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Effect of the reconstructed sagittal balance on outcomes in the elderly with degenerative low-grade spondylolisthesis: single center four-year cohort study

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Objective To explore the effect of surgical reconstruction of the local sagittal balance on the outcomes and quality of life in elderly with degenerative low-grade spondylolisthesis. **Design**: a retrospective non-randomized single center cohort study. **Material and methods** This article reviewed 110 elderly patients (91 (82.7 %) females and 19 (17.3 %) males) with degenerative spondylolisthesis who underwent surgical treatment at the Federal State Medical Center, Novosibirsk. The mean age was 66 years (range, 60 to 83 years). Radiography, spiral computed tomography, MRI of the lumbar spine were performed for all patients who were also asked to use the visual analog scale and the Oswestry disability index (ODI). Sagittal spino-pelvic radiographic parameters including PI, SS, PT, LL, SL (Segmental Lordosis), LL4–S1 (Lordosis L4–S1) were measured and related to age. Global lumbar lordosis measurements were made using the formula: LL = 0.54 × PI + 27.6°. Comorbidity assessment was produced with the body mass index (BMI) and the Charlson Comorbidity Index (CCI). Patients were subdivided into three groups according to the severity of the sagittal imbalance as described by Barrey: (1) balanced, (2) balanced with compensatory mechanisms and (3) imbalanced, and their outcomes evaluated. **Results** Increased body weight was observed in 97.3 % of patients. The mean BMI was 33.7. A comorbid condition was detected in all patients (n = 110). The mean CCI was 57.4 %. The mean PI was 57.4°. Most of patients (n = 95, 86.4 %) had significant segmental imbalance due to the loss of segmental lordosis at the lower lumbar motion segments. Pelvic retroversion was identified as the compensatory mechanism in the pelvis area in 95 % of patients with measurements of PT based on the available PI. A statistically significant increase in LL4-S1 was observed in the groups due to reduction of spondylolisthesis and restoration of the segmental lordosis. A statistically significant increase in LL was observed in the imbalanced group only. No statistically significant differences in ODI scores were observed in TLIF and ALIF/LLIF patients. Complications graded in the Clavien-Dindo classification were identified in 65 (59 %) cases with greater complication rate in TLIF patients (n = 59, 69 %), as compared to ALIF/LLIF (n = 6, 24 %). From them, 5 (0.5 %) were graded IIIB. **Conclusion** Differentiated use of surgical technologies and MIS is the method of choice for elderly patients with comorbidities. Patients with compensated sagittal balance can benefit from direct spinal canal decompression, reduction and stabilization of degenerative spondylolisthesis using the posterior approach. Treatment of patients with impaired spino-pelvic balance should be aimed at reduction and restoration of the segmental lordosis (SL) using lordotic cages to ensure good clinical and radiological results.
Keywords: degenerative spondylolisthesis of the lumbar spine, elderly patients, sagittal balance, lateral lumbar interbody fusion

INTRODUCTION

The prolongation of life span is inevitably associated with a higher incidence of degenerative spine disease [1]. It's estimated by the World Health Organization that the world's population aged 60 years and older will total about 2 billion in 2050, up from 900 million in 2015 [2]. Degenerative spondylolisthesis is annually detected in 39 million (0.53 %) people worldwide with a higher incidence among population of Europe and Asia [1, 3]. Recently, surgical indications have changed for elderly patients with multiple comorbidities due to advancements in anesthesiological management and surgical technologies [3, 4]. Lumbar spine stabilization surgery in elderly patients [4, 5] has been reported to be associated with high complication rates. Minimally invasive decompression, decompression stabilization and corrective procedures are used to decrease surgical complication rate in elderly, in particular [4–6]. Sagittal realignment of the lumbar spine has an important impact on the degenerative pathology, and is a strong predictor of successful treatment [7]. Current evidence with high intra-observere agreement shows that sagittal imbalance can cause worse clinical outcomes, a loss of health-related quality of life [8], and restoration of optimal spino-pelvic alignment parameters is known to improve daily life activities [9, 10].

Radiographic parameters used for preoperative planning include Pelvic Incidence (PI), Pelvic Tilt (PT), Sacral Slope (SS), Lumbar Lordosis (LL), PI–LL, Sagittal Vertical Axis (SVA) and compensatory mechanisms and can have altered measurements in

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elderly with degenerative spine disorders. However, the role of reconstruction of the parameters has not been identified in this cohort of patients. Lumbar interbody fusions have been widely used to treat degenerative lumbar disease and include TLIF, ALIF and LLIF employing interbody cages to improve segmental lumbar lordosis. Minimally invasive surgery (MIS) is designed to reduce surgical aggression in elderly patients. Nevertheless, clinical outcomes, complication rate, restoration of sagittal balance are still controversial in the elderly cohort and give reasons for a major question: can reconstruction of sagittal balance parameters influence outcomes in elderly patients with degenerative low-grade spondylolisthesis?

Objective To explore the effect of surgical reconstruction of the local sagittal balance on the outcomes and quality of life in elderly with degenerative low-grade spondylolisthesis. Level of evidence 2c ("Outcomes" research, UK Oxford, version 2009).

Design: a retrospective non-randomized single center cohort study.

MATERIAL AND METHODS

This is a review of 110 consecutive elderly patients (as classified by WHO) who underwent surgical treatment for degenerative low-grade spondylolisthesis classified by Marchetti – Bartolozzi [11]. There were 91 (82.7 %) female and 19 (17.3 %) male patients aged 60 to 83 years (mean/median 66/66 [62; 68] years [1st; 3d quartile]. The treatment was performed at the spinal department of the Federal State Medical Center, Novosibirsk. The participants were recruited between January 2014 and December 2017. Inclusion criteria were primary acquired degenerative spondylolisthesis as classified with grading system proposed by Marchetti – Bartolozzi; segmental instability at the level of spondylolisthesis (scored 5 and over by White-Panjabi (1990)) [12]; patients aged 60 years and over; chronic pain scored 5 and over on VAS [13], VAS LBP (Visual Analog Scale low back pain) and VAS LP (Visual Analog Scale Leg Pain); no benefits from comprehensive conservative treatment at two-month follow-up. Exclusion criteria were patients with the history of spine surgeries; spine tumors and inflammations; absence of archive data. Patients were differentiated by sex, age, body mass index (BMI) and Charlson Comorbidity Index (CCI). Visual analogue scales (VAS LBP, LP) for pain were used to assess spine and lower limb pain. Oswestry Disability Index (ODI) was used to quantify disability for low back pain [14].

Preoperative diagnostic workup included medical history, physical examination, neurological assessment, questionnaires, neurovisualization (radiography, magnetic resonance imaging, spiral computed tomography). Plain standing radiographs of the lumbar spine in coronal and sagittal planes showing femoral heads were used to examine spino-pelvic balance. Sagittal balance measurements were produced with sagittal balance software Sagittal Balance Academy (www.sagittal-balance.com). The lumbar spine flexion and extension views in sagittal plane were obtained to assess spondylolisthesis with the Meyerding classification system [15] and identify unstable spinal motion segments. Slippage was measured with techniques described by A.A. White and M.M. Panjabi [12], and spinal motion segments were considered unstable with the score of 5 and over. Sagittal spine alignment was rated as balanced, balanced with compensatory mechanisms and imbalanced [16, 17]. Major spino-pelvic parameters measured included PI, SS, PT, LL, LL4–S1 (Lordosis L4–S1: lordosis at L4-S1 level). The SRS-Schwab classification was used to quantify spinal deformity using PI–LL, SVA and PT parameters [18]. Formula **PI = LL ± 9°** was employed to determine correlation between SPB and health related quality of life. SVA (*Sagittal vertical axis*) and PI–LL (PI minus LL) measurements were related to the age [18]. The formula **LL (L1–S1) = 0.54 × PI + 27.6**, was used for global LL measurements, and the formula **PT = 0.44 × PI – 11.4** was employed to calculate normal theoretical values of PT [19, 20]. The formula **L4S1 = 0.66 × L1S1** was used to measure lumbar lordosis.

Intrathecal contrast enhanced spiral computed tomography was performed for the patients preoperatively and postoperatively to evaluate spinal canal compromise, the posterior and anterior longitudinal ligaments. Postoperative CT scans were practical for assessing pedicle screw position to rule out malposition based on the Rao classification system (2003) [22]. Estimation of fusion was produced at 24-month follow-up based on CT-based classification offered by Tan et al. [23]. A 1.5-tesla MRI was performed for all patients. Central spinal canal stenosis was defined as decrease in the sagittal size < 13 mm, sagittal sized of the dural sac < 10 mm, the cross-sectional area of the canal < 15 mm, interfacet distance < 15 mm, the cross-sectional area of the dural sac < 130 mm^2 [24–26]. Qualitative grading of severity of lumbar spinal stenosis based on the morphology of the dural sac on magnetic resonance images was produced using the technique performed by Schizas et al. (2010) [27]. Lateral spinal stenosis was defined as the lateral recess < 30° and < 3 mm [24].

Sagittal T1-weighted imaging was the main sequence to identify lumbar foraminal stenosis with intervertebral foramen < 3 mm or foramen height < 15 mm [25] with four grades of intervertebral foramen narrowing as classified by Lee et al. [28].

Surgical treatment was indicated for the patients with persistent vertebral pain and/or caude equina syndrome of radiculopathy or neurogenic intermittent claudication being resistant to a 12-week conservative treatment. The eligibility criteria for assessemnt included sex, age, body mass index (BMI), sagittal modifiers PI, SS, PT, LL, global LL, Segmental Lordosis (SL), age related LL4-S1 measured pre-op and post-op [18, 19]; variation of lumbar sagittal alignment measured with Barrey index (ratio of the C7 plumb line to the sacral inclination) [29]; dynamics in pain measured on VAS LBP, VAS LP; dynamics in health related quality of life measured with ODI; surgical complications as described by Dindo-Clavien [29]; length of hospitalization, operating time and intraoperative blood loss.

Surgical methods

Surgical intervention strategies were established based on the clinical and imaging findings, nerve compression syndromes, clinical instability of the spinal motion segments (SMS) and sagittal alignment. Cauda equina syndrome due to central, lateral or foraminal spinal stenosis and vertebral pain syndrome due to unstable index SMS were observed in 85 (77 %) patients. Lateral spinal stenosis of 28 out of 85 patients and foraminal spinal stenosis in 12 cases were treated with complete resection of the facet joint and restoration of the segmental lordosis using TLIF [31, 32] combined with MIS pedicle fixation [33]. Bilateral decompression was performed for 36 patients with central stenosis using unilateral posterior approach [34, 35], and interbody cages were placed to improve segmental lordosis with TLIF [31, 32] combined with MIS pedicle fixation [33, 36]. The remaining 25 (23 %) had mild cauda equina syndrome with evident vertebral pain syndrome due to unstable SMS. These patients underwent reduction of spondylolisthesis to regain disc height and increase intervetebral foraminal dimensions using lordotic cages [37, 38] with MIS ALIF [39] and MIS LLIF [36, 40]. Lordotic cages were used to fill in deficient LL at L4-S1 level at the appropriate lordotic angle. Cages with different lordotic angles of 8° and 16° were used for ALIF coupled with plating. Segmental lordosis correction was 8° in LLIF with pedicle fixation of the SMS using minimally invasive approaches [33]. Indirect spinal decompression (n=8) and indirect decompression of the intervertebral foramen (n=5) were performed for clinically significant foraminal stenosis [9].

Statistical data analysis was performed using R 3.5.3 version [41]. Wilcoxon signed-rank test was used to compare preoperative and postoperative parameters, the two-sample Mann–Whitney U test was applied for two independent variables and Kruskal-Wallis test was employed for comparisons of three groups. A box-and-whisker plot presented the median, interquartile range, the maximum/minimum sampled values at a distance of 1.5 times the IQR and outlier values.

RESULTS

Clinical and neurological characteristics of patients

Patients' characteristics by sex, age, BMI, CCI, ODI, VAS and clinical manifestations of neurogenic claudication are presented in Table 1. All patients had vertebrogenic pain syndrome ranging from 4 to 10 VAS scores.

Table 1

General patients' characteristics

Parameters	Cohort of patients (n = 110)
BMI	33.7/33.8 [29.3; 37.4]
CCI	0.6/0.8 [0.2; 0.9]
ODI	62.5/64 [56; 68]
VAS LBP	7.4/7 [7; 8]
VAS LP	6.7/7 [6; 8]

Most patients (n = 107; 97.3 %) had increased body weight and presented with excessive weight with 25 ≤ BMI < 30 (n = 28; 25 %), grade II obesity with 30 ≤ BMI < 35 (n = 32; 29 %), grade III obesity with 35 ≤ BMI < 40 (n = 34; 31 %) and grade IV obesity with BMI > 40 (n = 13; 12 %). Mean BMI was 33.7. All patients were diagnosed with comorbidities with 87.3 % (n = 96) associated and 12.7 % (n = 14) isolated disorders. Mean CCI was 57.4 % (range, 0 % to 90 %). Segmental instability at the spondylolisthesis level as graded by White-Panjabi resulted in vertebrogenic pain syndrome scored 5 on VAS scale (n = 18; 16.4 %) and in vertebrogenic pain syndrome combined with radiculopathy (n = 48; 43.6 %). The condition was caused by direct nerve root compression due to lateral spinal stenosis at the spondylolisthesis level (n = 31; 64.6 % for 48) and foraminal stenosis (n = 17; 35.4 % for 48). Vertebrogenic pain syndrome appeared to be associated with intermittent neurogenic claudication due to central spinal stenosis at the spondylolisthesis level (n = 44; 40.0 %). MRI scans revealed Schizas A4 (n = 26; 23.6 %), B (n = 24; 21.8 %), C (n = 43; 39.1 %) and D (n = 17; 15.5 %) spinal stenosis. No clinical manifestations of nerve root compression were observed in 18 among 26 patients with Schizas A4 central spinal stenosis.

Radiological characteristics

Grade I (n = 104; 94.5 %) and grade II (n = 6; 5.5 %) spondylolisthesis according to the Meyerding classification system were identified in the cohort of patients. The majority of surgeries were produced at the LL apical segment L4–L5 (n = 85; 77.3 %) (Table 2).

Table 2

Distribution of surgical procedures by levels and approaches

Level	ALIF	LLIF	TLIF	Total
L2–L3	–	–	1	1 (0.9 %)
L3–L4	2	2	15	19 (17.3 %)
L4–L5	10	11	64	85 (77.3 %)
L5–S1	–	–	5	5 (4.5 %)

Sagittal alignment

Sagittal modifiers of the lumbosacral spine are presented in Table 3.

There were statistically significant differences in baseline PT (p = 0.044) in patients who underwent direct decompression-stabilizing surgeries (TLIF) and indirect procedures (ALIF и LLIF) with measurements unrelated to age. Patients were subdivided into three groups according to the severity of the sagittal imbalance as described by Barrey: (1) balanced with Barrey index < 0.5 (n = 15); (2) balanced with compensatory mechanisms with segmental and local imbalance only with Barrey index < 0.5 and deviations from target values of PT, SS, LL, LL4–S1 (n = 69); (3) global sagittal imbalance with Barrey index > 0.5 and deviations from target values of PT, SS, LL, LL4-S1 (n = 26). Distribution of patients according to Barrey index is presented in Table 4. Although most patients had high PI values there were no significant differences in PI among the groups (p = 0.07). The PI was unlikely to contribute to the global sagittal imbalance in this cohort of patients. There were statistically significant differences in PT (p < 0.001 for groups 1 and 2, p < 0.001 for groups 1 and 3). There were no significant differences in PT in groups 2 and 3 (p = 0.33) because PT was a common important compensatory mechanisms of the segmental and local sagittal alignment in the patients.

Table 3

Preoperative sagittal modifiers (mean/median [the first; third quartile])

Sagittal modifiers	TLIF (n = 85)	ALIF, LLIF (n = 25)	p
PI	57.5/57.1 [49.2; 65.5]	53.4/53.1 [49.2; 57.6]	0.068
LL	55.1/55.9 [47.6; 62.8]	53.7/51.7 [45; 59]	0.369
Target LL	58.7/58.4 [54.2; 63]	56.4/56.3 [54.2; 58.7]	0.068
LL4–S1	30.9/31.2 [25.7; 36]	30.1/27.9 [24; 36]	0.695
Target LL4–S1	38.7/38.6 [35.8; 41.6]	37.2/37.1 [35.8; 38.7]	0.068
PT	23.8/23.8 [18.7; 28.1]	20.5/21 [16.2; 23.9]	**0.044**
Targete PT (age related)	24.1/25.1 [22; 25.1]	24.6/25.1 [22; 25.1]	0.333
Target PT (formula)	13.9/13.7 [10.2; 17.4]	12.1/12 [10.2; 13.9]	0.068
SS	34.3/33.7 [27.6; 40.2]	32.9/31 [28; 36.4]	0.332
SL	6.2/5.9 [3; 9]	5.9/5.9 [3.8; 9]	0.882
SVA	21.2/16 [-13.5; 38]	27.8/25 [0; 50]	0.364
PI–LL	2.4/1.9 [-5; 7.8]	-0.4/1.2 [-6.1; 5]	0.426

Table 4

Characteristics of patients according to Barrey index

Description	Groups of patients graded by Barrey index		
	1	2	3
Number of patients	15	69	26
Ratio ALIF and LLIF / TLIF (% TLIF)	0/15 (100 %)	16/53 (77 %)	9/17 (65 %)
Barrey index	-0.4/-0.3 [-0.5; 0]	0/0 [-0.2; 0.3]	1.2/0.9 [0.7; 1.4]
PI	53.2/54.7 [45.5; 61.3]	57.4/57.1 [50.9; 64.9]	56.3/55 [49.8; 62]
PT	15.8/14.4 [14; 17.7]	23.5/23.9 [19.5; 27.6]	26/23.9 [21.1; 30.6]
LL	57.6/58.4 [47.7; 63.1]	57/56.5 [50.4; 64.6]	47.3/44.9 [40.9; 53.8]
SVA	-14.7/-13.5 [-34.5; -2.2]	2.7/3.5 [-16.5; 25]	77.6/64.5 [47.2; 89.8]
PI–LL	-4.4/-3.8 [-6.8; 0.7]	0.4/1.3 [-7.2; 6.3]	9/8.6 [1.9; 16.2]
LL4–S1	37.3/38.2 [35; 39.2]	31.5/31 [26.3; 35.6]	24.9/24 [18.6; 27.8]
Deviations from target LL4–S1 (number)	–	58	25

There were no significant differences in SVA in groups 1 and 2 ($p = 0.16$), and there were statistically significant differences in SVA between group 3 and groups 1 and 2 ($p < 0.001$ for both comparisons) that indicated to the global sagittal imbalance in patients of group 3 only. Deficit of the lower lumbar lordosis (LL4–S1) was detected in 58 patients of group 2 and nearly all patients ($n = 25$) of group 3 and could be presented as the trigger of impaired spino-pelvic alignment. The findings indicated to significant segmental imbalance due to the loss of segmental lordosis at the level of lower lumbar SMSs in the majority of elderly patients ($n = 95$; 86.4 %) with degenerative spondylolisthesis. With adequately compensated sagittal imbalance in group 2 and insufficient compensatory mechanisms causing global sagittal imbalance in group 3 there were no statistically significant differences in LL ($p = 0.96$) between group 1 and group 2, whereas the differences in LL were statistically significant between groups 1 and 3, and between groups 2 and 3 ($p = 0.007$ and $p < 0.001$, respectively). There were also no statistically significant differences in PI–LL ($p = 0.96$) between group 1 and group 2 ($p = 0.45$) (Table 5). The PI–LL measurements were statistically higher in group 3 only as compared to those in group 1 and group 2 ($p = 0.0006$ and $p = 0.007$, respectively). Age-independent measurements of PT were greater than reference values (normal PT $\leq$ 20) in groups 2 and 3 and were suggestive of sagittal malalignment. Age-specific values for sagittal parameters determined by Schwab et al. [18] demonstrated PT to be greater in 31 patients of group 2 and 13 patients of group 3 that accounted for 40 % of all patients with spondylolisthesis. Although there were no statistically significant differences in PT ($p = 0.96$) between group 2 and group 3 ($p = 0.35$), the extent of sagittal malalignment measured with Barrey index was much higher in group 3. With equations for PT based on PI offered by Lu Huec et al. [19] pelvic retroversion was identified as the compensatory mechanism in 104 patients (95 %). There were statistically significant differences in PT being higher than invidivual target values between the groups: group 1 and group 2 ($p < 0.001$), group 2 and group 3 ($p = 0.04$), and group 1 and group 3 ($p < 0.001$). Mean values of positive deviations of SVA were also statistically significant in group 3 as compared to groups 1 and 2 ($p < 0.001$ for both comparisons). There were no significant differences in SVA between groups 1 and 2 ($p = 0.31$).

Characterization of compensatory mechanisms of sagittal malalignment

Most patients were diagnosed with types 2 and 3 sagittal imbalance graded by Barrey with specific compensatory mechanisms of spinopelvic alignment (Table 6).

Table 5

Measurements of PI-LL, PT, SVA in patients grouped according to Barrey and comparisons with target values

Parameters	Groups of patients as specified by Barrey		
	1	2	3
PI–LL	-4.4/-3,8 [-6.8; 0.7]	0.4/1.3 [-7.2; 6.3]	9/8.6 [1.9; 16.2]
Deviation from normal value (age-specific)	-12.1/-10.8 [-14.5; -9.2]	-9/-9.6 [-15.2; -3.4]	-0.6/-0.1 [-8.7; 5.7]
Number of patients showing greater measurements	0	11	13
PT	15.8/14.4 [14; 17.7]	23.5/23.9 [19.5; 27.6]	26/23.9 [21.1; 30.6]
Normal age-specific PT			
Deviation from normal value	-7.5/-7.6 [-8; -6.3]	-0.8/-0.9 [-4.3; 2.9]	1.5/0.2 [-5; 5.8]
Number of patients showing greater measurements	0	31	13
Normal PT calculated with formula 0.44 × PI – 11.4			
Deviation from normal value	3.8/3.7 [0.8; 6.4]	9.6/9.9 [5.8; 14.8]	12.6/12.6 [9.9; 16]
Number of patients showing greater measurements	13	66	25
SVA	-14.7/-13.5 [-34.5; -2.2]	2.7/3.5 [-16.5; 25]	77.6/64.5 [47.2; 89.8]
Deviation from normal value (age-specific)	-59.8/-68 [-75; -42.7]	-47.8/-48.6 [-67.7; -28.3]	26.8/10.9 [1; 50.4]
Number of patients showing greater measurements	0	3	20

Table 6

Characterization of compensatory mechanisms of sagittal malalignment described by Barrey

Type	N	Group 1	Group 2	Group 3
No compensatory mechanisms	15	15		
↓LL4_S1 ↓LL ↑PT	54		32	22
↓LL4_S1 nLL ↑PT	13		11	2
↓LL4_S1 ↑LL ↑PT	9		9	
↑LL4_S1 ↑LL ↑PT	9		8	1
nLL4_S1 ↑LL ↑PT	7		6	1
nLL4_S1 nLL ↑PT	3		3	
Total	110	15	69	26

Notes: ↑, target value increased; ↓, target value decreased; n, normal

Most patients (n = 54; 49 %) had segmental imbalance at the involved SMS level and decreased LL4–S1 combined with local sagittal malalignment and LL being less than target individual values. Increased PT appeared to be the compensatory mechanism for lumbar spine in 95 (84.4 %) cases. Pelvic retroversion was shown to be unable to compensate the deficit of the lower lumbar lordosis developing to the global lumbar lordosis (deficit of LL revealed in 54 patients) that necessitated compensation from superjacent levels with associated decreased thoracic kyphosis, increased cervical lordosis, etc. This factor needs to be further explored and was not the goal of our study. Compensatory mechanisms of the superjacent levels including thoracic and cervical spine were shown to be effective to maintain the global sagittal alignment of 28 patients of group 2, whereas 22 patients of group 3 suffered from the the global sagittal imbalance with the threshold Barrey index of 0.5 experiencing no compensation from the superjacent levels.

Major sagittal modifiers, VAS and ODI scores measured preoperatively and at a long term are presented in Table 7. No statistically significant differences in VAS and ODI scores observed at a long term between the groups were suggestive of equally good clinical outcomes achieved in all patients. Statistically significant increase in lower LL was noted in the groups due to reduction of spondylolisthesis and restoration of segmental lordosis. Statistically significant increase in the global LL was observed in group 3 only.

There were no statistically significant differences in physical limitations measured in TLIF and ALIF/LLIF patients with ODI irrespective of the extent of sagittal malalignment at baseline quantified with Barrey index (Fig. 1). Differentiated use of both surgical technologies was shown to be equally efficient for elderly patients with degenerative spondylolisthesis. Bony union assessed at 24-month follow-up with X-ray CT imaging offered by G.H. Tan (2007) showed grade I complete fusion (n = 91; 79.1 %), grade II partial fusion (n = 19; 17.3 %), grade III unipolar pseudarthrosis in 5 TLIF patients (4.6 %) without clinical manifestations. No revision surgery was required for clinically significant pseudarthrosis in the study groups.

Complications

Overall complications observed in the groups numbered 65 (59 %) with greater adverse events recorded in TLIF patients (n = 59; 69 %) as compared to ALIF/LLIF patients (n = 6; 24 %). Surgical complications described in the Dindo-Clavien classification system (2004) and validated for the lumbar spine surgery [42] are presented in Table 8.

Table 7

Dynamics in sagittal balance parameters, VAS and ODI scores

Parameter	Group 1		Group 2		Group 3	
	pre-op	long-term	pre-op	long-term	pre-op	long-term
VAS LBP	7.3/7 [7; 8]	3.1/3 [2; 3.5]**	7.4/7 [7; 8]	3/3 [2; 3]**	7.4/7 [7; 8]	3.6/3 [3; 4]**
VAS LP	6/7/7 [5; 8]	2.1/2 [1; 3]**	6.8/7 [6; 8]	2.3/2 [1; 4]**	6.4/6 [6; 7]	2.4/2 [1; 4]**
ODI	62/6/62 [56; 70]	24/22 [19; 28]**	62.6/64 [56; 68]	26/24 [16; 36]**	62,5/64 [55.5; 66.5]	28/24 [18; 38]**
LL	57.6/58.4 [47.7; 63.1]	58.4/58.2 [52; 61.9]	57/56.5 [50.4; 64.6]	58.2/58,6 [52; 65.6]	47.3/44.9 [40.9; 53.8]	53.6/52,9 [51; 57]**
LL4-S1	35.7/37.3 [32; 39]	40.3/40.4 [37.4; 43.2]*	31.5/31 [26.3; 35.6]	35.1/35.3 [30.9; 40.3]**	24.9/24 [18.6; 27.8]	31.1/31.7 [29.2; 33.3]**
PT	15.8/14.4 [14; 17.7]	17.5/17.5 [13.6; 20.2]	23.5/23,9 [19.5; 27.6]	20.1/20 [14.9; 24.1]**	26/23.9 [21.1; 30.6]	21.7/21.2 [17.1; 25]*

Note: * $p < 0.05$, ** $p < 0.01$

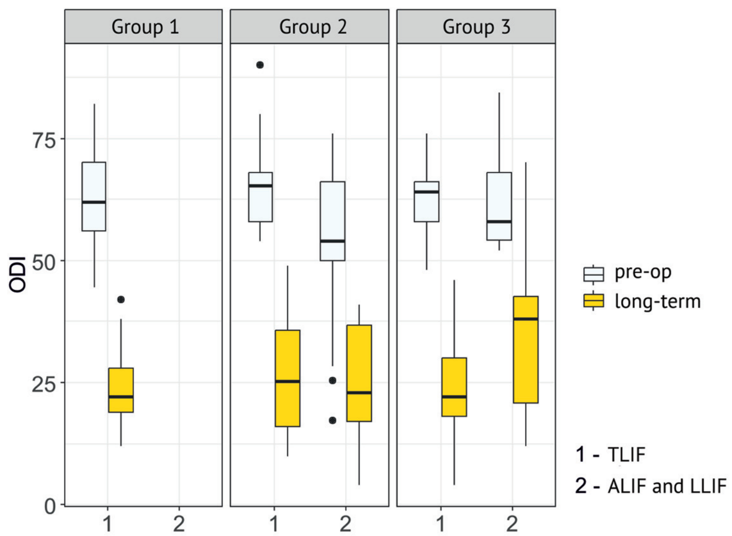

Fig. 1 Dynamics in ODI preoperatively and at a long term

Table 8

Surgical complications as described in the Dindo-Clavien classification system (2004)

Group	Complications	TLIF (n = 85)	ALIF (n = 12)	LLIF (n = 13)	Total (n = 110)
I	Injury to the dura mater (no CSF leak postsurgery)	5			5
	Injury to end plate	6	1	1	8
	Lateral screw malposition Rao grade 1 and 2	20		1	21
	Blood loss of 500 mL and over	11			11
II	Urine tract infection (MI)	1	1		2
	Epidural hematoma	1			1
	Superficial SSI	5			5
	Drug-resistant neuropathic pain	2		1	3
	Aggravated neurological deficiency	1		1	2
	Blood loss of 500 mL and over hemotransfusion	2			2
III B	Failed hardware	1			1
	SSI	2			2
	Intracanal screw malposition Rao grade 3	2			2
Total		59 (69 %)	2 (17 %)	4 (31 %)	65 (59 %)

DISCUSSION

Which classifications of degenerative spondylolisthesis can be considered optimal?

The need to realign sagittal balance is the key factor while choosing the strategy of surgical reconstruction. C. Barrey et al. [17] identified three types of sagittal aligment in patients with degenerative spondylolisthesis. The grading system showed good intraobserver reliability in adults suffering from degenerative spondylolisthesis in terms of different treatment strategies to be applied for specific zone of involvement [11, 43–45]. The review included more patients with types 2 and 3 saggital balance as graded by Barrey. The role of sagittal realignment was supported by dynamics in functional disability scores quantitatively measured using the ODI with no statistically significant differences in the indices between TLIF and ALIF/LLIF patients.

What is the role of age-specific values of sagittal parameters for preoperative spino-pelvic realignment?

Realignment targets are known to include PT, LL, LL4–S1, SVA. Age-unadjusted PT was shown to be very important with the use of established formulas for precise preoperative planning. The extent of age-specific spino-pelvis parameters showed statistically significant differences when measuring age-adjusted PT according to Schwab et al. [18] and formulas offered by Lu Huec et al. [19].

Is the local sagittal balance to be restored?

Our findings showed that 86.4 % of elderly patients with degenerative spondylolisthesis had impaired spino-pelvic alignment with increased PT, deficit of the lower lumbar lordosis (69 %), decrease in the global lumbar lordosis (46 %) and compensatory posterior pelvic shift. Statistically significant increase in lower lumbar lordosis was noted in the groups at a long term due to reduction of spondylolisthesis and restoration of segmental lordosis. Statistically significant decrease in pelvic retroversion was observed in groups 2 and 3 at a long term because this sagittal modifier could characterize the possibility to compensate sagittal malalignment at lumbar spine and was correlated with health-related quality of life [18].

How would you differentiate between health-related quality of life and risk of surgical treatment for elderly patients?

Several studies [3, 6, 8, 46] have previously described surgical treatment of degenerative spondylolisthesis as a more effective approach for elderly patients as compared to nonsurgical management. Surgical treatment with MIS technologies can be used in a safe manner even for very old patients [5, 7, 47–51]. Nikhil et al. compared two-year clinical and radiological outcomes after minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) among three groups of patients: young (under 50 years), middle-aged (50-65 years) and older (> 65 лет) patients. MIS-TLIF showed comparable results in selected older patients compared with young patients without increased complication risks. The minimally invasive lateral approach has been shown to be a safe technique to treat low-grade degenerative spondylolisthesis providing pain relief to 80 % and translation decrease by 75 % [7, 38, 52]. Cassinelli et al. found that advanced age, the presence of medical comorbidities did not increase the rate of major or minor complications in elderly patients who underwent lumbar decompression and arthrodesis with MIS technology [6]. Willhuber et al. reported postoperative complications analyzed at 90 days according to the classification of Dindo-Clavien with an overall rate of 28.8 %, of them 21 (26.7 %) were grade I, 24 (30.3 %) were grade II, 5.7 % graded as IIIA and 37.3 % graded as IIIB and required reoperation. Our series exhibited complication rate of 59.1 % (n = 65) with 3.6 % (n = 4) graded as IIIB. Neither fatality cases nor deep SSIs were recorded in our patients with 97.3 % obesity and 100 % comorbidity cases.

Can indirect decompression be practical for neurological manifestations?

LLIF cages placed with the lateral approach fail to provide sufficient volume of the spinal canal to arrest neurological manifestations in cases of clinically significant spinal stenosis due to posterior compression with hypertrophied facet joints, ligamentum flavum, synovial cyst [52]. Direct microsurgical decompression and TLIF are indicated for clinically significant lateral stenosis rated with criteria developed by Mamisch et al. [24], severity of lumbar central canal stenosis graded C and D with Schizas classification system and lumbar spinal foraminal stenosis graded IV with Lee classification system. Differentiated use of direct and indirect decompression techniques was shown to be the key aspect for elderly patients with degenerative spondylolisthesis. Positive dynamics in spine and lower limb pain could facilitate improvement of health-related quality of life measured with ODI irrespective severity of sagittal malalignment at baseline with both surgical approaches. No statistically significant differences in health-related quality of life measured with ODI were noted in TLIF and ALIF/LLIF patients with complication rate being significantly less with use of direct decompression.

CONCLUSION

1. Identification of a dominating clinical and imaging syndrome as major criterion is crutial for preoperative planning to ensure good outcomes and health-related quality of life for patients with degenerative spondylolisthesis.

2. Preoperative diagnostic workup is very important for elderly patients with degenerative low-grade spondylolisthesis because cauda equina syndrome and clinical instability of SMSs are associated with decreased quality of life in 84 % of the patients and 86 % demonstrate radiological signs of sagittal malalignment of lumbar spine.

3. Differentiated use of surgical technologies and MIS is the method of choice for elderly patients with comorbidities. Patients with compensated sagittal balance can benefit from direct spinal canal decompression, reduction and stabilization of degenerative spondylolisthesis using the posterior approach. Treatment of patients with impaired spino-pelvic balance should be aimed at reduction and restoration of the segmental lordosis using lordotic cages. Minimally invasive ALIF and LLIF provide correction with minimal complications and good long-term outcomes.

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