International Orthopaedics (SICOT) (2016) 40:1219–1225
DOI 10.1007/s00264-016-3126-2

ORIGINAL PAPER

Utility of the pedicle subtraction osteotomy for the correction of sagittal spine imbalance

Iulian Popa[1] · Manuel Oprea[1] · Diana Andrei[2] · Peter Mercedesz[3] · Mihai Mardare[1] · Dan V. Poenaru[1]

Received: 8 November 2015 / Accepted: 4 February 2016 / Published online: 24 February 2016

Abstract
Introduction Pedicle substraction osteotomy (PSO) in the lumbar spine is indicated in the treatment of large sagittal deformities of the lumbar spine. Substantial complications associated with PSOs include pseudarthrosis and mechanical failure. The purpose of the present study was to assess the complications of this procedure and the causes of mechanical complications.
Material and methods Fifteen patients aged between 38 and 79 years (mean age 63.8±12.82) were operated on between June 2011 and September 2014 for sagittal imbalance by means of one-level PSO. Pre-operative and post-operative values of radiological spino-pelvic sagittal parameters were measured. Clinical and radiological evaluations were conducted pre-operatively and post-operatively at six months and one year. Clinical evaluation included intra- and post-operative complications.
Results Mean pelvic incidence was 54.86 ± 11.82°. Lumbar lordosis (LL) was measured to be 12.26 ± 18.48° pre-operatively and increased to 42.73 ± 14.05° post-operatively ($p < 0.05$). Mean gain of lordosis after PSO at index level was calculated to be 28 ± 11° (range, 14–41). SVA decreased post-operatively from 93.46 ± 36.69 mm to 61.73 ±38.68 mm ($p < 0.05$). Several complications ($n = 8$), including two minor (one dural tear with no clinical consequences and one transient radicular deficit) and six major with re-intervention, were observed in our series.
Discussions Optimal post-operative correction in the sagittal plane: SVA <50 mm, LL= –(PI+10°) is an important parameter to reduce the risk of developing sagittal decompensation which is a common condition after PSO. Rate of complications after PSO is not negligible in the literature up to 45%.
Conclusions The main cause of mechanical complications was insufficient sagittal correction. To limit the risk of mechanical complications and to achieve a good sagittal balance, PSO must be associated with additional SPOs or a second corrective surgery to obtain a solid anterior fusion.

Keywords Sagittal spine imbalance · Pedicle substraction osteotomy · Mechanical complications

✉ Iulian Popa
medexpe@gmail.com

1 Orthopaedic and Traumatology Department, "Victor Babes" University of Medicine and Pharmacy, 300086, Matei Corvin str. 3, Timisoara, Romania

2 Medical Rehabilitation and Rheumatology Department, "Victor Babes" University of Medicine and Pharmacy, Timisoara, Romania

3 Medical Rehabilitation and Rheumatology Department, "Agrippa Ionescu" Hospital, Balotesti, Romania

Introduction

In case of sagittal spine imbalance, different compensation mechanisms are intervening—as much as the spine remains flexible, the kyphosis may be compensated by the hyperextension of the spine above and below the kyphotic segments. When the spine is rigid, the only way to compensate the kyphosis is to rotate the pelvis backward (retroversion). This mechanism is limited by the value of pelvic incidence (PI) and can be surpassed, with the patient being forced to flex the knees (Fig. 1a and b). Although both lumbar lordosis (LL) and thoracic kyphosis (TK) have an influence on final alignment, it has been demonstrated that it is the amount of lumbar lordosis in relation to the pelvic incidence (PI) that is the most influential parameter for the prediction of the final spinal balance. For this reason, pedicle substraction osteotomy

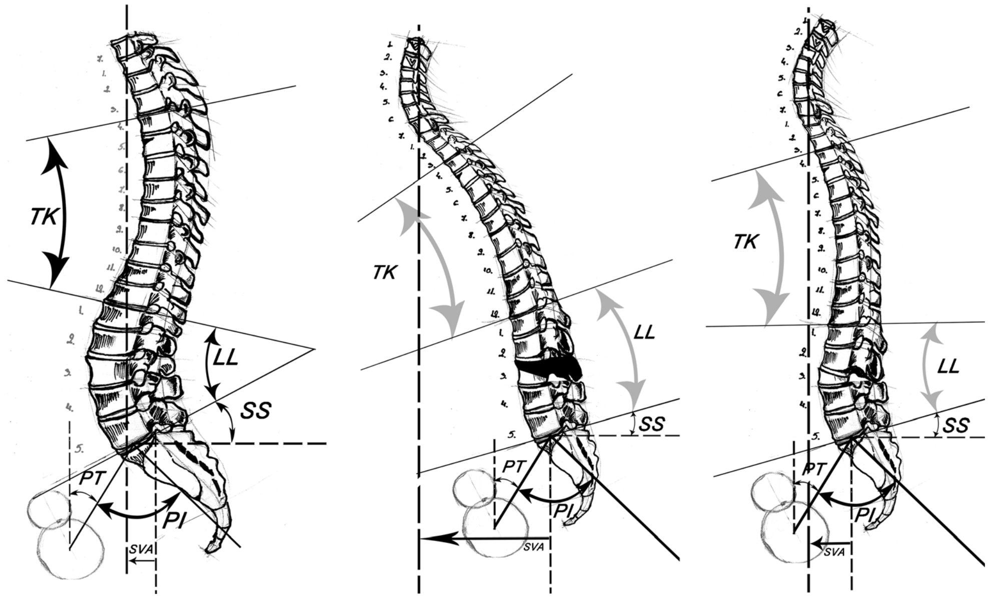

Fig. 1 **a** Sagittal spinopelvic radiological parameters in correct sagittal balance. **b** Sagittal spine imbalance. c Sagittal spine balance after PSO

(PSO) in the lumbar spine is indicated in the treatment of large sagittal deformities of the lumbar spine or its combination with coronal deformity, especially when the deformities are rigid and when a large correction of LL (25° or more) is necessary. In fact, PSO is frequently realized because of increasing rate of postoperative flatback syndrome [1] and also a better understanding of pathogenic factors of axial pain in patients with ankylosing spondylitis [2] or sagittal balance principles in patients with kyphotic deformity due to spinal tuberculosis [3].

The procedure is not risk-free [4]. Risk should be carefully assessed and discussed with the patient to obtain appropriate informed consent. Substantial complications associated with PSOs include substantial blood loss, transient neurologic deficit, pseudarthrosis and mechanical failure [5].

Materials and methods

Fifteen patients (3 males and 12 females) aged between 38 and 79 years (mean age 63.8 ±12.82) were operated on between June 2011 and September 2014 for sagittal imbalance by means of one-level PSO with pre-operative and post-operative valid standing full spine radiographs reviewed retrospectively. Seven of the patients had more than one previous surgery and fixed sagittal imbalance. All patients were operated by the same surgeon.

A radiograph was only considered valid if the following were visible: both the hip joints, S1 endplate, L4 upper endplate, L1 upper endplate and T3, T4, T5 upper endplate plus C7 vertebral body. The minimum follow up was six months.

Pre-operative and post-operative value of lumbar lordosis (LL), thoracic kyphosis (TK), sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS) were measured.

As shown schematically (Fig. 1a and b), T4-T12 thoracic kyphosis (TK) was recorded as the angle between the upper plateau of T4 and the lower plateau of T12, measured based on the Cobb method. Lumbar lordosis (LL) was based on the angle of the upper plateau of S1 to the upper plateau of L1. Sagittal vertical axis (SVA) or sagittal slope was taken as the measure of the horizontal distance between the C7 plumb line and the vertical line through the upper posterior limit of S1. The pelvic incidence (PI) is defined as the angle between the line perpendicular to the sacral plateau and the line connecting the midpoint of the plateau with the centre of femoral rotation. This morphological parameter is considered a constant, independent of the spatial orientation of the pelvis. The pelvic tilt (PT) corresponds to the angle between the line connecting the midpoint of the sacral plateau to the axis of femoral rotation and the vertical line. The sacral slope (SS) corresponds to the angle between the line of the sacral plateau and the horizontal line.

Many variants of spinal osteotomies have been described in the literature [5, 6]. For PSO, the upper endplate of the index vertebra and the upper intervertebral disk are usually respected. In some cases, when great angulation of correction is necessary (up to 30°), resection of the adjacent superior disk can be performed (Fig. 1c). This osteotomy resects not only the posterior vertebral body and posterior elements, but also an end plate and at least one adjacent disk.

The difference between pre- and post-operative value of the regional angle at the PSO level measured between the superior endplate of the adjacent upper vertebra and the inferior

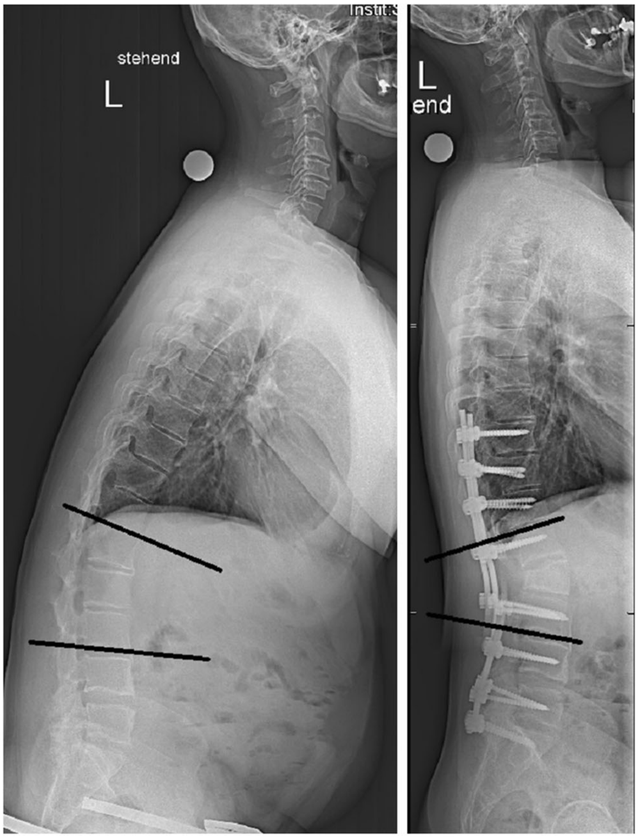

Fig. 2 Gain of lordosis provided by the PSO procedure. **a** Pre-operative. **b** Post-operative

endplate of the adjacent lower vertebra corresponds to the gain of lordosis provided by the PSO procedure (Fig. 2).

All radiological parameters were calculated using a specific validated quantitative analysis software SpineView 2.1 [7].

Indications for PSO were:

- Degenerative lumbar hypolordosis/kyphosis (n = 1)
- Post-operative flat back (n = 10)
- Post-traumatic lumbar hypolordosis/kyphosis (n = 3)
- Ankylosis spondylitis (n = 1)

Clinical and radiological evaluations were conducted pre-operatively and post-operatively at six months and one year. Clinical evaluation included intra- and post-operative complications.

Results

Pre- and post-operative radiological data and complications are summarized on Table 1.

Pre-operative 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 [8].

Table 1 Radiological characteristics of patients

Patient	Sex	Age (years)	Indication	PSO level	PI	SS preop	SS postop	SVA preop	SVA postop	LL preop	LL postop	Complication
1	F	79	Post-traum. lumbar Hypolordosis	L2	89	39	48	118	50	40	73	Dural tear
2	F	72	Degenerative lumbar hypolordosis	L2	50	35	32	130	60	37	55	–
3	F	76	Flat back	L2	58	36	31	80	110	13	37	Mechanical failure
4	F	53	Flat back	L1	40	22	24	87	125	4	37	–
5	F	77	Flat back	L2	65	28	31	40	25	33	55	Mechanical failure
6	F	70	Flat back	L2	56	11	20	66	39	30	59	–
7	M	58	Posttraum. lumbar kyphosis	L2	43	4	5	58	100	−18	20	Pseudarthrosis Mechanical failure
8	F	38	Achondroplasia Flat back	L1	63	38	40	75	−8	33	51	–
9	M	40	Ank. spondylitis	L2	45	25	25	200	100	−4	25	–
10	F	57	Flat back	L2	60	35	26	63	15	−20	31	–
11	F	74	Flat back	L3	54	34	34	115	95	2	24	Deep infection Mechanical failure
12	F	71	Flat back	L3	59	11	37	92	10	0	46	Mechanical failure
13	M	63	Flat back	L3	52	22	28	100	65	9	40	–
14	F	78	Post-traum. lumbar Hypolordosis	L2	44	14	20	89	80	10	42	–
15	F	54	Flat back	L2	45	16	22	89	60	15	46	Radicular deficit
		63.8 ± 12.8			54.86 ± 11.82	24.66 ± 11.03	28.2 ± 9.71	93.46 ± 36.69	61.73* ±38.68	12.26 ± 18.48	42.73* ±14.05	

F female, *M* male, *LL* lumbar lordosis, *SVA* sagittal vertical axis, *PI* pelvic incidence, *SS* sacral slope

SVA are expressed into millimetres (mm); LL, PI, SS, were measured in degrees (°)

* $p < 0.05$

Our target LL was based on the formula: LL = −(PI + 10°) [9]; in almost all cases, after the PSO there is a normalization of the lumbar lordosis measured between L1 and S1 (Fig. 2).

In cases where, after the pre-operative planning, we consider that PSO is not enough to get a good balance, we recommend additional SPOs (Fig. 3) or a second surgery by anterior approach, which was in most of our cases denied by the patients. In those cases, the undercorrection was the main cause of mechanical failure (4 cases, 26.66 %).

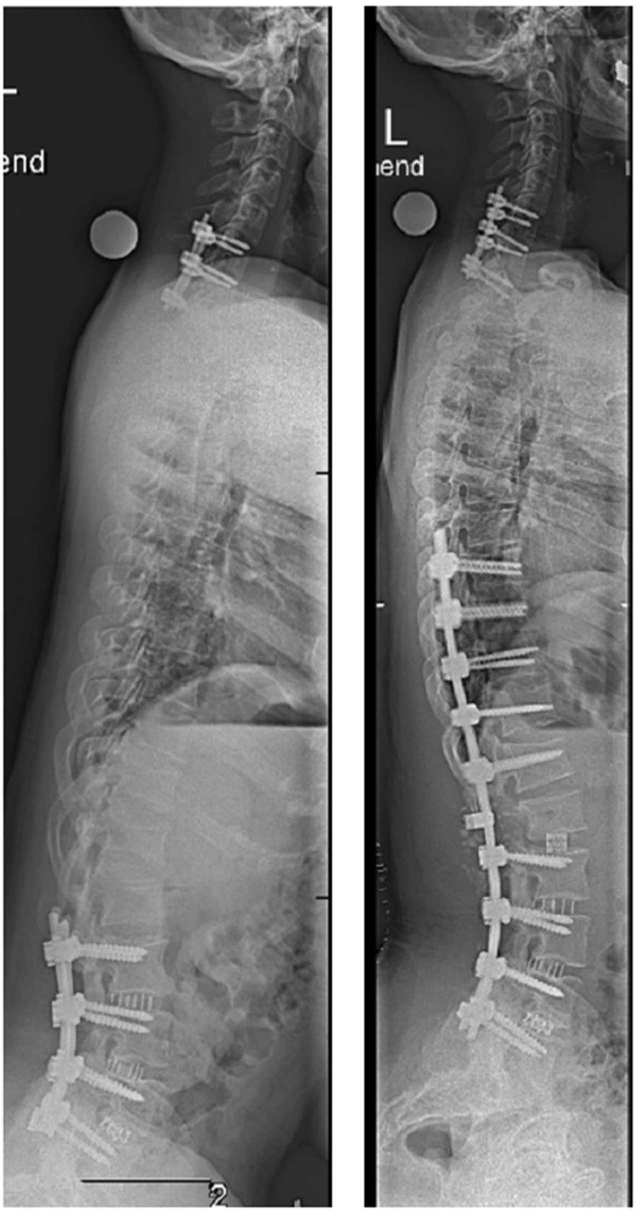

Fig. 3 Lateral X-ray showing good spinal sagittal balance after dorsal spondylodesis T8 – L5 with PSO L1, TLIF L1-L2 and Smith-Petterson osteotomies T9 – T12 in a patient with achondroplasia who was operated four years previously with dorsal instrumentation L2-L5, TLIF L4-L5 and XLIF L2-L3, L3-L4

In most cases (n = 10, 66.66 %), PSO was performed at L2. Only two cases were realized at L1 and three at L3. The instrumentation included the sacrum in 66.66 % of cases. Mean pelvic incidence was 54.86 ± 11.82°. Lumbar lordosis (LL) was measured to 12.26 ± 18.48° pre-operatively and increased to 42.73 ± 14.05° post-operatively ($p < 0.05$). Mean gain of lordosis after PSO at index level (Fig. 2) was calculated to 28 ± 11° (14–41°).

SVA decreased post-operatively from 93.46 ± 36.69 mm to 61.73 ± 38.68 mm ($p < 0.05$).

The adaptation of the spinal parameters to the new pelvic parameters takes obviously more time, as suggested Harms et al. [10]. In two cases the adaptation of the spinal parameters corresponded to a slight change of the pelvic parameters (increased retroversion) that suggested progressive loss of sagittal correction and are risk factors for follow-up complications. A suggestive case is represented in Table 2, Fig. 4. In these cases, we recommend a surgical intervention before a mechanical complication appears.

The late complication rate (hardware failures and mechanical complications) of PSO is substantially higher than other corrective procedures available for the treatment of sagittal imbalance, and the biomechanical explanations are still purely speculative [11].

Several complications (n = 8), including two minor (one dural tear with no clinical consequences and one transient radicular deficit) and six major with re-intervention were observed in our series.

In our series, we had mechanical complications in five cases (33.33 %). In one case there was rod breakage due to pseudarthrosis (6.66 %) (Fig. 5) and in four cases fracture of the cranial instrumented vertebra and loosening of the pedicle screws (26.66 %) due to undercorrection (Fig. 6).

The management of the mechanical complications after PSO required for the case with rod breakage, corpectomy, and additional anterior column support to maintain correction, for the case with cranial vertebra fracture, corpectomy, additional anterior column support and extension of instrumentation (Fig. 6) and for the other four cases with cranial instrumented vertebra fracture, extension of instrumentation was enough to avoid further complications.

The main goals of revision surgery after PSO failure are to restore the spinal balance through a posterior approach (hardware revision and extension of instrumentation) and correction through anterior approach in order to obtain a solid fusion [11].

Discussion

Optimal post-operative correction in the sagittal plane: SVA < 50 mm, LL = −(PI + 10°) is an important

Table 2 Radiographic changes suggesting progressive loss of sagittal correction

Measure	Pre-operative	Post-operative	Six months	12 months	18 months
SS	22	24	24	19	20
PT	18	16	16	21	20
PI	40	40	40	40	40
FA	25	15	15	10	0
LL	4	37	40	35	35
SVA	200	100	77	77	73
TK		24	38	50	50

LL lumbar lordosis, *SVA* sagittal vertical axis, *PI* pelvic incidence, *SS* sacral slope

SVA are expressed into millimetres (mm). LL, PI, SS, and FA (femoral angle) were measured in degrees (°)

parameter to reduce the risk of developing sagittal decompensation which is a common condition after PSO [12]. Rate of complications after PSO is not negligible in the literature up to 45 % [13, 14]. Amzallag et al. [14] 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 five years. He found that the aetiology of the spine deformity influences the rate of complications after PSO (more complications for iatrogenic flat-back syndrome and patients with multiple spinal interventions).

Smith et al. revealed an incidence of 15.8 % of symptomatic rod breakage in patients who underwent PSO procedure at least at one level [15]. According to Cho et al. the instrumentation failure/pseudarthrosis is the most frequent follow-up complication with a 34 % rate in the PSO population [16].

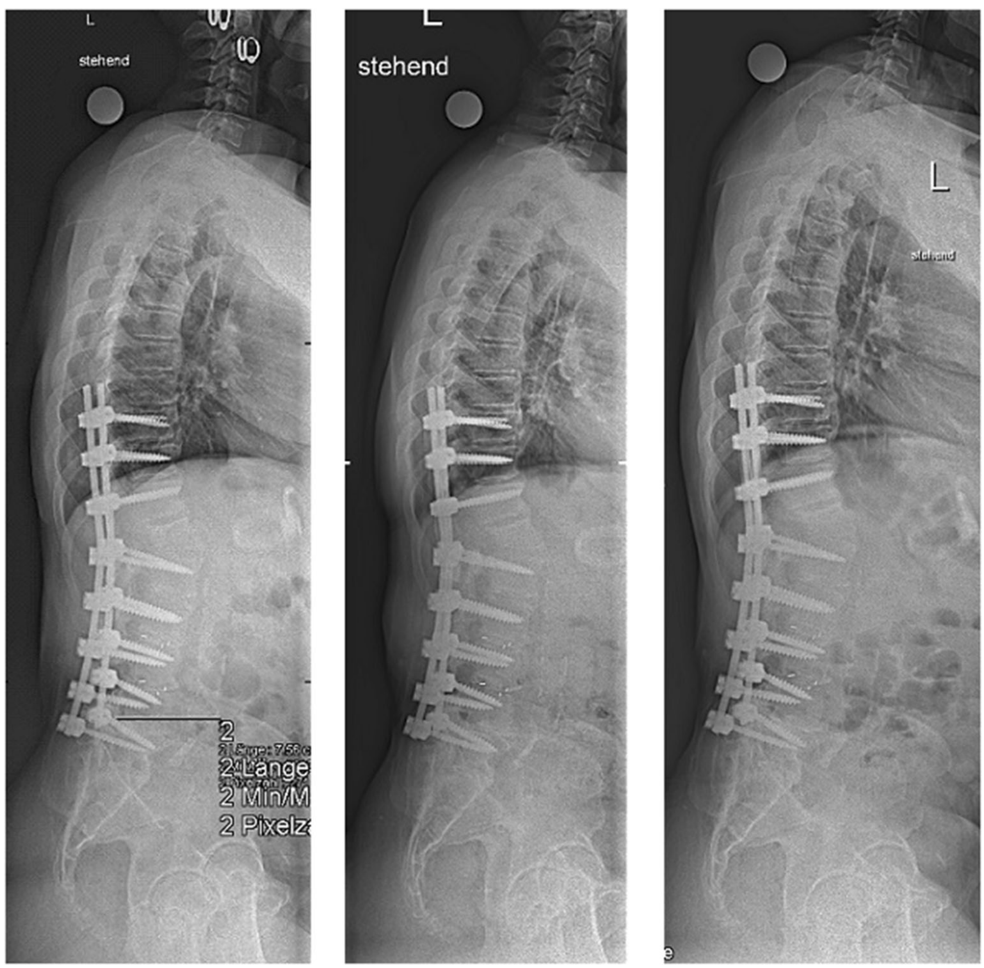

Fig. 4 Radiographic changes suggesting progressive loss of sagittal correction. **a** Post-operative PSO L1. **b** Six-month follow up. **c** 18-month follow up

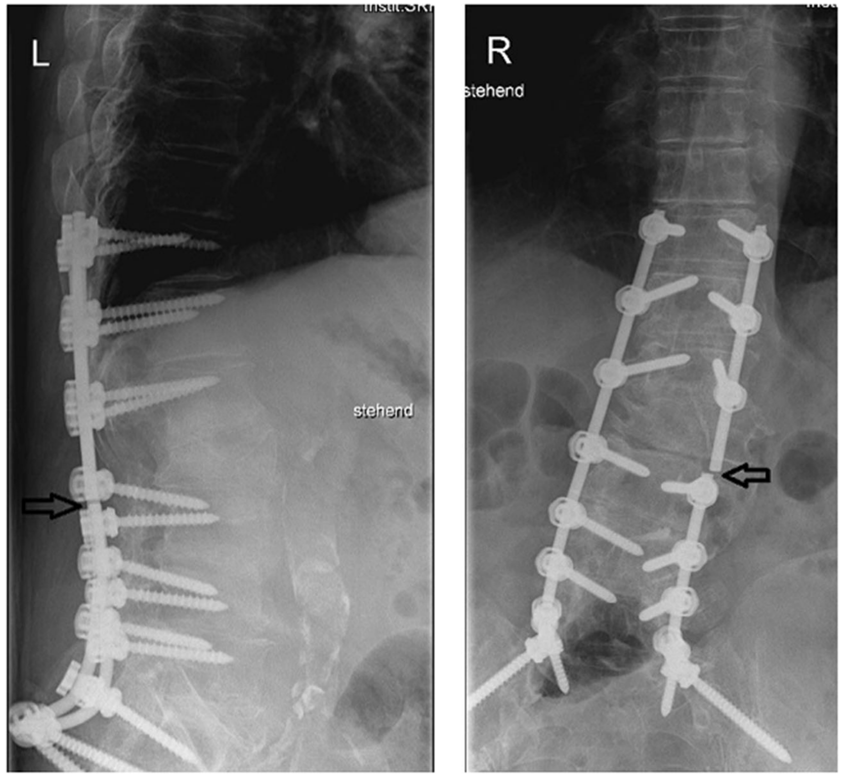

Fig. 5 Rod breakage due to pseudarthrosis 24 mo after PSO L2 and T11-ilium spondylodesis

Lehman et al. [17] recommended that two transverse connectors will significantly improve torsional rigidity of the entire construct and at the PSO site, with no differences in rigidity for flexion-extension and lateral bending, or with the addition of only one transverse connector. Le Huec et al. [18] states that good surgical practice should be associated with an anti-adhesion barrier to decrease fibrosis formation. In our practice, for complex spine surgeries, we always use a collagen membrane for adhesion prevention.

Fig. 6 Lateral X-ray of a patient six months after posterior spinal fusion from T9 to S1, PSO L3 and PLIF L1-L2 demonstrating jonctional kyphosis with T9 fracture and T9 screw loosening (**a**). We performed extension of instrumentation to T3 and corpectomy T9 by costotransversectomy (**b**)

Conclusions

PSO is a highly efficient technique to recreate lordosis in the lumbar spine and is indicated to treat rigid sagittal imbalance due to a great variety of spinal pathologies. It is technically demanding and should be performed by experienced teams. Particular attention must be payed to pre-operative planning before sagittal correction procedures [19]. The main cause of mechanical complications, such as non-union or junctional kyphosis, was insufficient sagittal correction, as calculated by the formula $LL = -(PI + 10°)$. The risks of insufficient correction are greater in patients with higher pelvic incidence and those patients who required very high correction. In these cases, PSO is not enough to achieve a good sagittal balance, and it must be associated with a SPO or a second corrective surgery by anterior approach. To limit the risk of mechanical complications and to achieve a good sagittal balance, PSO must be associated with additional SPOs or a second corrective surgery by ALIF or XLIF to obtain a solid anterior fusion.

References

1. Potter BK, Lenke LG, Kuklo TR (2004) Prevention and management of iatrogenic flatback deformity. J Bone Joint Surg Am 86(8): 1793–1808
2. Braun JV, Van den Berg R, Baraliakos X, Boehm H, Burgos Vargas R, Collantes-Estevez E, Dagfinrud H, Dijkmans B, Dougados M, Emery P, Geher P, Hammoudeh M, Inman RD, Jongkees M, Khan MA, Klitz U, Kvien TK, Leirisalo-Lepo M, Maksymowich WP, Olivieri I, Pavelka K, Sieper J, Stanislawska-Biernat E, Wendling D, Ozgocmen S, van Drogen C, van Royen BJ, van der Heijde D (2011) 2010 update of the ASA/EULAR recommendations for the management of ankylosing spondylitis. Ann Rheum Dis 70(6): 896–904
3. Rajasekaran S (2012) Kyphotic deformity in spinal tuberculosis and its management. Int Orthop 36(2):359–365
4. Berven SH, Deviren V, Smith JA, Emami A, Hu SS, Bradford DS (2001) Management of fixed sagittal plane deformity: results of the transpedicular wedge resection osteotomy. Spine (Phila Pa 1976) 26(18):2036–2043
5. Bridwell KH, Lewis SJ, Edwards C, Lenke LG, Iffrig TM, Berra A, Baldus C, Blanke K (2003) Complications and outcomes of pedicle subtraction osteotomies for fixed sagittal imbalance. Spine (Phila Pa 1976) 28(18):2093–2101
6. Bridwell KH (2006) Decision making regarding Smith-Petersen versus pedicle subtraction osteotomy versus vertebral column resection for spinal deformity. Spine 31:S171–S178
7. Champain S, Benchikh K, Nogier A, Mazel C, De Guise J, Skalli W (2006) Validation of new clinical quantitative analysis software applicable in spine orthopaedic studies. Eur Spine J 15(6):982–991
8. Barrey C, Perrin G, Michel F, Vital JM, Obeid I (2014) Pedicle subtraction osteotomy in the lumbar spine: indications, technical aspects, results and complications. Eur J Orthop Surg Traumatol 24(Suppl 1):S21–30
9. Berjano P, Langella F, Ismael MF, Damilano M, Scopetta S, Lamartina C (2014) Successful correction of sagittal imbalance can be calculated on the basis of pelvic incidence and age. Eur Spine J 23(Suppl 6):587–596
10. Harms J (2002) Severe Spondylolisthesis: Pathology, Diagnosis, Therapy. Springer Science & Business Media, FOV-80
11. Luca A, Lovi A, Galbusera F, Brayda-Bruno M (2014) Revision surgery after PSO failure with rod breakage: a comparison of different techniques. Eur Spine J 23(6):610–615
12. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V (2010) Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. Spine 35:2224–2231
13. Hyun SJ, Rhim SC (2010) Clinical outcomes and complications after pedicle subtraction osteotomy for fixed sagittal imbalance patients: a long-term follow-up data. J Korean Neurosurg Soc 47:95–101
14. Amzallag J (2008) Complications of spinal osteotomies: multicenter study of 402 cases [in French]. Paris Val-de-Marne University, Creteil
15. Smith JS, Shaffrey CI, Ames CP (2012) Assessment of symptomatic rod fracture after posterior instrumented fusion for adult spinal deformity. Neurosurgery 71:862–868
16. Cho KS (2012) Major complications in revision adult deformity surgery. Risk factors and clinical outcomes with 2- to 7-year follow-up. Spine 37:489–500
17. Lehman RA Jr, Kang DG, Wagner SC, Paik H, Cardoso MJ, Bernstock JD, Dmitriev AE (2015) Biomechanical Stability of Transverse Connectors in the Setting of a Thoracic Pedicle Subtraction Osteotomy. Spine 15(7):1629–1635
18. LeHuec JC, Sadikki R, Cogniet A, Rigal J, Demezon H, Aunoble S (2015) Role of a collagen membrane in adhesion prevention strategy for complex spinal surgeries. Int Orthop 39(7):1383–1390
19. Le Huec JC, Leijssen P, Duarte M, Aunoble S (2011) Thoracolumbar imbalance analysis for osteotomy planification using a new method: FBI technique. Eur Spine J Suppl 5:669–680