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ORIGINAL ARTICLE

Three-level lumbar Ponte osteotomies with less invasive pelvic fixation improve spinal balance, quality of life and decrease disability in adult and elderly women with moderate adult spinal deformity

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Abstract

Purpose To report on quality of life and radiological changes of Ponte osteotomies (POs) with long fixation for primary and revision surgery, in elderly women with adult spinal deformity (ASD).

Methods Sixty-seven (67) women, aged 69 ± 7 years, received 3 POs, spinopelvic fixation plus TLIFs. Forty-nine (73%) patients received primary and 18 (27%) revision surgery. Survivorship analysis was made for unplanned revision surgery for broken rods (BR); proximal junction failure (PJF); and deep wound infection (DWI). ODI and SF-36 were used for disability (ODI) and quality of life (SF-36) evaluation.

Results In total, 201 lumbar POs were made and 9.55 ± 3 levels fused. All patients were available 49 ± 11 months postoperatively. Postoperatively, SVA, CSVL, PI-LL, scoliosis, PT and T9-spinopelvic inclination were reduced, while LL and SS were increased significantly. At the final visit, PI−LL ≤ 10° was achieved in 26 (39.4%) patients; ≤ 15° in 51 (76%) patients, while all 67 patients showed a PI−LL ≤ 20°. Unplanned reoperation was performed in 11 (16.4%) patients: for BR in 5 (7.5%); for PJF in 3 (4.5%) and for DWI in 3 (4.5%) patients, respectively. With end point the reoperation for any reason the survival ± SE was 67.8% ± 0.1; for PJF 89.6 ± 0.065; and for BR 76% ± 0.1 in the final evaluation. There was no difference in survival between the primary and revision surgery groups ($P = 0.568$). ODI and SF-36 scores were improved postoperatively.

Conclusions Three-segment lumbar POs offered and maintained sufficient improvement of lumbar lordosis along with restoration of the sagittal and coronal spinal alignment, improvement of quality of life and disability of female adult and elderly population after primary and revision surgery for ASD.

Keywords Adult spinal deformity · Scoliosis · Ponte osteotomy · Broken rod · Proximal junction failure

Introduction

Reconstruction spine surgery is considered as the final therapeutic option for symptomatic adult spinal deformity (ASD) patients. Currently, the goals of ASD surgery are the reduction of pain, the realignment of the spine, the reduction of the deformity and the improvement of quality of life in adult and elderly patients. The contemporary ASD surgery includes posterior, anterior, lateral interbody fusion or combined surgery.

A posterior-only surgical approach can address both sagittal and coronal spinal deformities preventing the morbidity of an anterior approach, obtaining similar correction to that provided via a combined approach [1, 2].

There are few reports available on the multi-level lumbar Ponte (POs) [2] of Smith Peterson (SP) osteotomies alone or in combination with interbody implants and iliac screws, especially in long fusions and osteoporotic spine in ASD patients [2, 3]. The combination of spinopelvic fixation and TLIF provides an improved spinal construct in terms of biomechanical strength reducing complications (rod breakage, pseudarthrosis, etc.) [2, 3].

We present a single-institution experience evaluating the use of 3-level POs plus spinopelvic fixation and TLIF for the restoration of sagittal and coronal alignment in a homogenous elderly female ASD population in primary and revision surgery. We hypothesized that adequate lumbar lordosis

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can be restored with POs and TLIF in order to: (a) achieve lumbopelvic harmony, (b) restore sagittal and coronal balance and (c) improve disability in patients with moderate imbalance.

Materials and methods

From January 2011 till January 2013, 219 Ponte lumbar osteotomies were performed for symptomatic ASD in 73 (67 females and 6 males) consecutive adult and elderly patients as primary and revision surgery in a single Orthopedic Spine Institution, by the same surgical team. In order to have a homogenous population, only the 67 women, aged 69 ± 7 years, were included in this study. The ASA score was I–III and the BMI was 30 ± 6. ODI and SF-36 questionnaires were used preoperatively till the last observation for patients who did not receive revision surgery for BR and PJF. The inclusion criteria were: women aged > 50 years, postmenopausal status, SVA 5–9 cm, degenerative lumbar or thoracolumbar scoliosis ≤ 40°, lumbar spondylolisthesis Meyerding I–III, "iatrogenic" postsurgical deformity, > 5 levels instrumentation, follow-up > 2 years and available full spine and pelvis roentgenograms preoperatively and at 3 time points postoperatively until the final observation (Table 1).

The exclusion criteria were: non-degenerative deformity etiology; fresh vertebral fracture; spinal cord injury; spinal metastasis; active spinal infection; and Parkinson dystonia. The diagnosis of sagittal imbalance was based on the following radiographic parameters at baseline: (a) SVA ≥ 5 cm, (b) PI−LL > 10° and (c) PT > 20°.

Table 1 Overall demographics of 67 female patients who underwent 201 POs for primary and revision cases

Age (y)	69 ± 7 (range 51–77)
BMI	30 ± 6 (range 21–41)
Previous fusion, *N* (%)	18 Pts (26%)
Levels previously fused in 18 Pts (*N*)	4.9 ± 2.3 (range 2–6)
Deformity	
Adult degenerative scoliosis	28 (41.8%)
Loss of sagittal balance, osteoporosis	67 (100%)
"Latrogenic" sagittal and/or coronal deformity	18 (27%)
Surgical data	
Average spinal levels fused	9.6 ± 3 (range 5–17)
Total osteotomies	201
Osteotomies per patient	3
Mean blood loss (mL)	660 ± 310
Mean operative time (h)	4 ± 1.2
Average follow-up (months)	69 ± 26

Standing anteroposterior and lateral full spine; and pelvis roentgenograms were taken on admission, 3 months postoperatively and thereafter once a year, till the final observation. Forty-nine (73%) patients received primary surgery for ASD, and 18 (27%) received revision surgery after one or more failed instrumented lumbar fusion(s) performed in another institution (Table 1). The indications for unplanned revision surgery were: (a) broken rods with/without evident pseudarthrosis, (b) proximal junction failure (defined as fracture of the uppermost instrumented vertebra or screw cutoff in the uppermost instrumented vertebra) and (c) deep spinal infection. This study was approved by the authors' institution ethics committee. Written informed consents were obtained from all participants.

The roentgenographic parameters measured on admission and in the follow-up evaluations were: sagittal vertical axis (SVA), thoracic kyphosis T4–T12 (TK), lumbar lordosis L1–S1 (LL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), T9-spinopelvic inclination (T9-SPI) [6, 7], PI minus LL (PI−LL) and distal segmental lordosis L_4–S_1 (DSL). The coronal imbalance was measured by the horizontal offset of the C7-plumb line (C7PL) from the central sacral vertical line (CSVL). Pre- and postoperative consultations were made by an unbiased observer (VS, third author). We have not assessed the preoperative flexibility in this series as others also did [2] since the cooperation with old and elderly patients with often biplane deformity is often difficult and subsequently the results are rather unreliable. Furthermore, there was an issue with the revision cases where a preoperative flexibility could not represent the actual spinal flexibility after instrumentation removal. In contrary, we evaluated the spinal flexibility and determined the levels of osteotomies after placing the patients in prone position on the operation table after intubation. All roentgenographic measurements in preoperative and postoperative digital *X*-rays were made by two unbiased observers (EM 2nd and vs. 3rd author), who did not participate in these surgeries using the Surgimap program (Surgimap Spine, Nemaris Inc., New York, USA) with documented high reliability and reproducibility. Oblique roentgenograms for the evaluation of the achieved fusion were taken first, one year postoperatively. In the case of suspicion of pseudarthrosis, particularly in the presence of broken rods, CT scans were taken.

Surgical technique

Through a short longitudinal skin incision of 3 cm over each posterior superior iliac spine, one 8–9-mm-thick and 80–90-mm-long iliac screw was inserted through a notch appropriately made with chisel to cover the iliac screw tulip. Subsequently, a straight midline incision was made from the planned proximal vertebra to the S1-vertebra. In this series, three-level wide resection of posterior elements of the vertebrae, facet joints down to the lower vertebra pedicle was made. The complete removal of the spinous processes, superior and inferior facets, and all intervening ligaments were performed at each segment to achieve the desired level of correction. In the revision cases, the POs always included the pseudarthrosis levels which were identified and meticulously cleaned down till bleeding bone. One to three unilateral expandable oblique PEEK TLIFs filled with bone graft were inserted in 1–3 of the segments from L2–L3 to L5–S1. The expandable TLIF cage was inserted, after filling the intervertebral disc space with bone graft, in a diagonal fashion and pushed far anteriorly under image intensifier monitoring to identify its position in both anteroposterior (middle of the vertebral bodies of adjacent vertebrae) and lateral plane (anterior and middle third of the vertebra). The length of the selected TLIF is about 4–6 mm less than the projected diagonal-sagittal diameter of the endplate at the level of its insertion. Thus, in all cases the TLIF was located close to the anterior 2/3 of the endplates of the operated segment (Fig. 1). Two longitudinal rods, subfascially inserted between L5 pedicles and iliac screws, were appropriately contoured to the desired correction bridging the spine and iliac screws. Meticulous decortication of the posterior spinal elements was performed, and mixed autogenous local bone and homologous bone graft were placed. All surgeries were conducted under biplane image intensifier control and neuromonitoring. Custom-made TLSO is applied in all patients for 3 months.

Statistical analysis

Data were analyzed using SPSS (v.18, SPSS, Inc., Chicago, IL, USA). Continuous data were reported as mean ± SD and categorical data as frequencies and percentages. The continuous roentgenographic variables included in the analysis were: SVA, CSVL, TK, LL, PI, PT, SS, PI-LL and T9-SPI. For analysis purposes, the categorical variables were graded as follows: biplane deformity = 1,exclusively sagittal deformity = 0; proximal junctional failure (YES = 1, NO = 0); broken rods(YES = 1, NO = 0); deep wound infection (YES = 1, NO = 0). The Levene's test of variance homogeneity was used to test whether the variance within each of the populations was equal or not. The paired t test was used to compare the same continuous variable changes between two periods of observation. The unpaired *t* test was used to compare continuous variable changes between different groups. One-way ANOVA was used to compare the difference of means of continuous variables between 2 or more groups of each categorical variable, with Bonferroni multiple-comparison test, if the global tests indicated significance. Pearson's correlation coefficients were determined to compare continuous variables. Statistically significant differences were defined by $P < 0.05$. Kaplan–Meier survival analysis was used to calculate the survival within 95% CI for unplanned surgery for three major surgical complications: (a) BR, (b) PJF and (c) DWI. These complications were compared between the two surgery groups (primary vs revision) using log-rank Chi-squared test. Kappa values were used for inter- and intraobserver reliability in radiological measurements.

Results

Anthropometric and surgical details are shown in Table 1.

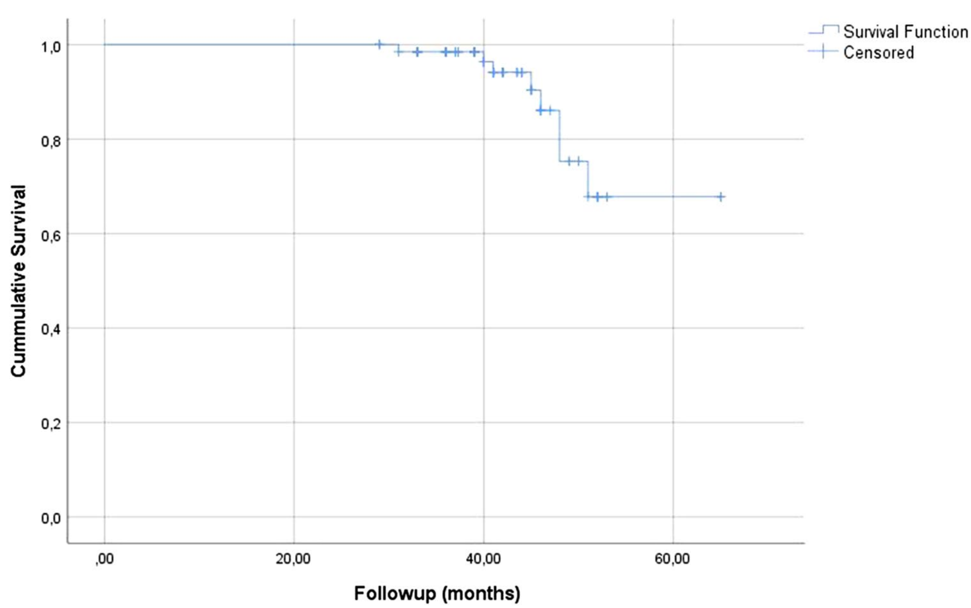

Fig. 1 Kaplan–Meier survival curve for all 67 patients for unplanned surgery for any reason

The intra- and inter-observer kappas for digital radiological measurements ranged from 0.94 to 0.96.

The preoperative ODI score of 65.66% ± 19.6 (severe disability) improved postoperatively to 36.44% ± 12.4 (moderate disability) ($P < 0.001$).

Eight from the 9 domains of SF-36 were improved significantly postoperatively. The domain general health did not improve postoperatively (Fig. 2).

The average ± SD follow-up was 49 ± 11, ranging 29–67 months. Postoperatively, scoliosis angle, CSVL, SVA, PT, T9-SPI, SS and PI−LL were reduced significantly, while LL and remained unchanged till the final evaluation. TK was increased significantly in 2 phases: postoperatively and at the final evaluation (Table 2).

The number of patients with lumbopelvic harmony increased significantly from 2 (3%) preoperatively to 26 (39.4%) patients at the final observation (Table 2).

There was no statistically significant difference in the roentgenographic parameters on baseline and at the last observation between primary and revision groups (Table 3).

The average segmental lordosis correction of 6.29 ± 2.3° achieved per osteotomy in the primary surgery group did not differ from that of 6.05 ± 1.87° achieved in the revision surgery group (unpaired *t* test, $P = 0.76$) (Table 3).

Age was significantly correlated with fused levels ($P < 0.05$), preoperative SVA ($P < 0.05$); T_9-SPI ($P < 0.05$); PT ($P < 0.001$) (Table 4).

BMI and the number of fused spinal levels were significantly correlated, with preoperative TK ($P < 0.001$) and L_4–S_1 lordosis ($P < 0.05$) (Table 4).

Fused levels were correlated with preoperative TK ($P < 0.02$) and with L4–S1 lordosis ($P < 0.01$).

Preoperatively, SS was correlated with LL ($P < 0.0001$) and TK ($P < 0.05$) preoperatively.

PT was correlated with lumbopelvic harmony ($P < 0.01$) and L4–S1 lordosis ($P < 0.01$).

Degrees of correction per osteotomy was correlated with preoperative L4–S1 lordosis ($P < 0.05$).

In the final evaluation, age was correlated with L4–S1 lordosis ($P < 0.001$), SVA ($P < 0.001$) and PT ($P < 0.01$).

PI−LL was correlated with SVA ($P < 0.05$) and PT ($P < 0.01$), while T9-SPI with PT ($P < 0.05$) (Table 5).

Complications

Eighteen major and 10 minor complications occurred in 18 (27%) patients (Table 6).

DWI, caused by *Pseudomonas Aeruginosa* or *E. Coli*, occurred in 3 (4.5%) patients 2–4 weeks postoperatively (Table 6). DWI was significantly more frequent in patients with higher preoperative BMI (ANOVA, $P = 0.008$) and PT (Table7).

PJF was recorded in 7 (14%) patients > 40 months postoperatively (Table 6).

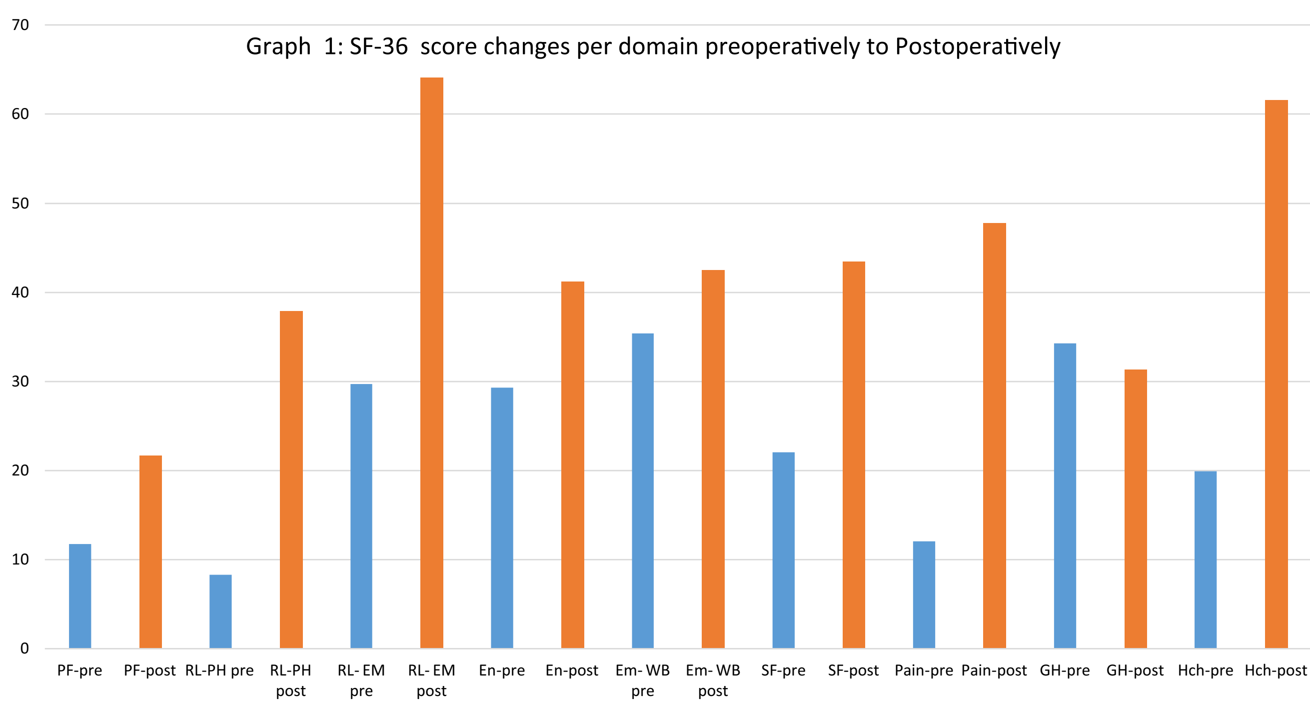

Fig. 2 SF-36 score changes per domain preoperatively to Postoperatively

Table 2 Roentgenographic parameters changes preoperatively to postoperatively and to the last follow-up

Parameter	Preoperatively	Postoperatively	*P* value pre/post	Last f-up	*P* value postop/last follow-up
Th kyphosis (T4–T12)	28.8° ± 12.26	32.62° ± 9.78	0.0035	34.35° ± 9.43	0.014
LL (L1–S1)	23.09° ± 10.6	42.14° ± 8.47	< 0.001	42.78° ± 7.33	0.12
PI−LL	28.62 ° ± 10.07	9.55° ± 10.32	< 0.001	9.58° ± 10.09	0.77
SVA (cm)	7.99 ± 0.82	3.38° ± 0.99	< 0.001	3.75 ± 0.94	0.26
T9-spinopelvic inclination	−8.9° ± 10.3	1.85° ± 5.9	< 0.001	3.29° ± 5.3	0.50
CSVL (cm)	2.42 ± 2.11	0.75 ± 1.4	0.043	0.81 ± 1.22	0.31
Scoliosis	25.15° ± 10.75	9.80° ± 6.94	< 0.001	9.86° ± 6.99	0.42
SS	20.59° ± 10.71	25.79° ± 9.5	< 0.001	27.39° ± 9.4	0.78
PT	34.5° ± 12.26	21.6° ± 7.06	< 0.001	19.86° ± 6.50	0.31
PI−LL difference*					
PI−LL ≤ 10	2 (3%)			26 (39.4%)	
PI−LL ≤ 15	6 (9%)			51 (76%)	
PI−LL ≤ 20	12 (18%)			67 (100%)	

LL lumbar lordosis, *PI−LL* pelvic incidence minus lumbar lordosis (pelvic harmony), *SVA* sagittal vertical axis, *CSVL* central sacral vertical line, *SS* sacral slope, *PT* pelvic tilt

*No patient showed PI−LL > 20 degrees either preoperatively or postoperatively

Table 3 Comparison of preoperative and postoperative roentgenographic parameters between 49 patients with primary versus 18 patients with previous instrumented fusion

	Primary group (*N* = 49 pts)			Revision group (*N* = 18 pts with previous fusion)		
Parameter	Preoperatively	Last f/up	*P* value*	Preoperatively	Last f/up	*p* value**
LL	20.37 ± 10.8°	40.85 ± 6.26°	0.21	26.27 ± 9.4	44.6 ± 8.6	0.29
TK	28.27 ± 11.14°	32.48 ± 9.4°	0.83	28.07 ± 15.08	35.38 ± 9.64	0.61
PI−LL	27.45 ± 10.78°	7.48 ± 9.66	0.69	29.7 ± 8.6	11.6 ± 10.5	0.66
SVA (cm)	7.57 ± 0.85	3.6 ± 0.92	0.57	7.44 ± 0.64	3.92 ± 0.93	0.79
T9-spinopelvic	−8.9 ± 10.35	2.8 ± 5.88	0.62	−8.38 ± 11.69	4.06 ± 4.98	0.88
CSVL (cm)	2.13 ± 1.67	1.53 ± 1.26	0.20	3.55 ± 2.24	0.45 ± 1.01	0.13
Correction per PO		6.29 ± 2.3°			6.05 ± 1.87°	0.76

LL lumbar lordosis; *TK* thoracic kyphosis, *PI−LL* pelvic incidence minus lumbar lordosis, *SVA* sagittal vertebra axis, *CSVL* central sacral vertical line

**P* value, unpaired t test between preoperative values of the two groups (primary vs revision group)

***p* value, unpaired t test between postoperative values of the two groups (primary vs revision group)

PJF was more frequent in cases with increased preoperative TK ($P = 0.01$) (Table 7).

BR was radiologically evident > 31 months postoperatively in 8 (12%) patients (Table 6). BR was more frequent in patients with higher preoperative PT values ($P = 0.006$) and L4–S1 lordosis ($P < 0.023$) (Table 7). The level of BR line was found in all revised cases close to pseudarthrosis and/or crosslink level.

Unplanned surgery for BR associated with symptomatic pseudarthrosis was made 31–51 months following our surgery in 5/8 (7.2%) patients and for PJF in 3/7 (4.5%) patients 40–48 months postoperatively (Table 6).

In all 5 cases that were revised for BR, pseudarthrosis was intraoperatively shown.

Survival analysis

With endpoint unplanned revision surgery, for BR, PJF and DWI, the cumulative survival ± SE was 96.4% ± 0.026 and 67.8% ± 0.1 forty (40) months postoperatively and final evaluation, respectively (Fig. 1).

With endpoint revision surgery for symptomatic PJF, the survival ± SE was 97.9% ± 0.021 and 89.6% ± 0.065 forty months postoperatively and at the final evaluation, respectively (Fig. 3).

With endpoint revision surgery for BR, the survival ± SE was 98.5% ± 0.015 and 76% ± 0.1 40 months postoperatively and at the final observation, respectively (Fig. 4).

Table 4 Pearson's correlation coefficient matrix between preoperative anthropometric and roentgenographic parameters in 67 patients

	Age	BMI	Fused levels	SVA	T9-spinopelvic	SS	PT	PI	PI−LL	LL	Degrees achieved with POs	TK preop	L4–S1 lordosis
Age	1	0.099	**−0.264***	**−0.257***	**−0.276***	−0.202	**0.372*****	0.011	−0.146	0.152	0.067	0.077	−0.106
BMI		1	−0.133	−0.195	0.057	0.150	−0.070	0.011	−0.143	0.149	−0.146	**0.371*****	**−0.274***
Fused levels			1	0.110	0.077	−0.236	−0.041	−0.212	−0.089	−0.162	0.058	**0.299****	**0.378*****
SVA				1	0.003	0.091	0.2	0.044	0.202	−0.141	−0.083	0.055	0.133
T9-spinopelvic					1	0.143	−0.103	0.033	0.179	−0.132	−0.076	−0.182	0.054
SS						1	−0.056	**0.555******	0.242	**0.416******	−0.199	**0.256***	0.007
PT							1	**0.322****	**0.360*****	0.032	−0.017	−0.059	**0.33*****
PI								1	**0.568******	**0.624******	−0.102	0.164	0.219
PI−LL									1	**−0.289***	−0.057	−0.210	**0.4*****
LL										1	−0.062	**0.391*****	−0.126
Degrees achieved with POs											1	−0.036	**0.276***
TT												1	0.018
L4-S1 lordosis													1

Significant P values are in bold

*$P = 0.05$

**$P < 0.02$

***$P < 0.01$

****$P < 0.001$

Table 5 Pearson's correlation matrix between roentgenographic and anthropometric parameters in 67 patients in the final follow-up evaluation

	L4–S1 lordosis	Age	BMI	SVA	Fusion levels	T9-spinopelvic	PI	PI–LL	SS	PT	LL	TK
L4–S1 lordosis	1	**−0.64******	0.042	0.177	0.198	0.008	−0.043	0.142	**−0.317****	0.072	**−0.278***	−0.192
Age		1	0.099	**−0.484******	**−0.264***	−0.227	−0.073	−0.006	**−0.363*****	**0.398*****	−0.235	0.164
BMI			1	0.098	-0.113	0.184	0.048	−0.031	−0.174	−0.055	0.067	**0.411*****
SVA				1	0.160	0.091	**0.299***	**0.265***	0.020	0.001	0.175	0.011
Fusion levels					1	0.083	−0.182	−0.167	−0.124	−0.180	−0.130	0.235
T9-spinopelvic						1	−0.052	0.053	0.202	**−0.267***	−0.142	0.035
PI							1	**0.738******	**0.425*****	**0.330*****	**0.623******	0.204
PI–LL								1	0.159	**0.347*****	0.091	0.060
SS									1	−0.058	**0.465******	−0.029
PT										1	0.111	−0.228
LL											1	0.24
TK												1

Significant *P* values are in bold

*$P = 0.05$

**$P < 0.02$

***$P < 0.01$

****$P < 0.001$

No significant differences were found comparing the primary and revision group with endpoint revision surgery for any reason (BR, PJF or DWI). The log-rank (Mantel-Cox) showed a Chi-square value of 0.326, $P = 0.568$ (Fig. 5).

Discussion

Currently, the most commonly used approach for correcting spinal imbalance in ASD is the posterior. Although low reoperation rates are intended, surgical complications mostly related to instrumentation increase the risk for unplanned surgery [2, 4–6]. In our study, 67 female patients, suffering from ASD and spinal imbalance, underwent successful 3-level lumbar POs for primary and revision causes with similar $6.29 \pm 2.3^{\circ}$ correction per osteotomy, without a significant loss of correction 49 ± 11 months following surgery. Overall, an average preoperative SVA of 8 cm was reduced to 3.3 cm, with a mean LL on long-term follow-up of 42°, and the cases with spinopelvic harmony increased from 3% preoperatively to 39.4% at the final observation. In this series, we demonstrated the effective use of posterior POs surgery for roentgenographic parameters and quality of life domains improvement in elderly women with moderate ASD (Figs. 2, 6). The restoration of the sagittal spinal balance in primary and revision cases is considered as the most important predictor for the patient's outcome in ASD surgery. Radiographic parameters such as SVA ≥ 5 cm and PT ≥ 26° are risk factors for complications and strongly correlated with spinopelvic harmony [7]. Lafage et al. [4] showed that SVA, PT and (PI-LL) are correlated with health-related quality of life. In our series, ODI was improved significantly from severe to moderate disability at the last observation in the patients who did not undergo revision surgery for BR and PJF. Significant postoperative improvements in 8 from 9 domains of SF-36 were shown in our patients.

High mechanical complication rates responsible for unplanned reoperations continue to be a significant concern for the spine surgeons in ASD reconstruction surgery [6–11]. The 27% complication rate in our series was within the reported rates (24.2–28.1%) in similar studies [2, 6–11].

The reported rate of unplanned surgery following ASD corrective surgery ranges from 10.5 to 16.5% [8, 9] and increases progressively with the time following surgery to 12.3% and 17.7% for 3- and 12–25-month follow-up [8, 9]; or 10.5 and 18.5% at 12-month and 60-month follow-up, respectively [9]. In our study, 8 (11.9%) patients underwent unplanned surgeries for mechanical complications (PJF, BR). The most common indication for reoperation after ASD surgery in the Crawford's series [7] was BR with pseudarthrosis, occurring 9–44 months after index surgery and accounted for 62% of the reoperations, while the second most common indication was PJF. Similarly, in our

Table 6 Twenty-eight major and minor complications in 18(27%) patients operated for adult spinal deformity

Major complication	Number of complication primary group *N* (%)*	Number of complication revision group *N* (%)*	Total (%)	Revision surgery per major complication
Proximal junctional failure	4 (8.1%)	3 (16.6%)	7 (10.4%)	3 (4.5%)
Broken rods	4 (8.1%)	4 (22.2%)	8 (12%)	5 (7.4%)
Deep wound infection	1 (2%)	2 (11.1%)	3 (4.5%)	3 (4.5%)
Minor complication				
Temporary neurological complication**		3 (16.6%)	3 (4.5%)	
			1 (1.5%)	
Accidental durotomy		1		
Iliac tulip-connector disassembly	1		1 (1.5%)	
Radiolucencies around iliac screws (no pain)	1		1 (1.5%)	
Pain from iliac tulip prominence		1	1 (1.5%)	
Urinary tract infection	1	2	3 (4.5%)	

*Percentages calculated per patients of each group

**All reversible within 2 months

Table 7 One-way ANOVA between major complications and preoperative roentgenographic and anthropometric parameters

	Age	BMI	SVA preop	T9-spinopelvic preop	PI preop	PI−LL preop	SS preop	PT preop	LL preop	TK	L4–S1 lordosis
PJF	0.77	0.143	0.35	0.22	0.41	0.55	0.92	0.5	0.7	**0.01**	**0.3**
BR	0.93	0.76	0.97	0.64	0.52	0.16	0.4	**0.006**	0.57	0.7	**0.023**
DWI	0.17	**0.008**	0.5	0.96	0.89	0.87	0.5	**0.011**	0.75	0.49	**0.71**

Significant *P* values are in bold

PJF proximal junctional failure, *DWI* deep wound infection, *BR* broken rods

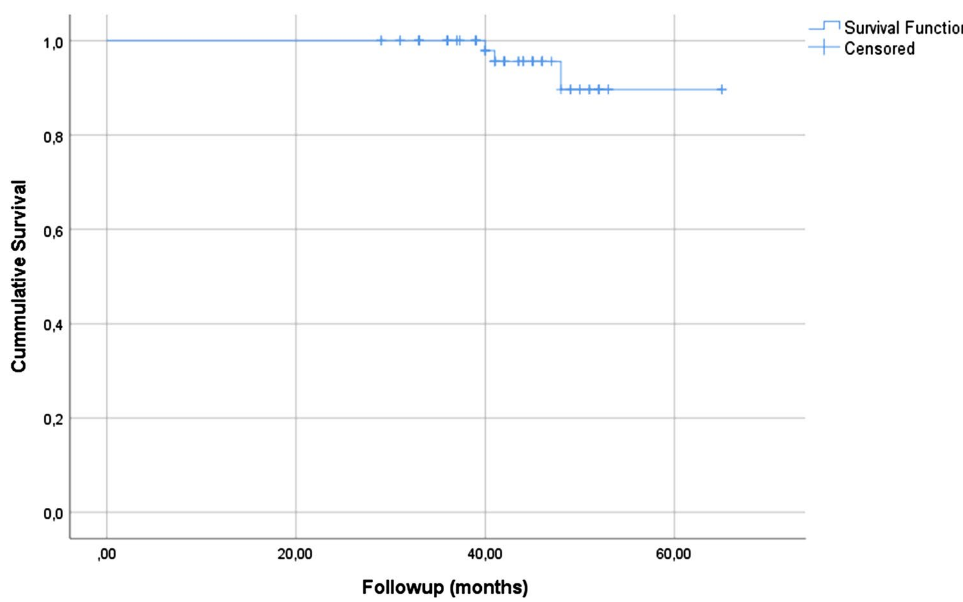

Fig. 3 Kaplan–Meier survival curve for all 67 patients for unplanned surgery for junction failure

series BR was the most common indication for reoperation, accounted for 5/11 (45.5%) reoperations. High preoperative PI−LL mismatch and PT were indicated as risk factors for BR in our series.

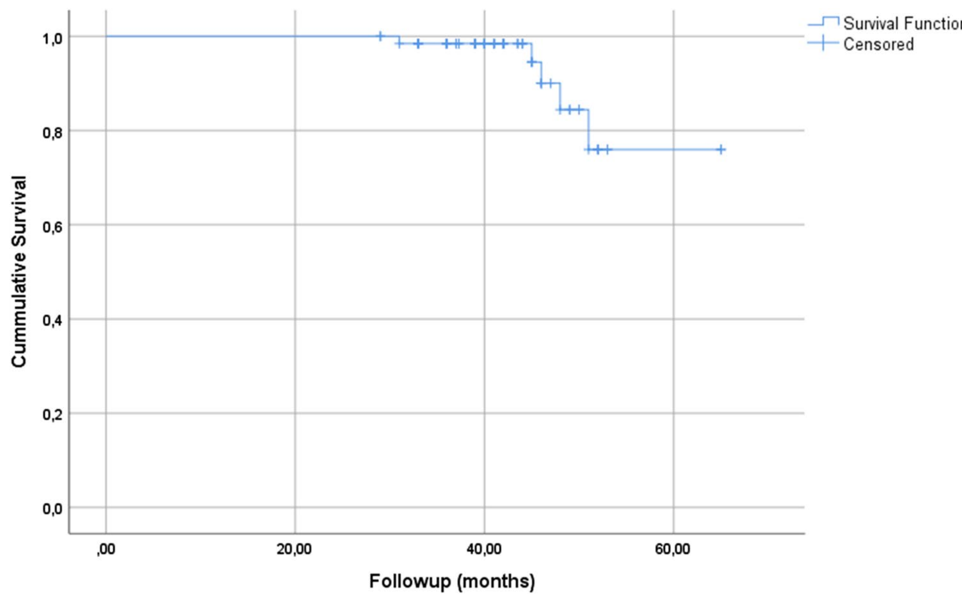

Fig. 4 Kaplan–Meier survival curve for all 67 patients for unplanned surgery for broken rods

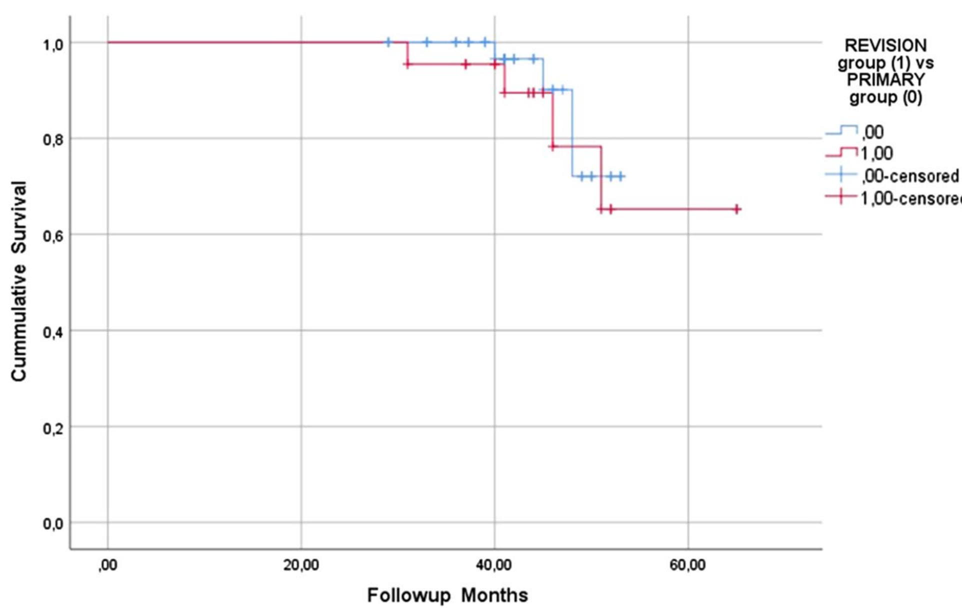

Fig. 5 Kaplan–Meier survival curve for 67 patients for unplanned surgery for any reason: primary versus revision cases. (Log-rank (Mantel-Cox) showed a Chi-square value of 0.326, $P = 0.568$)

Soroceanuet al [12] reported that age, osteopenia/osteoporosis, high preoperative and postoperative SVA, low preoperative LL, use of pedicle screws at the UIV, SVA correction, LL correction and fusion to sacrum/pelvis/iliac region are risk factors for PJK. In our series, increased preoperative TK was the single risk factor for PJF.

Increased age and BMI were the risk factors for DWI in our series. The deep infection rate of 3/67 (4.5%) in our series was within the previously reported limits of 2.2–8% [11, 13, 16–18] and occurred within the first months following surgery. The less invasive surgery used in this series for iliac screws insertion, avoiding opening of lumbosacral fascia could be related to this low complication rate together with low blood loss (660 ± 310 cc) compared to subtraction osteotomy [17].

The observed 10.4% PJF rate in our series was close to the 10% previously reported proximal junction kyphosis [6, 10, 11]. In our study, the risk factors for PJF were increased preoperative TK ($P = 0.01$) and increased LL correction ($P = 0.001$), obviously for mechanical reasons.

In our series, the intraoperative neurological deficit was 4.5%, slightly more than that the 3.1–3.7% reported rate [6, 10, 11]; however, it was temporary and occurred in revision cases at the segment of TLIF insertion.

Lafage and Schwab [14] stated recently that clinically, sagittal spinopelvic alignment and harmony (PI−LL ≤ 10°)

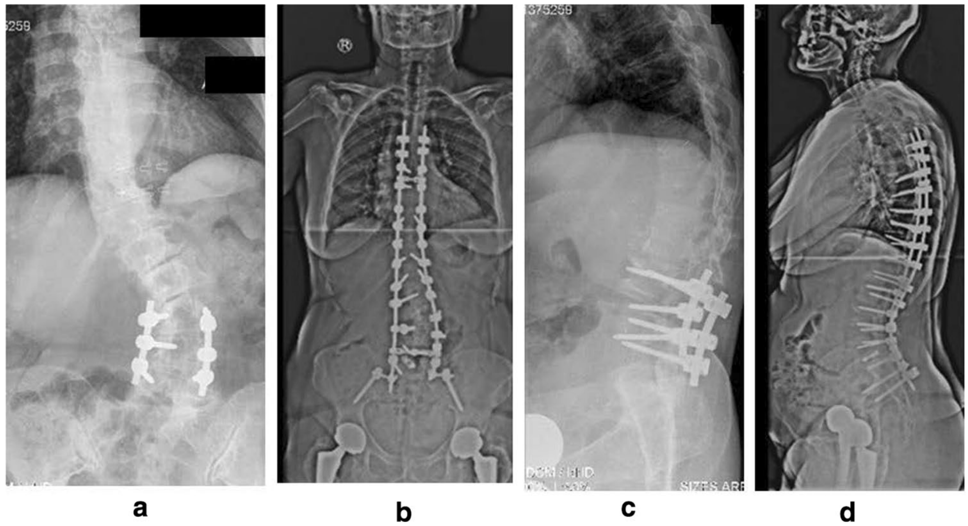

Fig. 6 Preoperative AP and lateral standing roentgenograms of a 71-year-old woman who had in another institution a wide decompression L3–L5 and instrumented fusion for spinal stenosis and adult scoliosis. Because of biplane imbalance (a,b) pain and disability the patient underwent successful posterior three-segment lumbar POs, TLIF L5/S1 and spinopelvic fixation with improvement of PT, SVA and LL-standing roentgenograms 24 months postoperatively (c,d)

vary with age. More specifically, older patients had greater compensation ability than their younger counterparts, more degenerative loss of lordosis and were more pitched forward. Thus, operative realignment targets should account for age, with younger patients requiring more rigorous alignment objectives than older ones. Ghobrial et al. [2] reported that lumbopelvic harmony was never fully restored in adult patients with ASD, reaching a mean of PI−LL = 14° postoperatively with an average improvement of 35%. In our series, lumbopelvic harmony rate increased from 3% preoperatively to 39% at the final observation.

There is a controversy regarding the contribution of TLIF, PLIF or ALIF on patient's prone positioning on operation table in LL recreation in association with posterior surgery for sagittal imbalance [20–22]. Some authors have proposed expandable TLIF cages in an attempt to create segmental lumbar lordosis and finally to improve sagittal balance [19, 20]. The expandable TLIF that was used in our series, was inserted in a diagonal fashion, and it was located close to the anterior 2/3 of the vertebral endplates of the operated segment (Fig. 7). Actually, the manufacturer has designed this expandable cage to create controlled height restoration, not segmental lordosis, thus indirectly decompressing the foramen and contributing to sagittal realignment. At least theoretically, we believe that this particular TLIF inserted in the anterior 2/3 of the endplate allows for some probably not significant lordosis creation by posterior segmental compression applied on the pedicle screws is this segment. Thus, in our series, the use of expandable TLIF cage did not significantly increase the segmental lordosis beyond the improvement that was achieved by the posterior spinal elements release, the PO and the prone positioning of the patient under anesthesia. As other authors previously showed, the preoperative hypolordosis was enhanced in our cases through prone positioning and extensive posterior release [8, 20, 21]. Finally, the expandable TLIF cage together with segmental instrumentation offered immediate stabilization and enhanced spinal fusion in the vast majority of the cases [8, 20, 21].

The reported correction per PO ranging from 10.2° to 10.7° [16, 17], is significantly higher than that achieved both in our (6.41° per PO) and Ghobrial [2] (5.05° per PO) series. We speculate that these differences should be due to the much younger population in the previous series associated with less spinal stiffness [16, 17], the instrumentation levels and surgical technique.

The clinical and biomechanical benefits using iliac screws are well established, offering higher rates of union at the lumbosacral junction [17, 23–25]. Some authors [11, 25] reported on pain related to iliac screws prominence at the posterior superior iliac spine, and some of them required revision for extraction of the screws. In our series there were only few 3 (4.4%) cases with minor complications related to iliac screws that however neither jeopardized surgical outcome nor made revision surgery necessary. PO although it is a commonly used osteotomy technique, and much confusion surrounds the nomenclature and technique of the Ponte (PO) or Smith-Petersen (SP) osteotomy [1, 17]. Smith-Petersen and colleagues first described the technique of posterior element osteotomy and posterior compression. In this technique, they used the disc space as a fulcrum to effect anterior column lengthening and posterior column shortening in the treatment of flexion deformities in individuals with "rheumatoid arthritis" and autofused (that is, ankylosed) spines. This method involved violation of the anterior longitudinal ligament and entailed significant risk of injury to vascular structures anterior to the spine. The description by Ponte et al. in 1984 [1] more directly captures the technique of this osteotomy most commonly used today without however

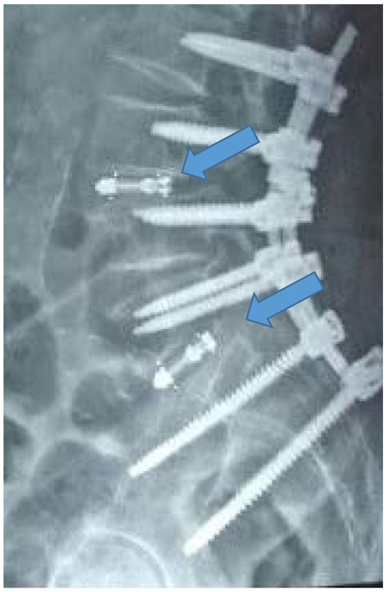

Fig. 7 Lateral standing roentgenogram of a 62-year-old woman who received 3-level TLIF L3/L4 and L5–S1 for ASD. Note the position of the expandable TLIF in the anterior 2/3 of the sagittal vertebral diameter (arrows). The TLIF did not add any significant segmental lordosis and, however, reconstructed the disc space height and immediately stabilized the olisthesis L3–L4

violating the anterior longitudinal ligament, and this was used in our paper.

In our patients, iliac screws maintained the spinal correction achieved by the three-segment POs and safeguarded fusion at the lumbosacral junction in the vast majority of the cases. In our series, 5 (7.5%) of our patients were revised for symptomatic BR and evident pseudarthrosis. Recent literature has linked BR with increased stress acting in the lumbar spine and replaced the single rod with dual rods bilaterally in the lumbar spine [23]. In all revised cases for BR we replaced each from the longitudinal 5.5-mm titanium rods with dual rods successfully.

This study has several limitations: (1) retrospective design; (2) relative small number of patients; (3) PLIFs were not in all osteotomy segments; and (4) no control group. However, there are possibly some innovations in this study: (1) selection—in contrast to previous studies—of a homogenous of elderly female patients with moderate biplane ASD, (2) one spine surgeon series, (3) the use of less invasive techniques for iliac screws and rods–connectors insertion, avoiding posterior sacral surface exposure with well-known associated complications, (4) correlative analysis of roentgenographic, functional results along with survival analysis of unplanned surgery for major complications and (5) comparison with historical similar ASD cohorts.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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