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ORIGINAL ARTICLE

Pedicle subtraction osteotomy in the lumbar spine: indications, technical aspects, results and complications

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Abstract Pedicle subtraction osteotomy (PSO) consists of creating posteriorly trapezoidal shape of a vertebra, usually L3 or L4, in order to recreate lordosis in the lumbar spine. It is usually indicated to treat rigid kyphotic lumbar spine associated with sagittal imbalance and due to degenerative changes or to iatrogenic flat back. PSO is technically demanding with high rates of complications and should be performed by experienced teams. We presently report our experience about PSO performed in the lumbar spine (below L1) through a series of 25 cases with a special focus on technical aspects and complications associated with the surgical procedure. Mean age was 64 ± 11 years old. PSO was performed at L4 in the majority of cases. Mean blood loss was 1,070 ± 470 ml, and mean duration of the surgery was 241 ± 44 min. VAS decreased from 7.5 ± 2 preoperatively to 3.2 ± 2.5 at 1 year, and ODI decreased from 64 ± 12 preoperatively to 32 ± 18 at 1 year, $p < 0.05$. Mean gain of lordosis after PSO varies from 20° to 40° and was measured to 27° ± 10° on average. Lumbar lordosis (T12-S1) was measured to 21° ± 10° preoperatively to 50° ± 11° postoperatively at 1 year, $p < 0.05$. A total of five major complications (20 %) were observed (two mechanical, one neurological and two infections) necessitating five reoperations. In conclusion, PSO was highly efficient to restore lumbar lordosis and correct sagittal imbalance. It was associated with a non-negligible, but acceptable rate of complications. To limit the risk of mechanical complications, we recommend fusing the adjacent disks whatever the approach (PLIF/TLIF/XLIF). Most complications can be reduced with adequate environment, informed anesthesiologists and experienced surgical team.

Keywords Lumbar spine · Osteotomy · Lordosis · Pedicle subtraction osteotomy · Spine surgery

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Introduction

Pedicle subtraction osteotomy (PSO) was initially described by Thomasen in 1985 for patients with ankylosing spondylitis [1]. In this population, different types of spinal osteotomy have been already described in the scientific literature as early of the 50's and the 60's [2, 3]. PSO consists of realizing posteriorly a wedge-shaped resection of the vertebral body with shortening of the posterior column and respect of the anterior cortex. In the lumbar spine, the goal of PSO was to recreate the lordosis and thus replace the spine above the pelvis in a physiologic position [4]. It is a demanding procedure

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requiring a perfect understanding of the principles of sagittal balance. It also requires a total mastery of intra-canal spinal surgery and a perfect comprehension of spinal biomechanics and principles of spinal instrumentation.

Pedicle subtraction osteotomy is indicated for patients with fixed sagittal imbalances. Commonest causes of sagittal imbalance include degenerative lumbar spine, flat-back syndrome, posttraumatic kyphosis and ankylosing spondylitis [4]. In fact, PSO is more and more frequently realized because of increasing rate of postoperative flat-back syndrome and also a better understanding of sagittal balance principles. In addition, it is now widely accepted that sagittal balance has to be taken into consideration for the optimal management of lumbar degenerative diseases [5].

The aim of this paper was to report our experience of PSO performed in the lumbar spine and confront it to the literature data. Through this paper, technical aspects and complications are especially presented detailed and discussed.

Materials and methods

Twenty-five patients operated between January 2009 and June 2012 for 1-level PSO were consecutively included in the study. All patients were operated by the same surgeon (CB). The mean age was 64 ± 11 years old [42–78]; there were 11 men and 14 women.

Only PSO performed in the lumbar spine (below L1) was included in the study. PSO realized in the thoraco-lumbar junction (T11-L1) and in the thoracic spine were excluded from the present case series.

Indications for PSO were

- Degenerative lumbar kyphosis ($n = 12$)
- Postoperative flat back ($n = 8$)
- Posttraumatic kyphosis ($n = 2$)
- Ankylosis spondylitis ($n = 3$)

Clinical and radiological evaluations were conducted preoperatively and postoperatively at 4 months and 1 year. Clinical evaluation included

- Surgical data (duration, blood loss)
- Visual analogical scale (VAS)
- Oswestry disability index (ODI)
- Intra- and postoperative complications

All patients underwent radiological assessment on full spine radiographs using the EOS™ imaging technology (Fig. 1).

Fig. 1 Pre- and postoperative evaluation of spino-pelvic alignment using high resolution and low radiation EOS™ system with visualization of the whole body from head to feet. This is the case of a patient who underwent PSO at L4 to treat iatrogenic flat-back syndrome

Radiological evaluation included measurement of:

- Local and global lordosis.
- Pelvic parameters (pelvic incidence, pelvi tilt, sacral slope).
- C7 positioning (by calculating the ratio C7 plumb-line/sacro-femoral distance [5]).
- Regional correction angle measured postoperatively at the PSO level and defined as the angle between the superior endplate of the adjacent upper vertebra and the inferior endplate of the adjacent lower vertebra (Fig. 2).

All radiological parameters were calculated using a specific quantitative analysis software (Optispine™, Lyon, France).

A CT-scan with multiplanar thin cuts was performed at 1 year for all the patients to assess the quality of bony fusion at the PSO level.

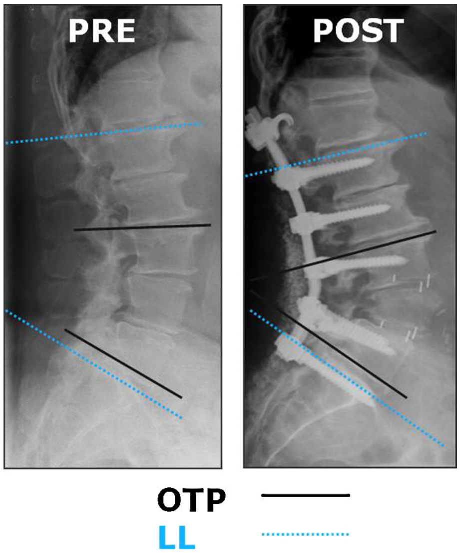

Fig. 2 Regional correction angle was measured at the index level between the superior endplate of the *upper* vertebral and the inferior endplate of the *lower* vertebral (continue *black lines*). Difference between pre- and postoperative value of this angle corresponds to the gain of lordosis provided by the PSO procedure

Technical aspects

Classical technique

The patient was placed in prone position under general anesthesia. Standard posterior exposure of the lumbar spine was realized. Attention was paid to perform meticulous exposure of all posterior bony structures: lamina, isthmus, facet joint and transverse processes.

Surgical steps included successively

- Implantation of pedicle screws at adjacent levels (at least two levels above and two levels below the PSO level).
- Resection of the base of transverse processes.
- Detachment of paravertebral muscles from the lateral part of the vertebral body.
- Resection of the inferior facets of the upper vertebra.
- Resection of isthmus, superior and inferior facets of the index vertebra. Lamina of the osteotomized vertebra is remained connected with the ligamentum flavum in order to perform a good bony continuum on the posterior elements after closure of the osteotomy.
- Pedicles are then resected using specific bone osteotome.
- Cancellous bone is progressively removed trough each pedicle using Taka clamp (decancellation) without removing any part of the adjacent disks. In case of hard bone inside the vertebral body (as observed in posttraumatic kyphosis for instance), the use of drill with progressive decreasing in size is very efficient and safe for this step of the procedure.
- Lateral cortical bone is removed in a wedge-shaped manner. Attention must be paid not to injure segmental vessels running along the lateral wall of the vertebral body.
- Posterior wall is finally resected by working with a Kerrison rongeur under the dural sac which is gently pushed on the opposite side.

In most cases, we consider that temporary rod is not really necessary in the lumbar spine.

Finally, closure of the PSO is performed using a combination of patient repositioning on the operative table (extension of the hips joints and elevation of the upper part of the trunk) and gradual and gentle compression between the pedicle screw heads (Fig. 3). Any abnormal resistance during PSO closure is highly suggestive of insufficient bony resection and persistence of cortical bridges especially on the lateral wall of the vertebral body. Excessive stresses on pedicle screws should be avoiding in order to reduce the risk of mechanical failure of the instrumentation. Otherwise, during PSO closure, meticulous attention must be paid to avoid any nerve roots and/dural sac entrapment. The absence of any compression of neurological structures must be absolutely verified at this stage.

After closure of the osteotomy, autografts associated with bone substitutes were applied on the surface of the posterior bony elements along all the instrumented spine.

Intraoperative monitoring of MEP/SSEP was not used for PSO performed in the lumbar spine under L2 (corresponding to the location of conus medullaris).

During postoperative course, thoraco-lumbo-sacral orthoses were systematically prescribed for at least 4 months to protect the instrumentation from excessive mechanical constraints.

Other variants

Many variants of spinal osteotomies have been described in the literature [6–9]. For PSO, the upper endplate of the index vertebra and the upper intervertebral disk are usually respected. However, in some cases, when great angulation of correction is necessary (>to 30°), resection of the adjacent superior disk can be performed, so-called “trans-discal” PSO (Fig. 4). In addition of greater correction, this technique reduces the need of interbody bone graft at the upper adjacent disk. Schwab et al. [10] recently proposed an anatomical classification of spinal osteotomies in 6 grades with respect to the extent of bone resection and potential destabilization effect of the surgical procedure:

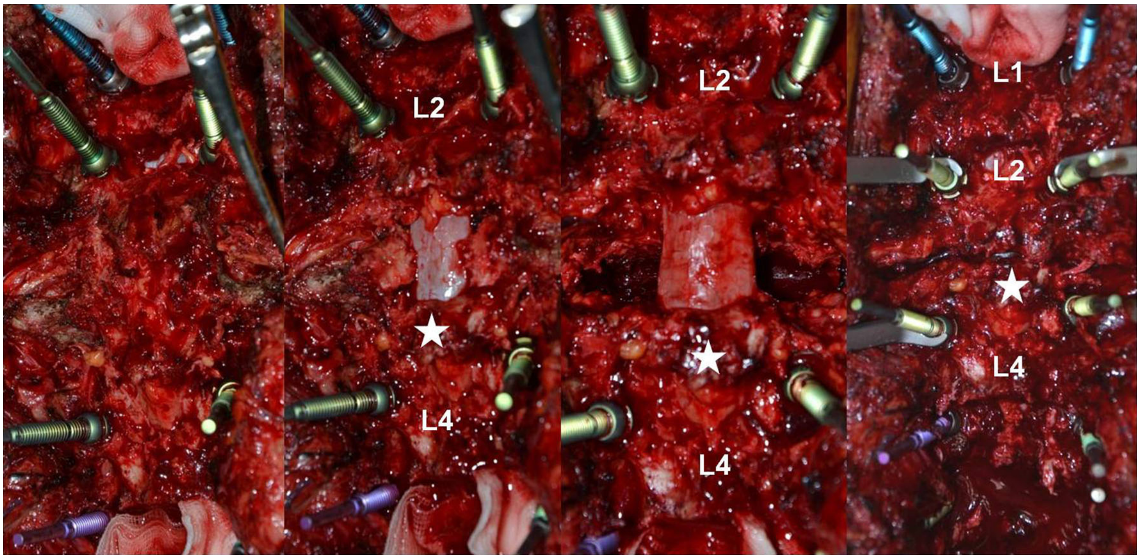

Fig. 3 PSO at *L3* (Schwab grade 3). Note that closure of the osteotomy resulted in good bone contact between the posterior arch of *L2* and residual posterior arch of *L3*, i.e., *L3* lamina (*white star*), providing bone-to-bone contact throughout all the three columns of the spine

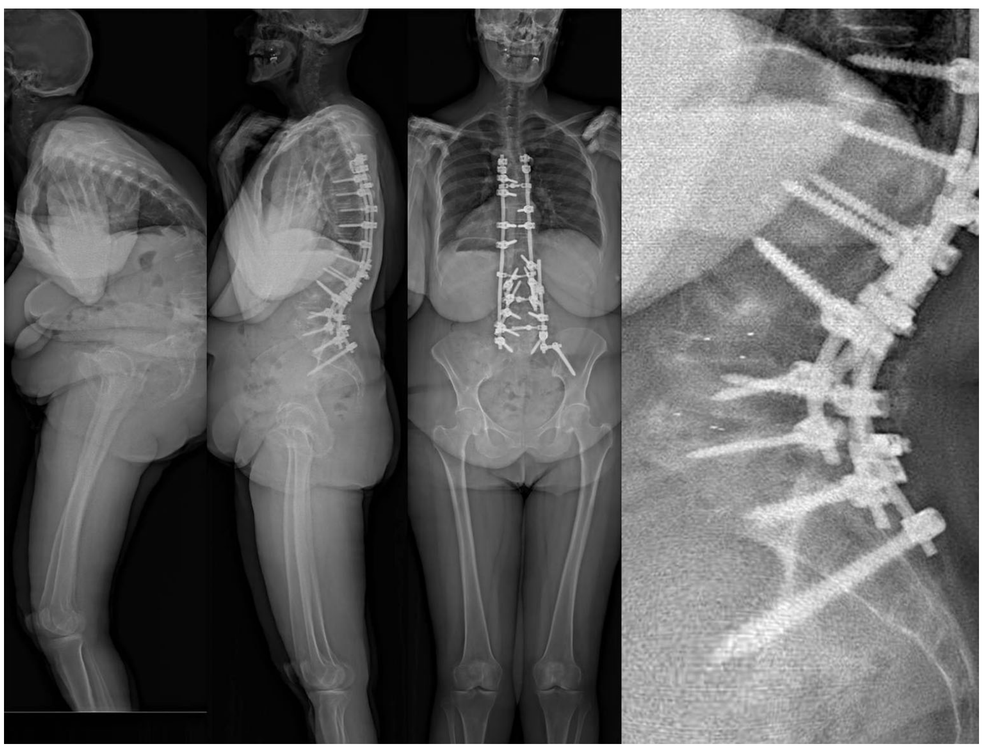

Fig. 4 Sixty-eight-year-old female with major sagittal imbalance. Preoperative parameters were PI = 46°, PT = 49°, SS = −3°, LL = +30°, TK = 41° and postoperative parameters were PI = 46°, PT = 17°, SS = 29°, LL = −70°, TK = 49°. Surgical procedure included trans-discal PSO at L3 (Schwab grade 4) with the use of multirod construct (patient operated by I Obeid, patient not included in the present series)

- Grade 1: partial facet joint resection.
- Grade 2: complete facet joint resection (both inferior and superior facets resected).
- Grade 3: pedicle and partial vertebral body resection (so-called PSO).
- Grade 4: pedicle, partial vertebral body and upper disk resection (so-called trans-discal PSO).
- Grade 5: complete resection of vertebral body and both adjacent disks.

- Grade 6: removal of multiple adjacent vertebrae and disks.

To summarize the Schwab classification, grades 1 and 2 correspond to more or less extensive facet joint resection, grades 3 and 4 to PSO more or less associated with adjacent disk removal and grades 5 and 6 to vertebral column resection.

Otherwise, some authors recommend to use not one but 2 rods per side when performing PSO (multirod construct). One rod is placed at the cranial part of the construct and the other at the caudal segment. The 2 rods are then connecting together using connector systems (Fig. 4). These authors argue that using 2 rods results in a better distribution of loads in spinal implants.

Additional fusion of adjacent disk

In the majority of patients (72 %), the adjacent disk to PSO was fused using whether TLIF during the posterior surgery and whether XLIF under a separate retroperitoneal surgery, usually realized 1–2 weeks later.

In case of severe DDD and good contact between posterior bony elements after closure of the PSO, additional interbody graft was not performed.

Results

Pre- and postoperative clinical and radiological data are summarized on Table 1.

Table 1 Main clinical, surgical and radiological data from the 25-PSO cases series

Patient	Age	Indication	PSO level	Blood loss intraoperative	Blood loss drains (24 h)	Duration	Preop ll	Postop LL	Complication
1	72	Deg. kyphosis	L2	880	650	214	10	41	–
2	66	Flat back	L4	1,900	700	245	18	45	–
3	52	Flat back	L4	1,150	650	225	38	60	–
4	77	Deg. kyphosis	L4	800	450	211	28	55	–
5	76	Ank. Spond.	L4	1,640	480	196	36	50	–
6	42	Flat back	L3	650	120	312	32	70	Deep infection
7	54	Flat back	L4	1,100	880	282	24	51	Dural tear
8	76	Ank. Spond.	L4	750	450	235	10	32	Pseudarthrosis
9	62	Posttraum.	L2	350	330	180	18	52	–
10	46	Flat back	L3	1,230	620	205	24	50	–
11	62	Deg. kyphosis	L4	2,000	650	240	26	54	–
12	73	Ank. Spond.	L4	1,100	720	206	2	25	Dural tear
13	64	Deg. kyphosis	L4	550	450	285	32	52	–
14	77	Deg. kyphosis	L4	2,100	800	343	35	60	–
15	58	Deg. kyphosis	L4	850	650	215	10	46	Instability
16	78	Deg. kyphosis	L4	800	230	247	34	60	–
17	71	Deg. kyphosis	L4	1,000	850	180	28	52	–
18	63	Flat back	L4	400	80	232	11	43	–
19	67	Deg. kyphosis	L4	640	280	198	8	62	Neurol. deficit
20	78	Post traum.	L2	1,200	80	275	12	52	–
21	51	Deg. kyphosis	L4	800	500	238	8	44	–
22	54	Flat back	L4	920	420	212	21	56	Neurol. deficit
23	56	Flat back	L4	1,300	560	239	20	48	–
24	68	Deg. kyphosis	L3	1,250	550	286	18	41	Deep infection
25	66	Deg. kyphosis	L4	1,400	700	327	11	52	–
Total	64 ± 11 [42–78]			1,070 ± 470 [350-2,100]	510 ± 230 [80–880]	241 ± 44 [180–343]	21° ± 10° [2–38]	50° ± 11°* [25–70]	

Blood loss are expressed into millimeters (ml) and duration for surgery into minutes (min)

LL Lumbar lordosis was measured in degrees (°) from T12 (lower plate) to sacral plate

* $p < 0.05$

Mean operative duration for PSO was 241 ± 44 min [180–343], and mean blood loss was measured to 1,070 ± 470 ml [350–2,100] during surgery with additional 510 ± 230 ml [80–880] during first-day drainage.

In most cases ($n = 22/25$, 88 %), PSO was performed at L3 or L4. Only 3 cases were realized at L2 and zero at L5.

The instrumentation included the sacrum in 60 % of cases ($n = 15/25$).

A second surgery, 1 week later, to perform XLIF surgery at the levels adjacent to PSO was conducted in 72 % of cases ($n = 18/25$). For additional XLIF surgery, mean operative time was 88 ± 27 min and mean blood loss was measured to 80 ± 62 ml.

VAS decreased from 7.5 ± 2 preoperatively to 3.2 ± 2.5 at 1 year, and ODI decreased from 64 ± 12 preoperatively to 32 ± 18 at 1 year, $p < 0.05$.

Several complications ($n = 8$ in total, including 3 minor and 5 major with reoperation) were observed in this series:

- 2 dural tears with no clinical consequence.
- 1 radicular deficit with partial recovery due to stenosis of the central canal (Fig. 5)
- 1 postoperative instability at PSO level (Fig. 6)
- 1 pseudarthrosis with screw pull-out.
- 1 transient radicular deficit.
- 2 postoperative infections necessitating reoperation during the first 2 weeks.
- No visceral or vascular injury occurs preoperatively in this series. No epidural hematoma with neurological deficit has been observed in our series.

Fig. 5 Iatrogenic stenosis of the central canal at the level of the PSO (*L4*) between the superior endplate of *L4* and the posterior arch. The patient presented with postoperative neurological deficit necessitating reoperation in emergency. Note that the complete bone-to-bone contact between the posterior arches of *L3* and *L4* did not permit to verify intraoperatively the integrity of the spinal canal at the first surgery

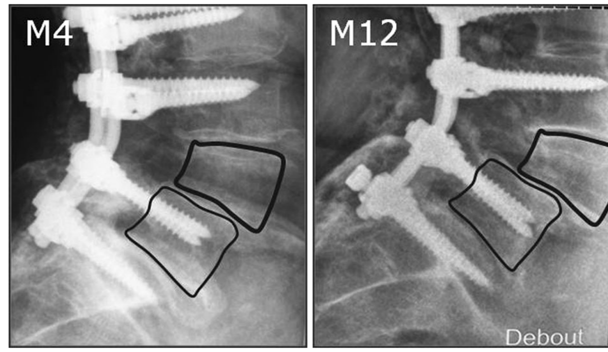

Fig. 6 This is the case of postoperative listhésis of the osteotomized vertebra (L4) after PSO procedure performed at L4. No graft at adjacent levels had been performed during initial surgery, and this should be avoided

Five patients underwent revision surgery during the first year after surgery (corresponding to 20 % of cases): 1 for canal stenosis with neurological compression, 2 for postoperative infections and 2 for mechanical complications.

Pelvic incidence was measured to 54.5° ± 12° preoperatively versus 56° ± 13° postoperatively (non-significant). Lumbar lordosis (T12-S1) was measured to 21° ± 10° preoperatively and increased to 50° ± 11° postoperatively at 1 year, $p < 0.05$.

Mean gain of lordosis after PSO at index level, defined as regional correction angle (Fig. 2), was calculated to 27° ± 10° [14–42].

Ratio C7plumb-line/sacro-femoral distance decreased postoperatively from 1.4 to 0.7 ($p < 0.05$).

One clinical case (iatrogenic flat-back syndrome) is presented in Fig. 7.

Discussion

PSO consists of wedge-shaped resection of the vertebral body by posterior approach allowing for recreation of lordosis without modification of the length of the anterior column. Mean gain of lordosis following PSO procedure varies from 20° to 40° [7–9, 11, 12]. Therefore, PSO is only indicated for cases demanding at least 25° of corrective lordosis.

Preoperative planning

Preoperative planning is essential to determine the amount of correction required and implies extensive analysis of spino-pelvic parameters. One must keep in mind that compensatory mechanisms have absolutely to be taken into consideration to calculate the amount of correction needed. The current article will not detail this preoperative step

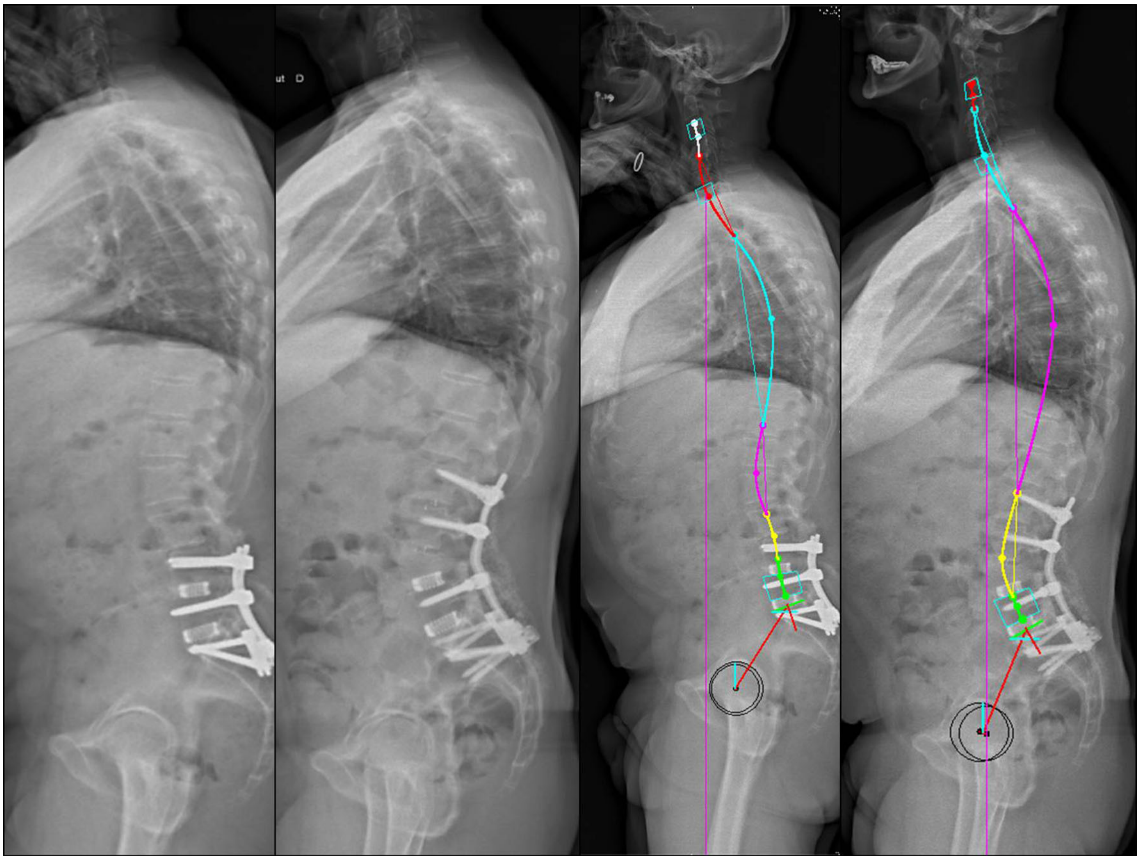

Fig. 7 Fifty-five-year-old male with iatrogenic flat-back syndrome after L4-S1 fusion (2-levels PLIF). Preoperative pelvic incidence was measured to 52° with 32° of pelvis tilt and only 9° of lordosis between L4 and S1. PSO was performed at L4 permitting to recreate lumbar lordosis, to obtain more physiologic spinal curves and overall realignment of the spine above the pelvis with drawback of C7 plumb-line

(refer to the paper by Lafage et al. in this special issue of EJOST on "spinal osteotomies").

Level of PSO

The level where the PSO is performed is usually L3 or L4; however, it may be performed at the levels above depending on the etiology of the imbalance. It can be interesting to perform the PSO at the apex of the lumbar kyphosis when exists or at the level where the kyphotic shape of the vertebra is the most pronounced (Fig. 8). For instance, to treat posttraumatic kyphosis in the current series, PSO was performed at the apex of the kyphosis.

In fact, PSO realized at L4 provides a greater correction and L4 is closer to the natural apex of the lumbar lordosis. On the other hand, PSO is technically easier at L3 or L2 with vertebra reduced in size at these levels. Otherwise, PSO performed at L4 requires to extent the instrumentation to the sacrum which is associated with increased rates of complications (pseudarthrosis, screw pull-out, infections…). Above L2, PSO is associated with an augmented neurological risk due to the presence of the spinal cord and conus medullaris and should absolutely be performed under intraoperative spinal cord monitoring.

If PSO is planned at L2, we strongly recommend to verify the precise location of conus medullaris on preoperative MRI.

Indications

PSO is usually indicated for fixed sagittal imbalance with significant loss of lordosis. In our series, the most frequent indication for PSO was the degenerative evolution of the lumbar spine. Loss of lordosis due to degenerative changes of the lumbar spine results in sagittal imbalance with mechanical pain, functional disability and compensatory mechanisms [13]. The sagittal imbalance is difficult to treat surgically necessitating extensive instrumentation of the spine. When the spine is not too rigid, simple instrumentation with posterior release (facetectomy) may be sufficient. On the contrary, when the spine is fixed in kyphotic

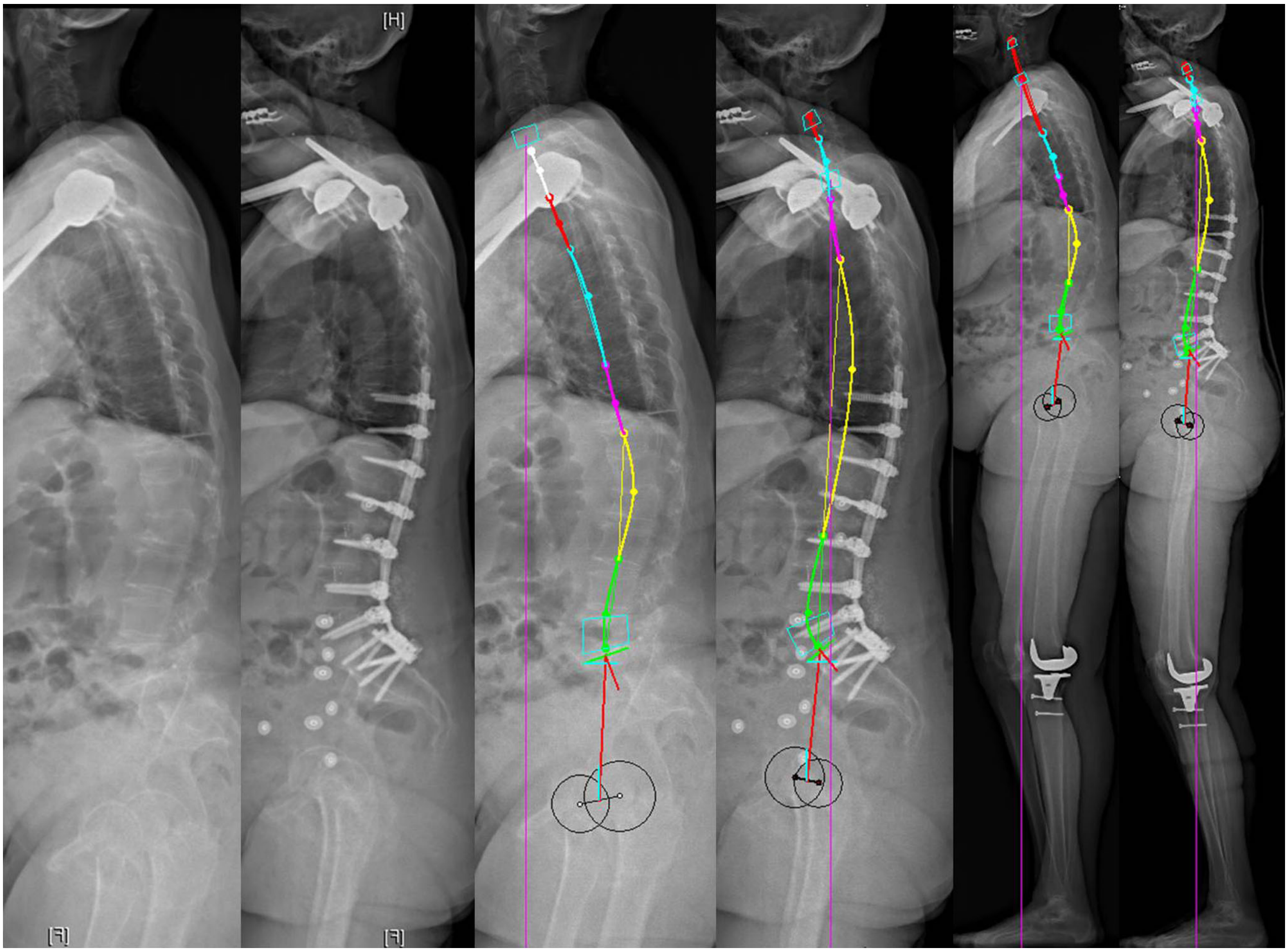

Fig. 8 In this case, PSO was performed at L2 corresponding to the apex of the T12-L3 kyphosis

position, only osteotomy techniques have the ability to correct the fixed sagittal imbalance.

To assess the flexibility of the deformity, dynamic/bending/traction X-rays can be used. CT-scan is also useful to evaluate and locate the presence of bony bridges. Spinal deformity is considered to be rigid when <30 % of reduction is observed on dynamic imaging modalities. However, it is also important to determine the causes of this rigidity (pain, bony bridges, facet arthritis, osteophytes, severe multisegmental DDD…) influencing the overall surgical strategy.

PSO versus SPO

To correct sagittal imbalance posteriorly, there is a variety of osteotomy techniques. Smith-Petersen osteotomy (SPO) consists of trans-foraminal posterior column osteotomy and was initially described in 1969 [6]. The correction achieved by SPO is inferior compared with PSO, varying from 5° to 10°; however, SPO can be realized at multiple levels. In the literature, complications and blood loss seem to be less frequent for SPO compared with PSO [9]. In our experience, contrary to PSO, gain obtained by SPO is more variable and less predictable making PSO for us the technique of choice when significant correction is required (>25°).

Complications

Rate of complications after PSO is not negligible in the literature up to 45 % [11, 12, 15]. As example, Amzallag et al. [11] reported in his thesis a 45 % rate of overall complications (35 % minor and 33 % major complications) depending on the nature of the spinal pathology causing the sagittal imbalance. Through a series of more than 400 procedures, this author estimated the risk of reoperation around 25 % at 5 years. He found that the etiology of the spine deformity influences the rate of complications after PSO (more complications for iatrogenic flat-back syndrome and multioperated patients). Complications following PSO procedure were divided into 4 categories: mechanical, infectious, neurological and general. In case of previous intra-canalar surgery, inclusion of pelvis in the construct, high ASA scale and patient age >65 years old, the PSO was associated with increased rate of complications.

In our series, intraoperative blood losses were particularly low in comparison with data published in the literature [4, 12, 15]. Although massive blood loss >4,000 ml has been reported, we did not encounter this situation until now. No specific technique was used except meticulous attention to hemostasis during each step of the procedure and shorten as much as possible the time separating the resection of the pedicles and the closure the osteotomy. In fact, adequate preparation of the lateral walls of the vertebra and complete exposure of the pedicle on each side prior to start pedicles resection permit to make shorter the most bleeding step of the procedure.

Optimal postoperative correction in the sagittal plane (i.e., SVA < 50 mm, LL = PI ± 10° and PT < 25°) is an important parameter to reduce the risk of developing sagittal decompensation which is a common condition after PSO [14].

To reduce the risk of mechanical complications related to the instrumentation, some rules have to be respected:

- Closure of the osteotomy with bone-to-bone contact posteriorly.
- Fuse the adjacent disks.
- Perform solid fixation, at least two levels above and two levels below.
- Prefer chrome-cobalt than titanium rod.
- Multirod construct should be promoted.

Finally, neurological complications are also frequent varying from 2 to 15 % in the literature [15, 16]. Strict attention must be paid during the procedure to avoid nerve roots and/or dural sac compression by bony structures during the closure of the osteotomy. If so additional canal enlargement may be necessary. Contrary to PSO performed at thoracic and thoraco-lumbar junction, the use and benefits of intraoperative neuromonitoring in the lumbar spine are still under controversies [4, 17].

Conclusion

PSO is a highly efficient technique to recreate lordosis in the lumbar spine and is indicated to treat rigid kyphotic lumbar spine due to a great variety of spinal pathologies. It is technically demanding and should be performed by experienced teams (surgical but also anesthesiologist team). Mean gain of lordosis after PSO varies from 25° to 40°, PSO is therefore recommended when at least 25° of corrective lordosis is required. In some cases, it can represent the only feasible solution to treat the spine deformity and correct the imbalance of the patient.

PSO is associated with a non-negligible, but acceptable rate of complications. To limit the risk of mechanical complications, we recommend systematically fusing the adjacent disks, whatever the approach (PLIF/TLIF/XLIF).

Conflict of interest None.

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