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ORIGINAL ARTICLE

Radiological and functional outcomes of high-grade spondylolisthesis treated by intrasacral fixation, dome resection and circumferential fusion: a retrospective series of 20 consecutive cases with a minimum of 2 years follow-up

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Abstract

Purpose Major concern during surgery for high-grade spondylolisthesis (HGS) is to reduce lumbosacral kyphosis and restore sagittal alignment. Despite the numerous methods described, lumbosacral fixation in HGS is a challenging technique associated with high complication rate. Few series have described outcomes and most of the results are limited to lumbosacral correction without global sagittal alignment analysis. This study aims at analyzing clinical and radiological outcomes of HGS patients treated with intrasacral rods on full spine radiographs.

Methods HGS patients (Meyerding III or higher) operated between 2004 and 2014 were reviewed. All patients underwent full spine stereoradiographic images. After L5 and S1 decompression, reduction and circumferential fusion with intrasacral rod fixation and fusion up to L4 were performed under fluoroscopy. The entry points for S1 screws were located 3–5 mm above and 5 mm lateral to the first sacral hole, toward the promontory. The two short distal fusion rods were then positioned into the sacrum guided by anteroposterior fluoroscopy using Jackson's technique. Then, sacral dome resection was performed and a PEEK cage was impacted in L5S1 after reduction. Postoperatively, the hip and knee were kept flexed at 45° for 1 week and extended progressively. Preoperative, 3 months postoperative and last follow-up (> 2 years minimum) clinical and radiographic data were collected. Sagittal parameters included lumbosacral angle (LSA), olisthesis, T1 spinopelvic inclination (T1SPi) and spinopelvic parameters.

Results 20 HGS patients were included (8 ptosis, 5 Meyerding IV). The mean age was 14 years. At final FU (7.2 years ± 3), LSA kyphosis and olisthesis were reduced (65° ± 14 vs 99° ± 11, $p < 0.001$ and 81% ± 19 vs 45% ± 18, $p < 0.001$, respectively). While L1L5 lordosis decreased, T1T12 kyphosis increased. At FU, global alignment with T1SPi was − 6° ± 3. No significant loss of correction was observed. Regarding complications, ten patients presented transient L5 motor deficit that occurred when patients were put in standing position. However, all recovered before 3 months postoperatively.

Conclusion Intrasacral rod fixation appears to be an effective technique to correct LSA kyphosis, compensatory hyperlordosis and restore global sagittal alignment with a postoperative T1SPi corresponding to the value of the asymptomatic subject and achieve fusion. However, it remains a demanding technique with high risk of transient neurologic complications.

Keywords High-grade spondylolisthesis · Sagittal alignment · Lumbosacral kyphosis · Neurologic deficit · Surgical complications

Introduction

Pediatric patients with high-grade spondylolisthesis (HGS) often present with severe low back and radicular pain, associated with lumbosacral kyphosis and subsequent sagittal malalignment. To maintain their balance, some patients develop a compensatory hyperlordosis with thoracic flattening, while others do not compensate and have anterior

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sagittal shift [1, 2]. Dubousset et al. described that HGS with lumbosacral kyphosis had global sagittal malalignment with pelvic retroversion and long lumbar lordosis to compensate for anterior malalignment [3].

Controversy still exists about the optimal surgical technique. On one hand, some authors described no need to reduce lumbosacral kyphosis and recommended in situ fusion [4]. On the other hand, others demonstrated the importance of lumbosacral deformity correction to restore sagittal alignment, prevent future disorders and poor patient outcomes in adulthood [5]. Indeed, long-term outcomes seem to be better in case of reduction [6, 7]. Therefore, a major concern during surgery for high-grade spondylolisthesis is to reduce lumbosacral kyphosis and restore sagittal alignment. In view of adults' spinal deformity literature, associated objectives are obtaining good fusion and sparing L5 roots with decompression. Despite the numerous methods described for lumbosacral fixation (with or without circumferential fusion), HGS surgical treatment is a challenging technique due to small dysplastic pedicles, nerve root stenosis and the need for a strong pelvic fixation due to the high stress applied during daily activities, especially in active adolescents, at the lumbosacral junction. Indeed, HGS surgery is associated with high pre- and postoperative complication rate ranging from 30 to 70% [8–11]. The most common postoperative complications such as implant failure, pseudarthrosis and loss of lumbosacral lordosis are mainly due to important loads in the lumbosacral area, the leverage applied on screws during reduction and poor sacral bone quality. In the 1990s, the intrasacral fixation technique was developed and responded to these goals. As reported in two studies, this sacral fixation provided a good stability and a strong power of reduction with promising results [12, 13].

Literature is sparse regarding HGS surgical outcomes and the few series available are usually limited in number (i.e., less than 15 on average) and do not provide long-term outcomes [11, 14]. Moreover, most of the studies are limited to segmental analysis and do not include global sagittal alignment [15]. The current study aims to describe long-term clinical and radiological outcomes of HGS patients treated with intrasacral rod fixation. We hypothesized that intrasacral fixation allows restoration of lumbopelvic sagittal parameters in high-grade spondylolisthesis, with indirect effect on proximal adjacent curves and global alignment.

Materials and methods

Patients

In this retrospective single center study, all patients operated for L5–S1 HGS (Meyerding grade III or higher) between 2004 and 2014 by one of the two senior spine surgeons were included, following institutional review board approval. A minimum 2-year follow-up was required. All patients were evaluated before surgery, in the early postoperative period (3 months) and at the last follow-up. None of the patients had prior spinal surgery.

Radiographic measurements

All patients underwent low-dose biplanar radiographs using the EOS system (EOS imaging, Paris, France), as previously described [16, 17]. Parameters assessed in the sagittal plane were L1S1 lumbar lordosis (LL), T1T12 and T4T12 thoracic kyphosis (TK) and the lumbosacral angle (LSA), measured between the superior endplate of L5 and the line tangent to the posterior edge of the sacrum [3, 18]. Slip was graded according to Meyerding's classification [19]. Pelvic parameters included pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS). Global sagittal alignment was assessed using the T1 spinopelvic inclination (T1SPi, angle between the vertical reference line and the line joining the center of the T1vertebral body with the middle of the bicoxo-femoral axis) and sagittal vertical axis (SVA, offset in mm between the C7 plumb line and the postero-superior corner of the sacrum) [15] (Fig. 1).

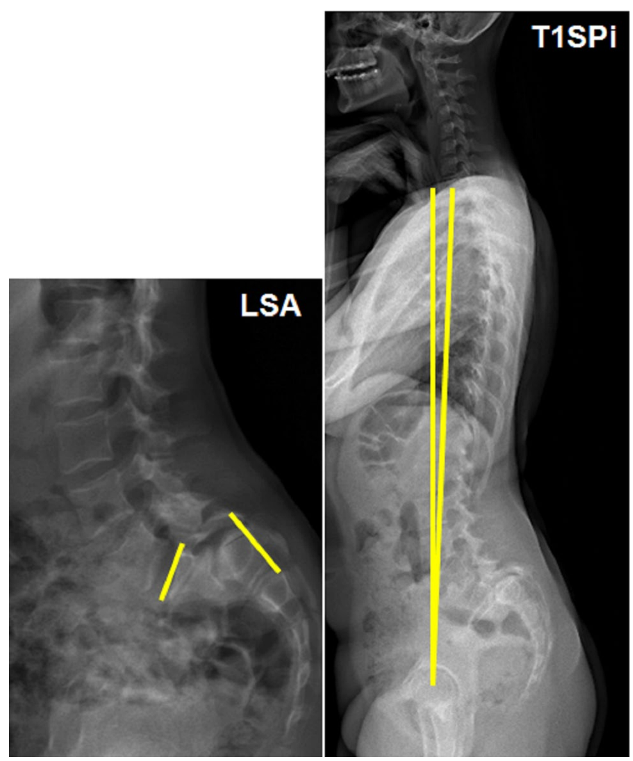

Fig. 1 Sagittal parameters: T1 spinopelvic inclination (T1SPI) and lumbosacral angle (LSA)

Surgical procedure

The operative strategy was similar in all procedures. Reduction and circumferential fusion with intrasacral rod fixation were performed under fluoroscopy. Patients were operated in the prone position, on a radio transparent carbon frame table. A single posterior approach was performed, exposing L4–S2 and both sacroiliac joints laterally. The first step of the technique was the L5 laminectomy with L5 and S1 nerve root decompression. Second, two sacral screws were inserted, using a modified version of Jackson's original technique [13, 20]. The entry points were located 3–5 mm above and 5 mm lateral to the first sacral hole. K-wires were introduced in the direction of the promontory (under fluoroscopy), to allow stronger fixation of two cannulated screws. Third, two short distal fusion rods were then positioned into the sacrum, through sacral screws, guided by anteroposterior fluoroscopy using Jackson's technique (Fig. 2). They were introduced beyond the sacral screws into the lateral sacral masses distally to the level of S3, creating an ''iliac buttress'' for the distal end of the rods that helps resist the loads across the lumbosacral junction and the two rods were linked by a transverse connector. Once the extent of rod insertion was considered satisfactory, their position was locked in the sacral pedicle screws. Then, two sublaminar bands (Jazz, Implanet, Bordeaux, France) were passed under the L4 lamina to enhance the resistance to pullout of the pedicle screws and to help in the reduction. After sacral dome resection (Fig. 3), lumbosacral kyphosis was reduced by rotating the sacrum in the sagittal plane and rods were locked in L4 screws (Fig. 4). Additional lordosis was performed by in situ bending. Finally, two cages with autologous bone graft were inserted in the L5S1 disc space (Capstone, PLIF posterolateral interbody fusion, Medtronic). Fusion was also obtained using posterolateral bone graft.

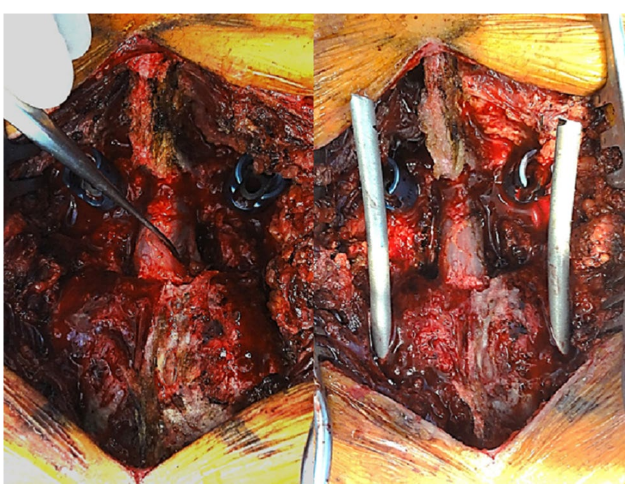

Fig. 2 Surgical procedure: intrasacral rod fixation

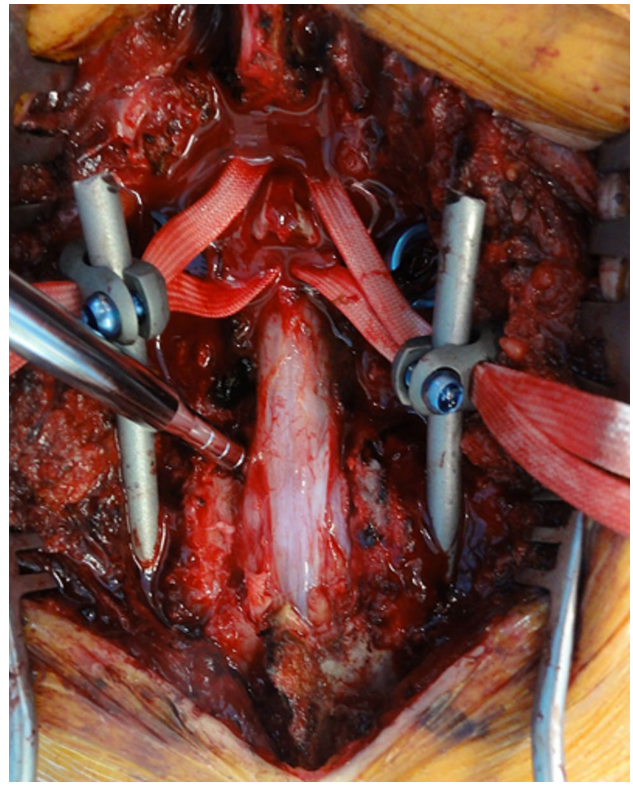

Fig. 3 Surgical procedure: dome resection

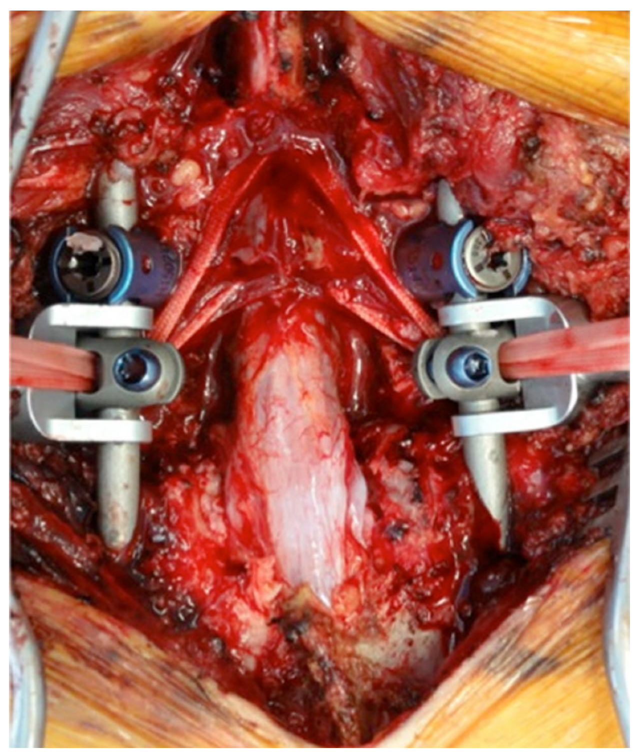

Fig. 4 Surgical procedure: reduction maneuver with L4 sublaminar band tensioning

After surgery, patients were positioned with the knee and hip flexed at 45°. Extension was performed progressively over a week's period. Patients were also protected by a brace for 6 months, postoperatively. To avoid early mechanical failure, the sitting position was forbidden for the first week and patient was installed with hip and knee with 45° flexion. Then, until the third postoperative month, the sitting position was allowed with a brace limiting hip flexion to 45° maximum. After 3 months, free sitting position was possible.

Statistical analysis

Statistical analysis was performed with Stata version 12.0 (Statacorp LP, Lakeway Drive, College Station, Texas). First, a descriptive analysis of the cohort was performed in terms of demographic, clinical and radiographic data. Then, pre- and postoperative radiographic parameters were compared. Third, the correlations between clinical, radiographic and surgical parameters were investigated. Normal distribution was assessed with Shapiro–Wilk test, and parametric or non-parametric tests were used as appropriate. A p value less than 0.05 was considered as significant.

Results

Preoperative descriptive analysis

Twenty patients with HGS were included: 8 ptosis, 5 grade IV and 7 grade III. The mean follow-up was 7.2 ± 3 years. There were 18 females and 2 males with a mean age of 14.4 ± 4 years. Preoperatively, eight patients had low back pain (LBP), two patients had sciatica and ten patients presented with both LBP and sciatica. Among the 12 patients with sciatica, 6 had bilateral radiculalgia, 2 had L5 deficit and 1 had bowel bladder deficit. Of note, 4 of the 20 patients had olisthesic scoliosis (average Cobb angle below 15°).

The mean preoperative L5 slip and lumbosacral kyphosis were 84% ± 19 and 63° ± 14, respectively. As expected, mean PI was high (67° ± 9). Mean LL was 64° ± 8 and mean TK was 27° ± 10. There was a pelvic retroversion of 29° ± 6. In terms of global sagittal alignment, SVA was 23 mm ± 20 and T1SPi was − 3° ± 5 (Table 1). SVA larger than 25 mm was observed in 11 patients with anterior malalignment.

Postoperative correction

The postoperative radiographic parameters are summarized in Table 2. Lumbosacral kyphosis and L5 slip were significantly improved by the procedure (respectively, 34° and 40% on average). As expected, lumbosacral kyphosis correction was associated with a postoperative increase in sacral slope (+ 7° ± 18, $p = 0.01$) and a decrease in pelvic tilt (− 4° ± 16, $p = 0.1$). While maximal lumbar lordosis decreased by 24% (− 15° ± 5), thoracic kyphosis significantly increased by 29% (+ 8° ± 8). Significant changes were also observed in global sagittal alignment with a posterior tilt of T1SPi (− 3.5° ± 1) without any change between postoperative time and follow-up. A postoperative posterior shift of SVA was observed (− 15 mm ± 6). No significant loss of correction occurred between early postoperative time and last follow-up (Table 2). Preoperative LSA was correlated with preoperative LL ($r = 0.519$), postoperative TK ($r = 0.523$) and postoperative LL ($r = 0.731$). Preoperative slip only correlated with preoperative LL ($r = 0.690$). Preoperatively, T1SPi was strongly correlated with LL ($r = -0.706$) and TK ($r = -0.646$). Postoperatively, LSA was correlated with TK ($r = 0.623$) and T1SPi ($r = -0.535$). At follow-up, T1SPI and SVA strongly correlated with LL ($r = 0.650$). All correlations were significant.

Table 1 Preoperative sagittal parameters

	Preoperative			
	Mean	SD	Min	Max
PI (°)	67	9	44	90
SS (°)	38	9	24	58
PT (°)	28	6	16	58
LSA (°)	65	14	47	94
listhesis (%)	81	19	55	100
L1S1 (°)	64	8	44	76
T1T12 (°)	27	10	10	44
T1SPi (°)	− 3	5	− 10	4
SVA (mm)	2.3	2	− 15	51

Complications

Fourteen of the 20 patients (70%) had postoperative neurologic disorders, among which 10 (50%) had transient L5 motor deficit with a neurologic testing between 1/5 and 3/5 (3 patients with bilateral deficit and 7 with unilateral), 9 (45%) had L5 hypesthesia and 1 had medullar ischemia (who was explored in emergency with MRI, CT scan and arteriography). Half of the complications occurred immediately postoperatively due to roots stretching during the reduction, and the other half occurred between 3 and 6 days postoperatively while the hips were progressively extended and the patients were put in standing position. None of the patients required revision surgery for radicular decompression. All patients totally recovered between 3 and 6 months postoperatively, except the patient with medullar ischemia who still walks with crutches and has a neurological bladder. Two patients (10%) required revision surgery (debridement) for wound infections.

Table 2 Comparison between preoperative, postoperative and follow-up parameters

	Preoperative		Postoperative		Follow-up	
	Mean	SD	Mean	SD	Mean	SD
PI (°)	67	9	69	12	69	11
SS (°)	38	9	46	10	43	12
PT (°)	28	6	25	8	25	9
LSA (°)	65§*	14	98§	13	99*	11
listhesis (%)	81§*	19	41§	19	45*	18
L1S1 (°)	64§*	8	50§	8	53*	13
T1T12 (°)	27§*	10	35§	12	36*	12
T1SPi (°)	− 3.0§*	5	− 5.1§	4	− 6.3*	3
SVA (mm)	2.3	2.0	1.6	2.4	0.6	2.6

§ Mean significant differences between preoperative and postoperative parameters

* Mean significant differences between preoperative and follow-up parameters

Five patients (25%) developed mechanical complications. One patient had L4 screw early pullout due to initial misplacement and required revision surgery: screws with larger diameters were inserted (6.5 mm instead of 5.5 mm) and protected with L4 sublaminar bands. Rod breakage was observed in four patients (20%), one rod out of two broke at more than 1-year follow-up (only Titanium rods) without any loss of correction. Anterior fusion was considered satisfactory and since patients had no complaint no revision was performed (Table 3).

Discussion

The current study, which represents to our knowledge the biggest series of HGS with more than 5-year follow-up, highlighted that intrasacral rod fixation was an efficient technique to correct lumbosacral kyphosis. The compensatory mechanisms involved to maintain the overall balance preoperatively were significantly reduced after surgery and no loss of correction was reported during the observation period. HGS remains a condition associated with high incidence of postoperative complications, though the vast majority remains transient.

Surgical technique

Several biomechanical studies have demonstrated the 3D stability of intrasacral rod fixation with a strong stiffness especially in flexion–extension constraints and axial torsion [19, 21–23]. Equally, the effectiveness of this technique has been documented in severe scoliosis (neuromuscular or idiopathic) as well as in cases of extreme lumbosacral instability (such as ptosis or lumbosacral destruction) [12, 24].

In such patients, pain might originate from spondylolisthesis with radicular pain due to nerve root stretching and with low back pain due to sheer forces on the articular process and disc. However, low back pain might also originate from global sagittal malalignment and hyperlordosis due to muscle fatigue to maintain posture in case of spinal deformity. Therefore, in addition to circumferential fusion, sacral dome resection is essential as well to allow for a good reduction of the lumbosacral kyphosis. Results of the current study with 50% reduction of the LSA and L5 slip are similar to those of other series with sacral dome osteotomy in HGS treatment [14]. After sacral osteotomy, reduction is obtained through sagittal rotation of the sacrum with insertion of rods in L4 screws. As a matter of fact, huge constraints are applied on the L4 screws. At the beginning of this technique, we started with screws in L5 instead of L4; nevertheless, most of the L5 pedicles were dystrophic and broke and then screw pullout occurred. Thus, we always use L4 screws and, to protect screws and avoid pullout, currently add two L4 sublaminar bands. We did not observe screw pullout since then. Circumferential fusion was systematically performed through the posterior approach with PLIF cages to enhance fusion and avoid risk of anterior approach and two stages of surgery (Fig. 5).

Radiological outcomes

Over the past decades, the importance of sagittal alignment on patient-reported outcomes has been strongly demonstrated [6, 7]. In parallel, abnormal sacropelvic orientation in L5–S1 lysis spondylolisthesis and its consequences on global sagittal alignment have been highlighted [25, 26].

The current results indicated that, preoperatively, L5 slip and lumbosacral kyphosis were associated with an increase in proximal lumbar lordosis and were responsible for anterior shift of the patient. Consequently, to maintain the spine balance, a preoperative flattening of thoracic kyphosis was observed as a compensatory mechanism. Postoperatively, correction of lumbosacral kyphosis was associated with a decrease of the proximal hyperlordosis

Table 3 Description of lumbosacral angle, Meyerding grade, complications and pre/postoperative neurologic status in the cohort

Patient	Gender	Meyerding grade	Age	Preoperative neurologic deficit	Postoperative neurologic deficit	Mechanical complications	Preoperative lumbosacral angle	Preoperative slip (%)	Postoperative lumbosacral angle	Postoperative slip (%)
1	Female	3	12.6	0	L5 transient motor and sensitive	0	65	69	90	50
2	Female	Ptosis	16.3	Sciatica	L5 transient motor	0	58	100	102	49
3	Female	Ptosis	13.0	0	L5 transient sensitive	L4 screw pullout	57	100	85	50
4	Male	4	15.9	Sciatica *2	0	Rod breakage	60	76	90	34
5	Female	4	14.9	0	L5 transient sensitive	0	47	90	88	40
6	Female	3	14.4	Sciatica *2	L5 transient sensitive	Rod breakage	94	52	112	37
7	Female	Ptosis	17.2	0	L5 transient motor	0	62	100	109	21
8	Female	Ptosis	13.4	0	0	0	58	100	100	26
9	Female	Ptosis	12.2	Sciatica *2, motor deficit, bowel	L5 transient motor and sensitive	Rod breakage	49	100	94	26
10	Female	4	12.3	Sciatica	0	Wound infection	80	80	100	38
11	Female	Ptosis	16.5	Sciatica	L5 transient motor and sensitive	Wound infection	52	100	66	100
12	Female	3	13.1	Sciatica, motor deficit	Medullar ischemia	0	65	65	99	27
13	Female	3	12.3	Sciatica	L5 transient motor and sensitive	0	59	69	94	31
14	Female	Ptosis	12.6	0	0	0	65	100	113	33
15	Female	Ptosis	15.1	Sciatica	0	0	60	100	114	45
16	Female	4	16.5	Sciatica *2	L5 transient motor	0	94	79	113	37
17	Male	4	16.3	Sciatica *2	L5 transient motor	Rod breakage	61	86	100	50
18	Female	3	11.1	0	L5 transient motor and sensitive	0	75	60	95	37
19	Female	3	14.9	Sciatica *2	L5 transient motor and sensitive	0	69	56	94	35
20	Female	3	17.1	0	0	0	71	55	97	29

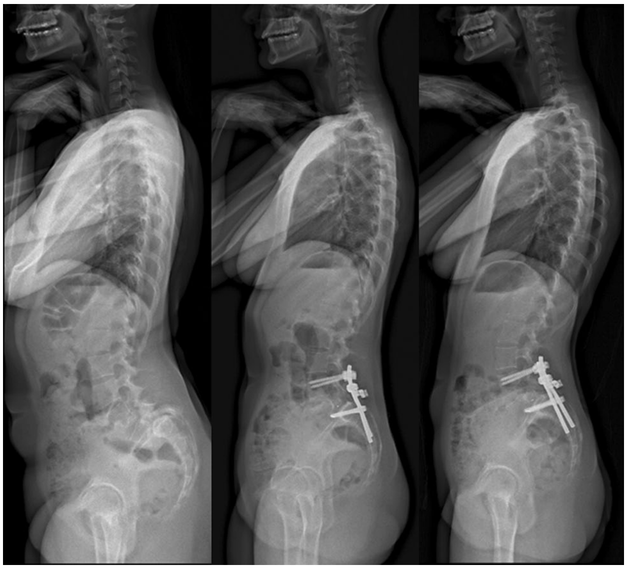

Fig. 5 Sagittal X-rays of HGS patient pre-, postoperatively and at last follow-up

and increase of the lumbosacral lordosis, and therefore decrease of the maximal lumbar lordosis. Indeed, sagittal rotation of the sacrum (obtained with correction maneuvers) induced increase in the sacral slope (i.e., increase of the lumbosacral lordosis) and decrease in the pelvic tilt. At the same time, thoracic kyphosis increased. When the alignment was restored, compensatory mechanisms stopped and so thoracic kyphosis increased [27].

Other authors obtained the same postoperative results. In 2008, Labelle et al. emphasized the importance of LSA correction to improve global sagittal alignment [28]. They observed that reduction of the lumbosacral kyphosis was related to increasing thoracic kyphosis and decreasing lumbar hyperlordosis, thus correcting the anterior global shift and avoiding the risk of proximal adjacent segment disease while improving the esthetics. In other HGS series, transsacral rod technique also allowed to perform a satisfactory reduction of the lumbosacral kyphosis [12]. In a series of 50 HGS patients treated with a fusion from L4 to the sacrum with a two-hole sacral plate (Chopin's clog), Moreau et al. obtained the same results, with a mean olisthesis reduction of at least 50% [15]. However, in the current study, LSA reduction was more important with Jackson fixation (34°) versus that in Moreau's series with sacroiliac screws (25°). They observed the same increase in TK of 7° on average and a correction of the global sagittal alignment (C7 Tilt from 8° anteriorly to 4° anteriorly). Of note, in the current series, after correction of global sagittal alignment, the values of T1SPi were close to those of asymptomatic subjects (− 1.4° ± 2.7) [29].

Complications

A high rate of neurologic complication was reported in HGS surgery whatever the surgical procedure [30]. Gaines et al. described 23 of 30 patients with temporary L5 weakness after reduction of L4 onto S1 with L5 vertebrectomy [11]. Patients recovered between 6 weeks and up to 3 years. Moreau et al.'s study with sacroiliac fixation and sacral dome resection for HGS found 34% patients with postoperative L5 radicular deficit, without sequelae at follow-up. Similarly, Vialle et al. reported 3 of 15 cases with L5 deficit and 3 with sphincter disorders after intrasacral rod fixation technique. All the patients recovered at follow-up [31]. In the current study with intrasacral rods, the shortening effect of sacral dome resection and the reduction with rotation maneuver without L5 posterior translation should diminish the damage and stretching on L5 roots. Nevertheless, postoperative transient motor deficit remained frequent. Maybe, the surgeon should not provide too much slip correction, but may better insist on lumbosacral kyphosis reduction to decrease the compensatory mechanisms and energy expenditure. Moreover, postoperative management and patient positioning with progressive extension of the hip are of upmost importance to avoid delayed neurologic deficit.

With a pseudarthrosis rate up to 19%, achieving a solid fusion is one of the major concerns in HGS surgery [32]. Several authors compared the rate of fusion with and without HGS reduction. In a recent literature review, Rindler et al. concluded that good fusion was obtained with FIS despite a 15% complication rate [30]. Transfeldt et al. in an evidence-based analysis of the literature concluded that the fusion rate was higher when HGS reduction was performed. More recently, Longo et al. obtained the same conclusions, for a similar rate of neurologic complication whether reduction was performed or not [33]. No pseudarthrosis was observed in the current study. The high rate of fusion could be explained both by the circumferential fusion with PLIF and by the restoration of sagittal alignment in an economic posture with thus less pullout forces applied on the instrumentation. Indeed, persistence of lumbosacral kyphosis larger than 90° was identified as a risk factor for nonunion [15]. Other authors proposed the anterior approach to achieve interbody fusion, but at the cost of a second procedure and thus higher risk of general complications [34]. Four rod breakages occurred in the first year of this study. Then, the rod alloy was changed: Titanium was replaced by cobalt chromium rods which are stiffer. No supplementary rod breakages were then observed.

This study presents several limitations. First, this is a retrospective study with prospectively collected data. A prospective one with health-related quality of life scores could provide further information. Nevertheless, the clinical and neurologic status was collected in this study. Another point is the small cohort of patients. However, HGS remain a rare condition and our series represents with 20 cases one of the biggest cohort in the literature. In addition, this study is only the second one to include the global sagittal alignment analysis, which is essential to evaluate long-term outcomes. The importance of full spine analysis with global sagittal and pelvic parameter measurements was corroborated by other authors; they also recommended decompression and circumferential fusion for HGS treatment [35].

Conclusion

The goals of HGS treatment are to relieve pain, prevent slip progression and improve function. All of these goals are achieved by surgical technique used in this study.

Therefore, intrasacral rod fixation appears to be an effective technique to correct LSA kyphosis and compensatory hyperlordosis, restore global sagittal alignment and achieve fusion. It avoids the need for a complementary anterior approach. However, this procedure remains a demanding technique with high risk of transient neurologic complications. Therefore, neurologic risk should be systematically assessed and patients should be accurately informed.

Compliance with ethical standards

Conflicts of interest E. Ferrero, V. Mas, C. Vidal, AL. Simon have no potential conflict of interest. K. Mazda has consulting activities for Zimmer and Implanet. B. Ilharreborde has consulting activities for Zimmer, EOS Imaging and Implanet.

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