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ORIGINAL ARTICLE

L5 pedicle subtraction osteotomy: indication, surgical technique and specificities

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Abstract

Purpose To evaluate the radiographic, functional outcomes, complications and surgical specificities of L5 pedicle subtraction osteotomy for fixed sagittal and coronal malalignment.

Methods A retrospective cohort of consecutive patients with prospectively collected data. Ten patients who underwent PSO at L5 were eligible for a 2-year minimum follow-up (average, 4.0 years). Patients were evaluated by standardized upright radiographs. Preoperative and postoperative radiographies, surgical data and complications were collected.

Results All surgeries were revision surgeries. The mean lumbar lordosis before surgery was − 22.5° (range, 8° to − 33°) and improved to − 58.5° (range, − 40° to − 79°). The sagittal vertical axis demonstrated a preoperative mean sagittal malalignment of 13.7 cm (range 3.5 to 20 cm), with correction to 4.6 cm postoperatively. Three patients required additional surgery at the latest follow-up for rod breakage.

Conclusions PSO of L5 can be a safe and effective technique to treat and correct fixed sagittal imbalance and provide biomechanical stability. The high complication rate mandates a careful assessment of the risk/benefit ratio of such a major surgery. Most patients are satisfied, particularly when sagittal balance is achieved.

Keywords Sagittal and coronal malalignment · Flat back · L1–S1 lumbar lordosis · L4–S1 lower lumbar lordosis · L5 Pedicle Subtraction Osteotomy

Introduction

Since the first description of pelvic incidence (PI) by Duval-Beaupère [1], the relationship between PI and lumbar lordosis (LL) is commonly used to restore a proper LL [2]. Lower segment (L4–S1) lumber lordosis is known to be two-thirds of the global LL [3]. Lack of lumbar lordosis can lead to disability and pain [4]. Surgery is an effective way to treat severe sagittal malalignment [5], and to restore a proper LL. Many surgical options have been described, and posterior techniques are commonly used. To obtain satisfying correction, osteotomies can be done, before reduction to increase spine mobility [6].

Pedicle subtraction osteotomy, as described by Thomassen [7], is an effective technique to restore a large amount of lordosis in patients with fixed sagittal deformity. This technique has mostly been described at L3 and L4 levels [8]. L5 osteotomies are not specifically described in the literature. Infrequently L4–L5 kyphosis occurs and an L5 osteotomy is needed to correct malalignment by restoring a proper lower LL.

To our knowledge, this is the first study which focuses specifically on L5 osteotomies. L5 osteotomies present specific indications, operative nuances and anatomic features that should be emphasized. Additionally, the potential correction of L5 deformities by radiographic assessment and complications has been reported for a series of ten patients with a minimum 2-year follow-up.

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Materials and methods

Patient series

Between February 2008 and May 2014, ten consecutive patients underwent L5 PSO. All the patients were included from a single center, and operated on by the same surgeon (IO). The surgery was carried out when the patient presented with a symptomatic, severe, and rigid lumbar kyphosis at L5. Rigidity was assessed with preoperative supine bolster-extension radiographs. The apex of the kyphosis deformity was located at L5 level in all the cases. Patients presenting a high-grade spondylolisthesis were excluded, as lumbosacral kyphosis induced by high-grade spondylolisthesis are managed with a specific surgical technique [9].

Radiographic evaluation

All patients underwent preoperative and postoperative full-spine EOS radiographs (EOS imaging, Paris, France) [10] to analyze the local and global spinal alignment.

The radiographic measured parameters were:

- Pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS).
- L1S1 lumbar lordosis (LL), L4S1 lumbar lordosis (L4S1–LL), T4–T12 thoracic kyphosis (TK), with positive values denoting kyphosis, negative values denoting lordosis.
- Sagittal vertical axis (SVA), lumbar lordosis index (LLI).
- C7 central sacral vertical line (C7–CSVL).

All parameters were measured using a specific dedicated software [11].

Operative data, complications and follow-up

Operative data, early and late complications were collected. All the patients had clinical and radiographic follow-up at 3, 6, 12 months, then yearly after the surgery. NRS (numerical rating scale) that was used to measure the pain was collected preoperatively and during the first follow-up.

Statistical analysis

Demographic, surgical, and radiographic parameters were evaluated using the descriptive statistics of means. Comparisons between the preoperative status and last follow-up were performed with paired t test. $P < 0.5$ value was considered to be significant.

Description of cases

All the ten cases were revision procedures.

Two patients (T12–L5, T9–L5) had diagnoses of distal junctional kyphosis (DJK). L5 PSO and extension to ilium was performed with L5–S1 transforaminal lumbar interbody fusion (TLIF).

Eight patients had postoperative flatback deformity (POFB). These patients did not have a TLIF at L5–S1, as preoperative CT scans demonstrated a fused L5S1 level.

Surgical technique (Fig. 1)

The overall surgical technique for PSO has been well-described [8]. We describe the L5 osteotomy specificities in this study.

When positioning the patient for L5 PSO, it is advisable to place the anterior pelvic pads more distally, leaving the ASIS free to allow pelvic anteversion which helps correct the sacropelvic pathology inherent to these parts. Neuromonitoring is performed routinely and in particular, of the L5 nerve root.

In these cases, new fixation points are first established including larger cobalt-chrome pedicle screws, to address osteolysis from pseudoarthrosis or to accommodate a larger rod. The distal fixation is to the ilium, with iliac screws, and bicortical S1 screws are used in all the cases.

A complete L5 posterior bone resection is approached from the lateral aspect traversing to the contralateral side. A wide decompression of the involved level is performed from L4 pedicle to S1 pedicle, ensuring that the L5 nerve roots are completely decompressed. L5 transverse processes are separated from the pedicle at each base and retracted laterally, providing access to the lateral wall of the pedicle subperiosteally. During the sub-periosteal dissection around the lateral walls of the L5 vertebral body, one is cognizant of the vascular elements such as the right iliac vein and the ascending lumbar vein, which are adjacent (Fig. 2). When the lateral aspect of the vertebral body is exposed, a surgical cellulose haemostatic mesh is placed to separate it from soft tissue laterally. A vascular injury would be extremely difficult to manage and protecting these elements is mandatory before performing the osteotomy. Moreover, the lateral wall dissection can be challenging, as the L5 vertebral body is very wide and the pedicles are very convergent. The 1 cm straight osteotome is applied to within the resected pedicle in a vertical orientation with 30° of convergence and directed anteriorly, then above and below the pedicle. Special attention should be made to stay in contact with the lateral wall during the entire paravertebral resection. The medial wall

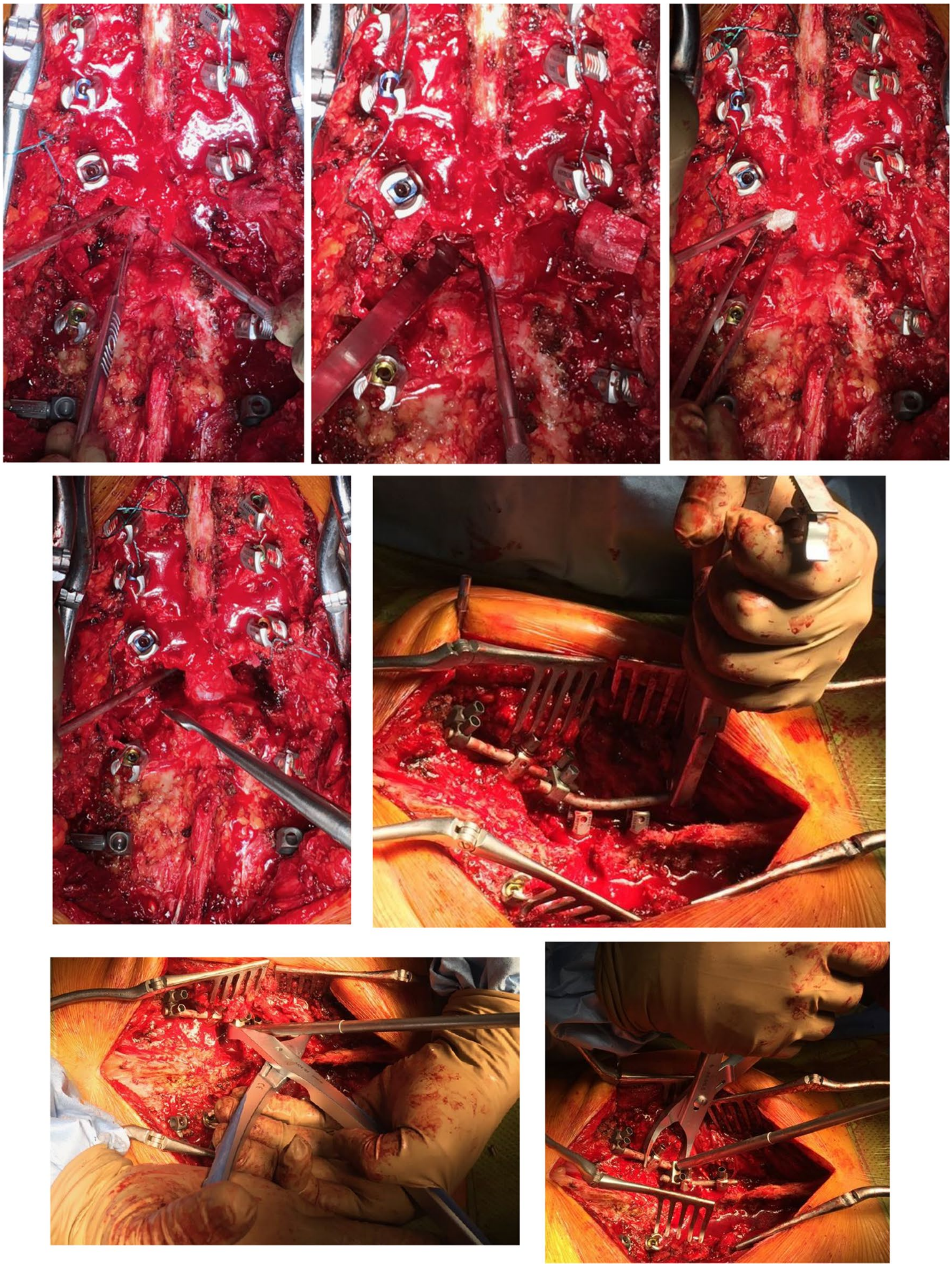

Fig. 1 L5 PSO with closure by domino compression, to correct sagittal and coronal malalignment

of the pedicle is resected on either side and the dural sac is retracted to either side to provide exposure to the posterior vertebral wall.

While the L5 vertebral body is normally wide, its height is frequently less than that of L3 or L4. To increase the amount of correction, and to reduce the risk of pseudoarthrosis, the

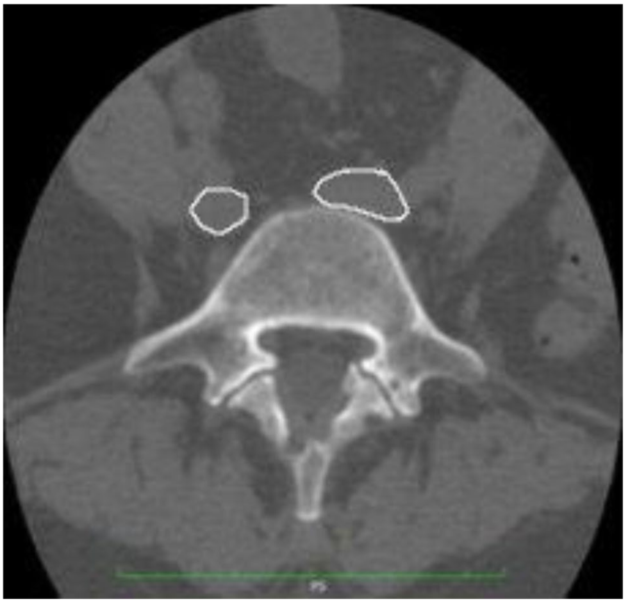

Fig. 2 Left and right iliac vein

L4–L5 disc is systematically removed when performing the osteotomy. The anterior part of the L5 vertebral body is narrow, therefore 1 cm of bone should be conserved at the anterior aspect and the osteotomy cut must finish 1 cm behind the anterior wall. That improves the safety of the procedure in respect of vascular structures and does not prohibit osteotomy closure.

Two rods on each side are used across the osteotomy level with connecting dominos. Rod diameter is usually 6 mm for caudal rods and 5.5 mm for cephalad rods, with a mixture of cobalt-chrome caudally and titanium cephalad. Contouring of the rods is dependent on the location of the domino, as the overlap must contain two opposing straight ends. In most cases, the caudal rods (IC-S1) were straight and the cephalad rod (L4–L3-/-L2) is given an exaggerated hyperlordotic curve. Importantly, the most proximal aspect is minimally contoured. The rod is inserted into the distal screws, innies blocked, domino applied and blocked, then lowered into the proximal screws as the osteotomy closes down. Compression across the osteotomy site is performed either through eccentric distraction between nearby pedicle screws and the dominos outside of the PSO site or concentric compression across the osteotomy. If an asymmetric correction is needed, a greater bone resection is performed at the convex side as well as at the reduction achieved by compression on the domino connector. The resected bone is used as autograft. All the remaining posterior laminae are decorticated to augment the fusion bed. Then, spanning satellite rods are applied bilaterally from the L1–L2 level to the S1-iliac level.

Results

Demographic data (Table 1)

Ten consecutive L5 PSO patients (6 females and 4 males) were included with a mean of 34.3 months follow-up (range 24 to 60 months). The mean age at surgery was 50.3 years (range 28 to 73 years). All the surgeries were revision procedures. As mentioned, two were late DJK with severe L4–L5 kyphosis and eight had POFB. Two of these patients presented with a L4–L5 pseudoarthrosis and one patient had

Table 1 Patients' data

No	G	Age	Diagnosis	Length of follow-up/months	OR time/min	UIV-LIV	Blood loss/mL	Complications
1	F	73	Postoperative flat back and coronal malalignment	60	400	T2-iliac	4000	Pseudarthrosis, dural tear
2	F	41	Postoperative flat back and coronal malalignment	54	540	T1-iliac	4500	Pseudarthrosis
3	M	45	Postoperative flat back and coronal malalignment	32	180	L3-iliac	225	Dural tear
4	M	28	Postoperative flat back	30	440	T4-iliac	2800	No
5	F	65	Distal junctional kyphosis	30	360	T12-iliac	1000	No
6	F	56	Postoperative flat back	28	390	T4-iliac	1790	Dural tear
7	M	36	Postoperative flat back	24	200	L3-Iliac	900	No
8	M	55	Postoperative flat back, L4–L5 pseudarthrosis and coronal malalignment	28	390	T9-iliac	3000	Pseudoarthrosis
9	F	36	Postoperative flat back and L4–L5 pseudarthrosis	24	360	L1-iliac	2000	No
10	F	64	Distal junctional kyphosis	24	260	L2-iliac	1200	No

major coronal malalignment. Patients with POFB had an average of 2.2 prior surgeries. Four patients presented a coronal malalignment with a C7–CSVL greater than 50 mm. Loss of lordosis was caudal to L4 in all the cases, so correction was indicated at the level of the pathology.

Operative data and complications (Table 1)

The mean estimated blood loss per patient for all the procedures was 2065 mL (range 225 to 4500 mL). The mean operative time of the procedure was 5.9 h (range 3 to 9 h). Three patients had intra-operative dural tears, which were repaired without any related complications.

Three patients developed a pseudoarthrosis and rod breakage; two of them had a pseudoarthrosis at L3–4 level and the third patient had a pseudoarthrosis at the L5 osteotomy level. The average time of rod breakage after surgery was 9 months (range 8, 11 months). The average follow-up time after revision surgery for rod exchange was 4 years (range 2, 7 years). No superficial or deep wound infections were reported. No transient or permanent deficits occurred in this series.

In the three cases of pseudoarthrosis described, the pseudoarthrosis level was at L3–L4 in two patients, and not at the expected L5 level. Rod breakages were in the early cases in the series, without the addition of a satellite rod, on the reduction side, comprising titanium alloy and of 5.5 mm diameter. These were managed by exchanging the rods and inserting additional satellite rods. After revision surgery, we did not report further complications after 4 years (range 2, 7 years) post revision surgery and patients progressed to osseous union.

Outcome analysis

NRS pain scale

All ten patients completed the visual analogue pain scores prospectively, preoperatively and postoperatively. The NRS average score was 7.56 preoperatively and 3.61 postoperatively ($P < 0.05$).

Radiological evaluation (Table 2)

Preoperatively, the mean segmental L4S1–LL was − 4.8° (range 2, − 12°), for a mean thoracic kyphosis of 26° (range 9, 66°). The mean L1S1–LL was − 22.5° (range 9, − 33°). The SVA was 137.3 mm (range 65, 208 mm).

Postoperatively, both segmental L4S1–LL and L1S1–LL significantly increased to − 34.2° and − 58.5°, respectively (− 4.8° vs. − 34.2°; − 22.5° vs. − 58.5°) and the SVA was measured at 4.6 mm (range 6, 94 mm). There was a significant difference between pre and postoperative alignment. The radiographic results are reported in Table 2.

Discussion

To our knowledge, this is the first case series, which specifically describes L5 osteotomies. In ten patients, an L5 PSO was performed with a safe and effective technique to treat and correct fixed sagittal imbalance and provide biomechanical stability.

PSOs are usually performed at L3 or L4 level to correct the lack of lumbar lordosis. An L3 osteotomy is technically easier to perform because of its location, and L3 osteotomies can provide a substantial correction [12]. Sometimes, the apex of the deformity can be located at the L5 level (Fig. 3). In these cases, a L5 osteotomy permits correction at the same level of the deformity and allows more harmonious and physiologic lumbar lordosis shape (Fig. 4). We maintain that, performing an osteotomy at the kyphotic level is the most appropriate way to obtain an anatomical correction [13]. When the kyphosis is located distal to L3 vertebra, it is already in a lordotic position and PSO at that level will not allow significant correction.

Global LL is commonly measured between L1 and S1 superior endplates. The importance of restoration of a

Table 2 Radiographic evaluation

	Pre-op		Post-op		Last FU		P*
	Mean	SD	Mean	SD	Mean	SD	
TK (°)	26	9.8	35.1	10.8	34.6	10.8	< 0.001
LL (°)	− 22.5	11.5	− 58.5	10.3	− 58.6	10.4	< 0.001
PT (°)	30.3	8.7	26	8.5	25.9	8.5	NS
PI (°)	68	6.86	67.7	7.4	67.7	7.4	NS
L4–S1 lordosis (°)	− 4.8	2.34	− 34.2	5.7	− 34.1	5.92	< 0.001
SVA (cm)	13.73	4.8	4.69	4.1	4.42	4.1	< 0.001
LLI	0.3	0.09	0.87	0.12	0.87	0.11	< 0.001
C7–CSVL (cm)	3.37	3.21	1.7	1.3	0.90	0.73	< 0.005

* *P* values comparing the preoperative status and last year follow-up results

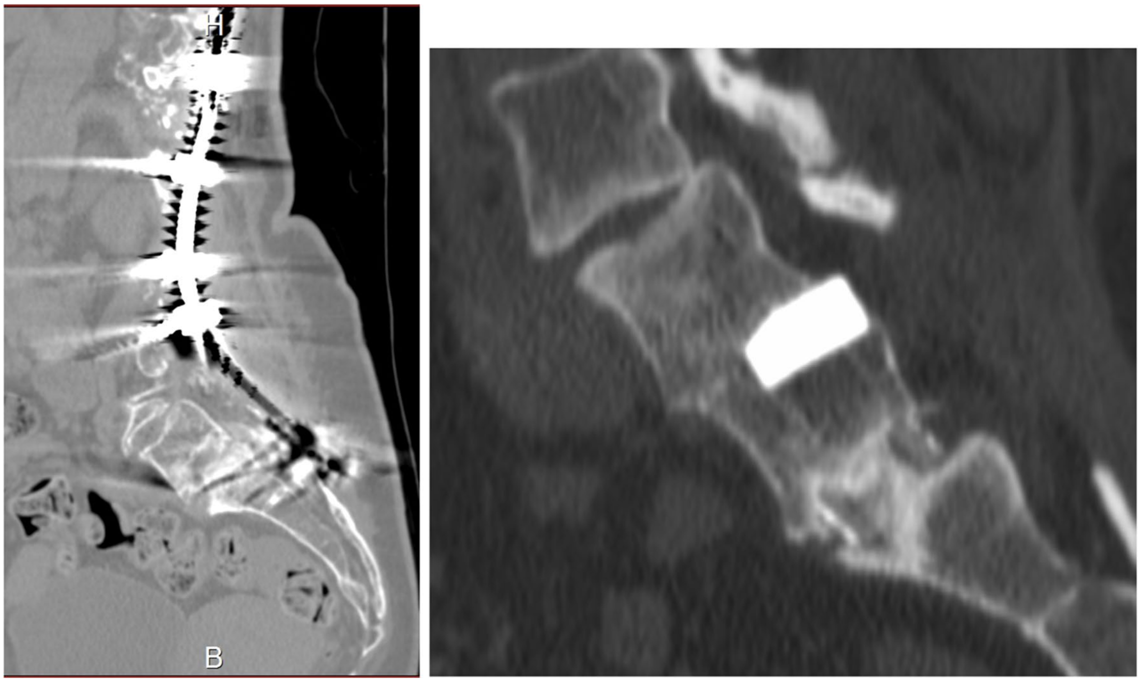

Fig. 3 Postoperative flatback with L4S1 segmental kyphosis. The kyphosis apex is located at L5 level, and L5 PSO will provide the greatest amount of correction

harmonious LL specifically adapted to the patient's back type is well-described by Roussouly [14, 15]. In a normal asymptomatic population, distal LL (L4–S1) accounts for two-thirds of the global LL [16], thus having a great impact on the patient's spinal balance. In this study, the average improvement obtained at L4S1-LL was 34.2°, demonstrating the effectiveness of the technique to correct lower LL. All the cases were revision surgeries based on the primary failure to restore lower LL and leading to revision surgery. The mean preoperative SVA observed in this series underlines the important impact of deformity on global malalignment.

Nevertheless, L5 PSO is a demanding technique. L5 lateral body dissection is challenging, because L5 vertebra is shallow and has a significant vascular environment. A deep lateral dissection is needed to avoid vascular injury, which is difficult because of pedicle orientation. Wolf et al. reported the importance of L5 pedicle convergence (18.5° vs. 12.8° for L3 pedicles) and the necessity of a wider exposure to obtain a satisfactory trajectory [17]. L5 vertebra is also the widest (48.1 mm vs. 42.1 mm for L3) vertebral body as shown by Van Schaik et al. [18, 17]. This offers the possibility of a greater correction, but with a high risk of bleeding especially when a large bone resection is needed. For better correction, and to increase the fusion rate of the L4–L5, the disc was systematically removed to obtain a bone-to-bone contact after reduction (type 4 Schwab PSO). This was advantageous in two cases, where a L4–L5 preoperative pseudoarthrosis allowed a type 4 Schwab osteotomy, thus treating the pseudoarthrosis and the sagittal malalignment simultaneously. Notably, the pseudoarthrosis was located at the disc above the osteotomy. It avoids the morbidity of a staged procedure and allows an important correction. TLIF was performed at L5S1 in case of L5 DJK to enhance stability.

Several L5 osteotomies have been previously reported. Radcliff et al reports a L5 PSO for a high-grade spondylolisthesis [19]. In our experience, high-grade spondylolisthesis can be managed by posterior approach only, but the sacral dome osteotomy and L5S1 disc resection is needed to provide the correction [9]. In this study, we excluded such patients, as the indication is different. In high-grade spondylolisthesis, surgery aims to restore lumbosacral angle, but in our study, the aim was to restore L4S1–LL. In Berven's series [20] two L5 PSO cases are reported and one case in Boachie's series [21]. Berven et all reported that the LL was improved after surgery from 15.5 to 45.7 [20]. Bridwell et al reported that the LL was improved after surgery from 14.5 to 50 [22]. The authors for such procedures reported no specific information. The degree of correction seems to be similar to our series. To restore the proper anatomy, the apex of kyphosis must orient the surgeon to choose the appropriate osteotomy level.

Asymmetrical pedicle subtraction osteotomy in the lumbar spine with coronal imbalance has been previously descried in the literature [23]. Postoperative coronal malalignment has a significant negative impact on the patient's

Fig. 4 Preoperative and postoperative sagittal full-spine radiographies. Performing the osteotomy at the apex of the kyphosis allowed an important correction with a relative short fusion. L4S1–LL was corrected from − 2° to 38°

outcome and needs to be taken into consideration during the surgical procedure. In our series, four patients presented a severe coronal malalignment. Performing an asymmetric PSO, with a greater bone resection at the convexity allows a satisfying postoperative coronal balance. Asymmetric bone resection and unilateral reduction, after pelvic fixation, seems to be an effective way to manage such problems [13].

In this series, the mean estimated blood loss per patient for all the procedures was 2065 mL, which compares adequately with the amounts quoted in the literature—2371 mL by Daubs et al, 2984 mL by Bridwell et al. and 2396 mL by Hyun et al [24, 25]. On the other hand, Barrey et al. reported a mean estimated blood loss of 1070 mL in a series of 25 patients with L2, L3 and L4 PSO [26].

Approximately 30% revision surgeries are reported with PSO [24]. Early evaluation with CT provided a rationale for prophylactic ALIF in the absence of osseous union, or in the case of rod breakage, to identify the level of pseudoarthrosis. The strength of the construct is reliant on its longevity until union is achieved. To ensure adequate distal construct strength, convergent bicortical S1 screws with divergent long iliac screws were sufficient, as no screw failures were reported. To ensure sufficient stability across the osteotomy site, we now propose the routine addition of a satellite rod on each side across the osteotomy, but critically, should not extend to the extremities of the construct to avoid PJK.

No transient or permanent deficits occurred in this series. In each case, the L5 foramen was checked intraoperatively, as was the L5 nerve root with neuromonitoring. When performing an L5 PSO or indeed any other revision procedure with prior L4–L5 interbody fusion, one expects to encounter ventral dural scarring. All patients were counseled for the possibility of a dural tear and potential nerve root injury. Our technique for approaching the dura from the lateral aspect, with the aid of using virgin tissue and reliable landmarks such as the transverse process and the pars, at least in this series, avoided this potential complication.

It is also interesting to underline that no proximal junctional kyphosis (PJK) complications were reported. Proximal junctional kyphosis is commonly reported for L3 or L4 lumbar PSO. A high apex of lordosis is a hypothesis for PJK, thus restoration of anatomical L4–S1 lordosis through L5 PSO is protective against this phenomenon, as supported by the absence of PJK in this series.

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Compliance with ethical standards

Conflict of interest No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript. No conflict of interest exists in the submission of this manuscript for all authors, and manuscript is approved by all authors for publication.

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Informed consent Informed consent was obtained from all individual participants included in the study.

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