statistical signficance p < 0.05.
†Pearson's correlation.
Dub-LSA, Dubousset lumbosacral angle; N/A, not applicable; N/S, not significant.

2012, and that the range of duration of follow-up is two to 25 years.

Compensatory postural mechanisms to accommodate for the lumbosacral kyphosis in HGDS in children include postural adaptations such as a long lumbar lordosis, thoracic hypokyphosis, pelvic retroversion, knee flexion and tiptoeing. In all, 18 (64%) of our population presented with clinical postural decompensation (Phalen-Dickson gait or forward stoop). Radiologically, 18 (64%) had an unbalanced pelvis and ten (35%) had global sagittal imbalance. Operative reduction has been recommended for patients with high-grade spondylolisthesis and global or pelvic imbalance.[8]

The need for reduction remains controversial. Results of previous studies reporting on HRQoL after surgery for high-grade spondylolisthesis in pediatrics are shown in Table VI. Helenius et al[21] and Joelson et al[21,22] reported clinical and radiological long-term results after in situ fusion of high-grade spondylolisthesis in young patients. They observed excellent outcomes in terms of function and pain domain scores, but lower self-image scores (mean 3.5 (SD 0.8)) than age- and sex-matched controls (4.3 (SD 0.51)) or compared to patients treated for adolescent idiopathic scoliosis (4.8 (SD 0.9)). While in situ fusion for high-grade isthmic spondylolisthesis is considered a safe and effective treatment option in the long-term, it requires prolonged postoperative immobilization in a brace or spica cast. Additional concerns are increased nonunion rates, olisthesis progression, and persistence of lumbosacral kyphosis.[23] In the series of Joelson et al,[19] three decades after in situ fusion 79% remained with an unbalanced pelvis and 11% with global sagittal imbalance. Interestingly, in this long-term study, no association between postoperative pelvic imbalance and long-term SRS-22r total scores (excluding the satisfaction domain) was observed.

The long-term benefit of sagittal balance has been the rationale for the use of reduction techniques. In the classification of the SDSG, it is suggested that surgical reduction is indicated in case of pelvic or global imbalance (based on low SS-high PT and the T1SPA < 0° respectively).[4] Reduction techniques do not always lead to improved sagittal alignment while they increase the risk of neurological deficits. The largest multicentre study (n = 61) reported that 39% of patients with an unbalanced pelvis were restored to a balanced pelvis, while 61% stayed unbalanced. Interestingly, 24% of the previously balanced patients became unbalanced postoperatively.[8] In the present study, 35% of patients had preoperative global sagittal imbalance. At average final follow-up of 8.9 years after transfixation and posterior stablization, all patients maintained global balance. Correction of lumbosacral kyphosis and improvement of anterolisthesis of L5 on S1 by one Meyerding grade have been achieved through positioning our patients prone with the hips in extension. This allowed anterior pelvic tilt and improvement of the position of S1 in relation to L5. Further improvement of the lordosis was achieved through angular correction of the UIV. The selection of L4 or L5 as the UIV did not affect the radiological correction of spinopelvic parameters or the SRS-22r scores. Pelvic balance was restored in 57% of patients with an

Table VI. This table summarizes the results of different case series reporting on clinical outcomes after high-grade spondylolisthesis surgery, using the Scoliosis Research Society 22-item, 24-item, or 30-item instrument.

Authors, year of publication	Age, yrs, range	No.	Surgical technique	Mean follow-up, yrs	Complications, n (%)	Neurological complications, total/permanent, n (%)	Nonunion, n (%)	Reoperations, n (%)	HRQoL instrument	Outcomes, mean (SD)
Smith et al, 2001[15]	8 to 52	9	Transfixation with fibular strut graft	3.6	10 (111)	2 (22)/0 (0)	2 (22)	2 (22)	SRS-22	Function 3.6 Pain 3.5 Self-image 3.6 Mental health 3.7 Satisfaction 4.6
Boachie-Adjei et al, 2002[16]	13 to 29	6	Posterior pedicle screw transfixation with direct decompression	3.6	3 (50)	3 (50)/0 (0)	0 (0)	0 (0)	SRS-24	General function 4.5 Postop function 4.2 Pain 4.3 General self-image 4.0 Postop self-image 4.5 Satisfaction 4.5
Helenius et al, 2006[17]	8 to 19	21	Posterolateral in situ fusion	21.7	3 (14)	4 (19)/0 (0)	0 (0)	5 (24)	SRS-24	Total score 3.7 (0.6), Appearance 4.0 (0.7)
		23	Anterior in situ fusion	14.0	5 (22)	0 (0)/0 (0)	3 (13)	1 (4)	SRS-24	Total score 3.8 (0.6) Appearance 4.4 (0.9)
		26	Circumferential in situ fusion	16.3	3 (12)	0 (0)/0 (0)	1 (4)	5 (19)	SRS-24	Total score 4.2 (0.4) Appearance 4.1 (0.8)
Lundine et al, 2014[18]	8 to 17	34	Uninstrumented in situ fusion w, w/o fibular strut grafting, Anterior interbody fusion, Instrumented in situ fusion, Instrumented fusion with reduction, Instrumented fusion with reduction and interbody grafting, L5 corpectomy.	7.5	N/R	N/R/ 3 (9)	4 (12)	11 (32)	SRS-30	Function 4.0 (0.8) Pain 4.2 (1.1) Self-image 3.7 (0.7) Mental health 4.0 (0.8) Satisfaction 4.2 (0.7)
	8 to 17	15	Untreated	7.6	N/R	N/R	N/R	N/R	SRS-30	Function 4.0 (0.4) Pain 4.2 (0.4) Self-image 3.7 (0.5) Mental health 4.3 (0.5) Satisfaction 4.2 (0.6)
Mac-Thiong et al 2019[8]	8 to 21	61	One uninstrumented in situ fusion, 36 PLIF/TLIF interbody fusion, seven transfixation screws/transfixating cage, three transfixation pedicle screws	2.3	14 (23)	7 (11)/2 (3)	0 (0)	4 (7)	SRS-22	Function 4.3 (0.5) Pain 4.0 (0.8) Self-image 4.2 (0.8) Mental health 4.2 (0.8) Satisfaction 4.5 (0.9)

Continued

Table VI. Continued

Authors, year of publication	Age, yrs, range	No.	Surgical technique	Mean follow-up, yrs	Complications, n (%)	Neurological complications, total/permanent, n (%)	Nonunion, n (%)	Reoperations, n (%)	HRQoL instrument	Outcomes, mean (SD)
Joelson et al., 2014 and 2019[19,20]	9 to 24	38	Uninstrumented in situ fusion	34	9 (26)	2 (6)/0 (0)	0 (0)	1 (3)	SRS-22r	Function 4.3 (0.8) Pain 4.1 (1.0) Self-image 3.5 (0.8) Mental health 4.1 (0.7) Satisfaction 4.0 (0.9)
Present study	9 to 20	28	Posterior pedicle screw transfixation	8.9	12 (43)	3 (10)/0 (0)	0 (0)	7 (25)	SRS-22r	Function 4.4 (0.6) Pain 4.2 (0.7) Self-image 4.2 (0.8) Mental health 4.1 (1.0) Satisfaction 4.7 (0.6) Total 4.3 (0.6)

unbalanced pelvis, and only one patient (11%) became unbalanced. Furthermore, we observed that the spinal profile changed to a more physiological shape: From preoperative to final follow-up, the inflection point from thoracic kyphosis to lumbar lordosis migrated two levels caudal, the apex of the lordosis one level, the PT and L5I decreased, while SS and TK increased significantly. Local lumbosacral kyphosis improved by 31°, comparable to previous series.[24]

SRS-22r is a validated HRQoL questionnaire for spondylolisthesis, but the impact of pelvic imbalance on HRQoL is unknown in preoperative patients.[25] Mac-Thiong et al[8] reported significant correlations between postoperative pelvic imbalance and lower SRS-22r self-image and satisfaction scores. When pelvic balance was assessed using the formula provided by Hresko et al,[4] we did not observe differences in SRS-22r self-image scores between the patients. In agreement with previous reports, PT decreased on average only 4° postoperatively, and most of the alignment changes occurred in the spine. As an alternative, L5I was introduced by Roussouly et al[26] which captures the reorientation of L5 relative to the femoral heads. Based on L5I < 60°, we observed significantly higher SRS-22r self-image (4.4 (SD 0.8)) and total scores in patients with a postoperative balanced pelvis compared to unbalanced (3.7 (SD 0.5), p = 0.029).[12] PT changes 2 to 4° from preoperative to post-surgery, therefore, L5I might be a better parameter to measure postoperative alignment changes as compared to the PT/SS ratio described by Hresko et al[4] Lower L5I correlated significantly with thoracic kyphosis and a lower inflection point. PT did not show a relationship with the measured spinal parameters (Table V). Therefore, the reciprocal spinal changes could be related to the improved SRS-22r self-image scores.

The major concern for reduction is iatrogenic neurological risk. The morbidity and mortality report by the Scoliosis Research Society demonstrated a neurological complication rate of 12% (n = 23) among 229 patients in whom reduction was attempted for low- or high-grade spondylolisthesis.[27] Partial olisthesis correction (< 50%) has been advocated by Petraco et al[28] to reduce the risk of tension radiculopathy. Furthermore, Longo et al[29] showed in a recent meta-analysis of eight studies no greater risk of neurological deficit when reduction is attempted, but they did not differentiate between temporary or permanent neurological deficit. We performed on average angular correction of the lumbosacral kyphosis of 31° and olisthesis correction of 27%, and observed a similar rate of radicular deficits (10%). The deficits, however, resolved within six weeks postoperative. Among the previous studies that described postoperative complications and HRQoL, only permanent radicular deficits were reported for studies including anterior interbody devices and sacral dome resections (Table VI).

The angular reduction and transfixation led to satisfactory long-term clinical outcomes in this series with no recorded nonunions. As we did not routinely perform neural decompression, posterior fusion was sufficient to achieve stabilization of the lumbosacral junction with the use of iliac crest autograft and without the need for additional anterior fusion (Figure 4). Compared to circumferential or interbody fusion techniques, we consider it as relatively simple and safe. As disadvantages of the presented surgical technique, we consider the high rate of instrumentation removal for local prominence (18%). The flexibility of the spondylolisthesis in our series of young patients is reflected in a 27% difference in slip percentage between preoperative standing radiographs and supine CTs. The correction possibilities in adults in whom the high-grade spondylolisthesis is fixed due to less lumbosacral flexibility needs to be studied. PI increased 10° in patients instrumented to the sacrum, whereas PI remained unchanged in patients instrumented to the pelvis. Both groups had the same amount of lumbosacral correction (30° increase of the Dub-LSA, 27% decrease in slip percentage). PI is a sagittal pelvic morphology parameter, describing the sagittal orientation and position of the sacral plate within the pelvic ring. Because the PI further increased when the SI-joints were not stabilized by instrumentation, we hypothesize that the SI joints can further rotate or remodel into pelvic kyphosis when they are left uninstrumented, but this has no recorded effect in segmental spino-pelvic balance.

In conclusion, in young patients with HGDS, the partial reduction and transfixation with posterior instrumentation and posterolateral bone graft can improve local lumbosacral alignment and restores pelvic and global balance with reliable fusion. The lumbosacral kyphosis correction led to an improved sagittal profile with increase in thoracic kyphosis and a lower inflection point. Significantly higher SRS-22r self-image and total scores were observed in the patients that had a balanced pelvis (L5I < 60°) at two to 25 years follow-up. The clinical relevance of correction of L5I needs further investigation.

Take home message

- There is a need to evaluate the long-term health-related quality of life and spinal balance after specific techniques of corrective surgery for high-grade dysplastic spondylolisthesis.
- Partial reduction and transfixation can improve local lumbosacral alignment and restores pelvic and global balance with reliable fusion in young patients with high-grade dysplastic spondylolisthesis.
- Significantly higher Scoliosis Research Society 22-item self-image and total scores were observed in the patients that had a balanced pelvis (L5I < 60°) at two to 25 years follow-up.

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