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A NEW CLASSIFICATION SYSTEM FOR DEGENERATIVE SPONDYLOLISTHESIS OF THE LUMBAR SPINE

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Abstract

Purpose: There is no consensus for a comprehensive analysis of degenerative spondylolisthesis of the lumbar spine (DSLS). A new classification system for DSLS based on sagittal alignment was proposed. Its clinical relevance was explored.

Methods: Health-related quality-of-life scales (HRQOLs) and clinical parameters were collected: SF-12, ODI, and low back and leg pain visual analog scales (BP-VAS, LPVAS). Radiographic analysis included Meyerding grading and sagittal parameters: segmental lordosis (SL), L1–S1 lumbar lordosis (LL), T1–T12 thoracic kyphosis (TK), pelvic incidence (PI), pelvic tilt (PT), and sagittal vertical axis (SVA). Patients were classified according to three main types—1A: preserved LL and SL; 1B: preserved LL and reduced SL (B5); 2A: PI–LL C10 without pelvic compensation (PT \ 25); 2B: PI–LL C10 with pelvic compensation PT C 25); type 3: global sagittal malalignment (SVA C40 mm).

Results: 166 patients (119 F: 47 M) suffering from DSLS were included. Mean age was 67.1 ± 11 years. DSLS demographics were, respectively: type 1A: 73 patients, type 1B: 3, type 2A: 8, type 2B: 22, and type 3: 60. Meyerding grading was: grade 1 (n = 124); grade 2 (n = 24). Affected levels were: L4–L5 (n = 121), L3–L4 (n = 34), L2–L3 (n = 6), and L5–S1 (n = 5). Mean sagittal parameter values were: PI: 59.3 ± 11.9; PT: 24.3 ± 7.6; SVA: 29.1 ± 42.2 mm; SL: 18.2 ± 8.1. DSLS types were correlated with age, ODI and SF-12 PCS (q = 0.34, p\ 0.05; q = 0.33, p\ 0.05; q = -0.20, and p = 0.01, respectively).

Conclusion: This classification was consistent with age and HRQOLs and could be a preoperative assessment tool. Its therapeutic impact has yet to be validated.

Level of evidence 4

Keywords: Degenerative spondylolisthesis Lumbar spine Classification system Spondylolisthesis Clinical relevance

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Introduction

Degenerative spondylolisthesis of the lumbar spine (DSLS) is a common cause of consultation with spinal surgeons. Initially described by the obstetrician Herbiniaux in 1782 [1], the term spondylolisthesis was first used by Kilian in 1853 [2]. DSLS is thought to be caused by various degenerative processes affecting the intervertebral disc and facet joints responsible for the translation and slippage of one vertebral body onto the subjacent one. Its pathogenesis still remains unclear. DSLS typically occurs at the L4-L5 level in women older than 50 with a high pelvic incidence (PI) [3],[4],[5]. It is also frequently associated with spinal stenosis [6]. These degenerative modifications contribute to produce the following symptoms: lower back pain, leg pain, postural syndrome and neurogenic claudication. Various classifications attempted to provide further understanding of this disease. However, they were based on etiology, topography, or slippage grading (percentage) and were restricted to a segmental analysis [7],[8],[9],[10]. Therefore, the role of regional or global malalignment was not considered. None of these classification systems provide surgeons with a comprehensive analysis of DSLS or guidance for optimal care. Recently, several studies reported the close relationship between DSLS and sagittal alignment [11],[12],[13],[14]. Spinopelvic malalignment plays a significant role in multiple spinal conditions [15],[16],[17]. It seems crucial to consider this parameter analyzing DSLS using preoperative full spine imaging.

A new classification system of DSLS based on sagittal alignment was proposed by Gille et al [18]. The clinical relevance of this new classification system remains to be determined to confirm or not its clinical value. This aspect was addressed in the present study by analyzing the relationships between the different types of DSLS and patient demographics, radiographical parameters and health related quality of life scales (HRQOLs).

Methods

Study design and population

All patients admitted to our spinal surgery department for surgical treatment of DSLS with spinal stenosis (central, lateral recess or foraminal) were retrospectively included between January 2011 and December 2015 following approval from our Institutional Review Board. The inclusion criteria were: (1) age > 18 years old, (2) degenerative spondylolisthesis of the lumbar spine requiring surgical treatment due to back pain associated with either neurogenic claudication or severe radiculopathy despite six months of optimal medical treatment and/or motor neurological deficit (3) complete data (demographic information, health related quality of life scales, full standing spine X-rays).

Patients were excluded if they presented with: (1) a coronal malalignment with coronal Cobb angle >10°, (2) other causes of spondylolisthesis (isthmic, congenital, traumatic, iatrogenic), (3) previous lumbar spine surgery, (4) active infection or neoplasm.

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Table 1 Description of the classification system and patients

Type	Description	Parameters	Sub-type	Sub-type description	Age	Number of patients (males / females)
Type 1	LL adapted to PI (harmonious spine)	PI-LL<10° (figure 1)	1A	Preserved segmental lordosis (SL)	64 ± 11	73 (22/51)
			1B	Altered SL, with preserved LL	62 ± 10	3 (2/1)
Type 2	Compensated malalignment	PI-LL>10° (figure 2)	2A	Preserved global alignment without pelvic compensation (Pelvic tilt PT <25°)	65 ± 12	8 (4/4)
			2B	Preserved global alignment with pelvic compensation (PT>25°)	66 ± 10	22 (11/21)
Type 3	Altered global alignment (SVA > 40mm)	SVA > 40mm	3		72 ± 9	60 (18/42)
Average					66 ± 10	166 (47/119)

Clinical parameters and health related quality of life scales

Clinical parameters (age, gender, body mass index) and health related quality of life scales (HRQOLs) were collected: Short Form-12 questionnaire (SF-12), Oswestry Disability Index (ODI), back pain and leg pain visual analog scales (BP-VAS, LP-VAS).

Radiographical parameters

Radiographic analysis included slippage level, slippage percentage, Meyerding grading and sagittal parameters: segmental lordosis (SL), L1-S1 lumbar lordosis (LL), T1-T12 thoracic kyphosis (TK), pelvic incidence (PI), pelvic tilt (PT), and sagittal vertical axis (SVA).

The classification system

The proposed classification was based on the rating of sagittal full-body standing radiographs (EOS system, EOS imaging, Paris, France) used in routine. It was derived from the sagittal modifiers of the SRS-Schwab classification for adult spinal deformity (ASD) [19]. The SRS-Schwab classification for ASD was shown to be correlated with HRQOLs [20]. Two orthopedic surgeons performed all radiographical measurements for each patient using a validated software (Surgimap® Nemaris Inc., New York, NY, USA).

A formal description of the classification is given in Table 1; briefly, type 1 corresponds to a harmonious and aligned spine (Figure 1), type 2 corresponds to a compensated spinal malalignment (Figure 2) and type 3 corresponds to an altered global sagittal alignment (Figure 3). Severity increases from type 1 to 3. Subtypes depend on segmental lordosis (type 1), or pelvic compensation (type 2). All patients were classified according to this classification system (Figure 4).

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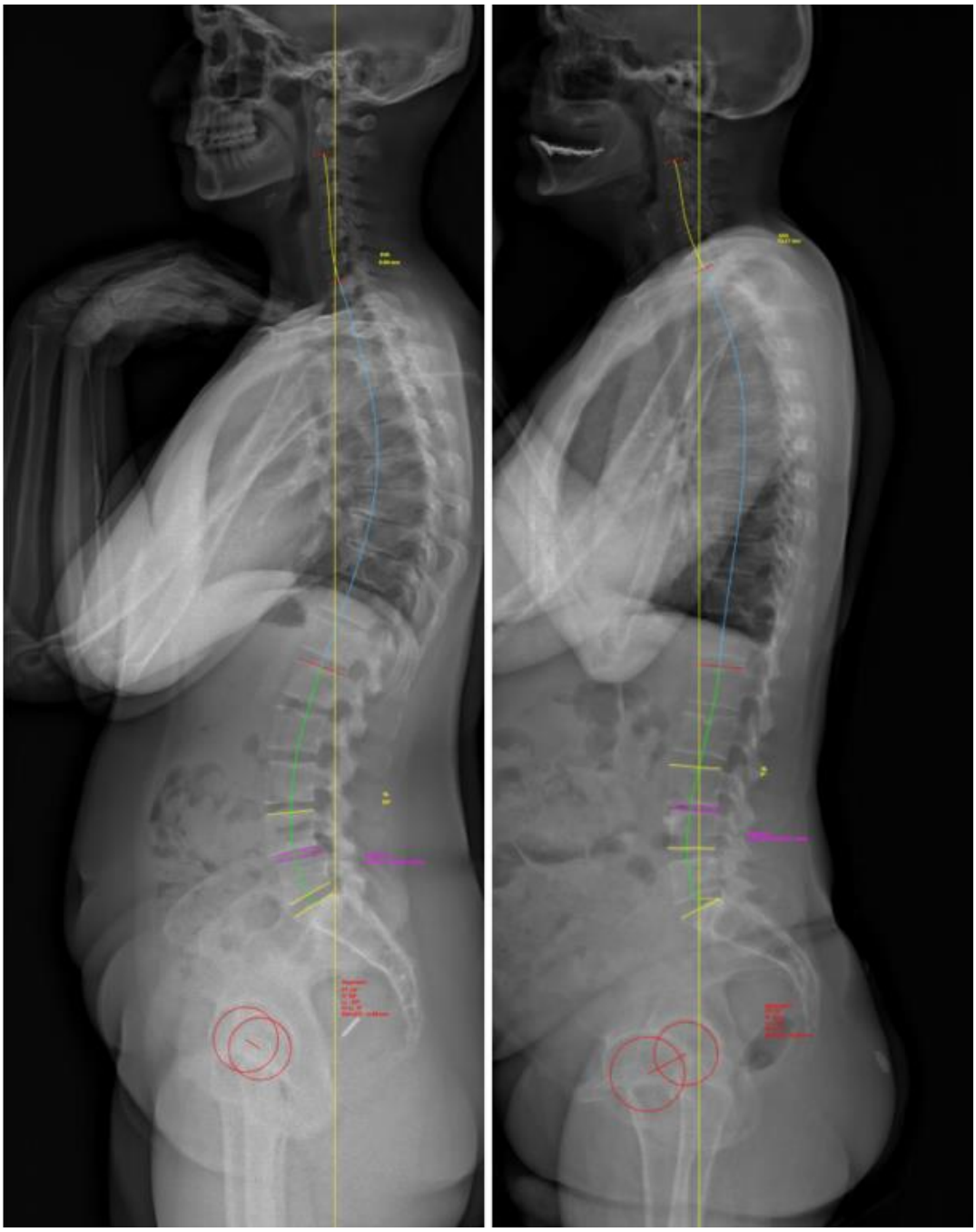

Fig. 1 Type 1 on lateral standing low-dose X-ray view. Harmonious and aligned spine

Statistical Analysis

Differences of clinical or sagittal spinal parameters according to spondylolisthesis types were assessed with non-parametric Kruskal-Wallis tests. Correlations between demographic data, HRQOLs and radiographical parameters were assessed using Spearman′s rank test, while differences were assessed with Mann-Whitney tests. Statistical analyses were performed using Matlab 2015b (Mathworks, Natick, MA, USA); statistical significance was set at $p = 0.05$.

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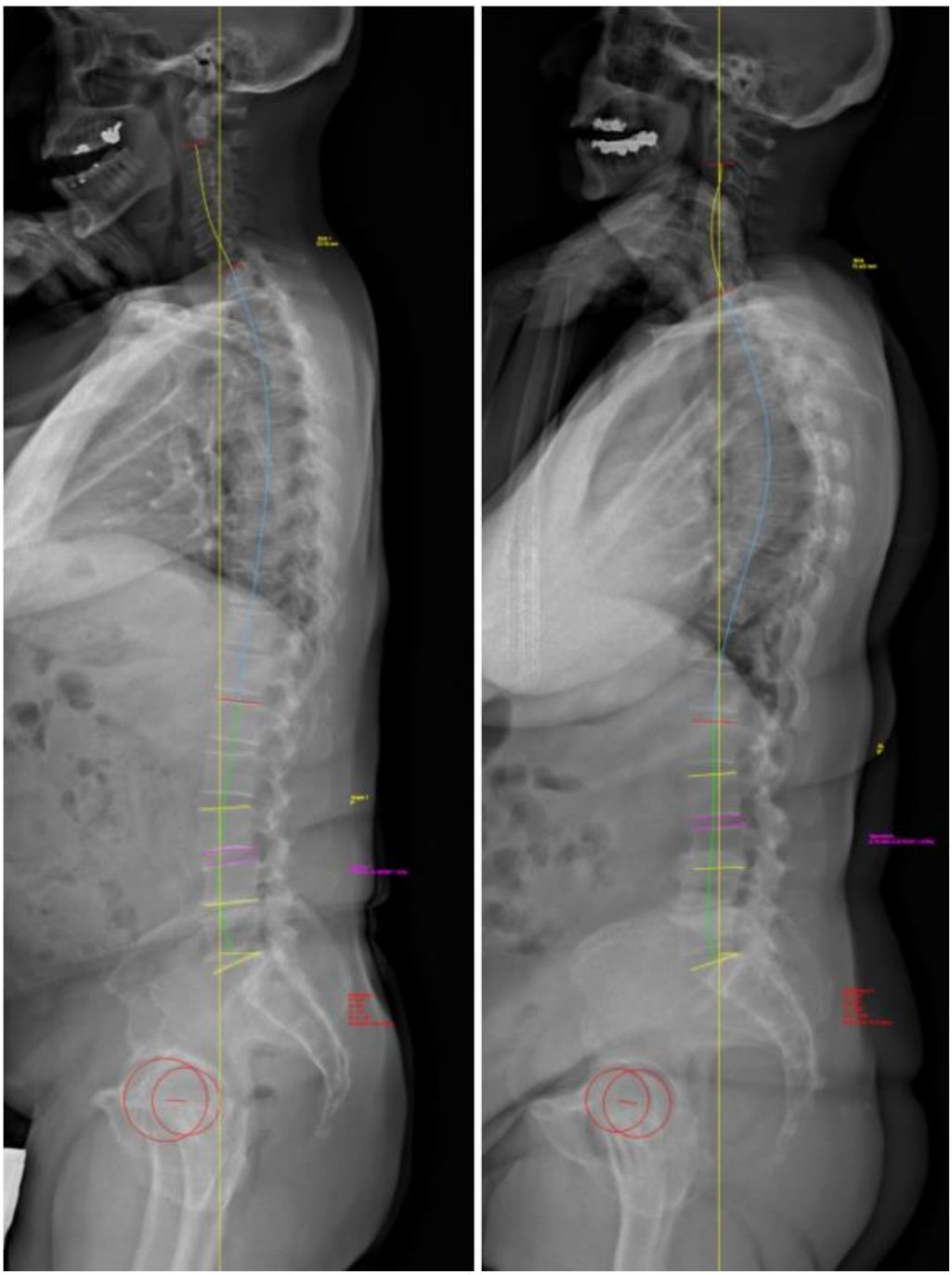

Fig. 2 Type 2 on lateral standing low-dose X-ray view. Altered global LL, compensated malalignment

Results

Demographic Data

A total of 166 patients who underwent surgery in our spinal surgery department with complete data were included. There were 119 females and 47 males with a mean age of 67.1 ± 10.5 years at surgery. All patients had DSLS with spinal stenosis. The majority of patients in this study had neurogenic claudication due to central spinal stenosis (90%). The remaining

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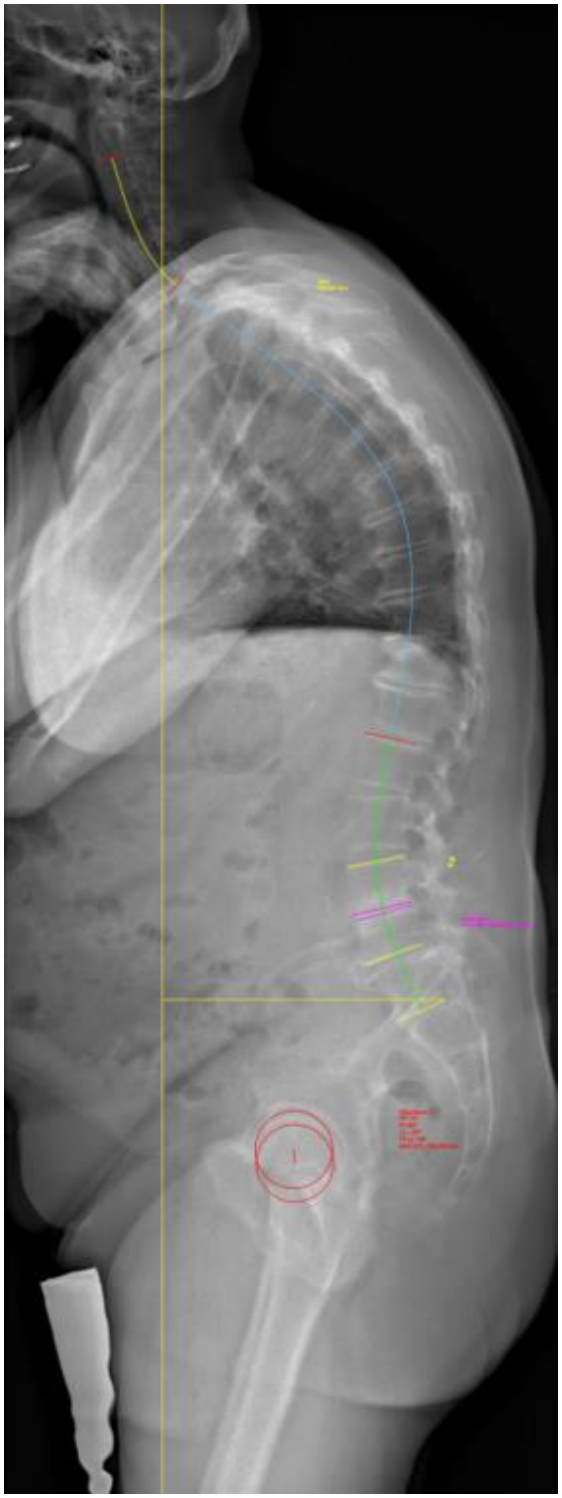

Fig. 3 Type 3 on lateral standing low-dose X-ray view. Altered global alignment

10% suffered from lateral recess or foraminal stenosis. Affected levels were: L4-L5 (n=121), L3-L4 (n=34), L2-L3 (n=6), and L5-S1 (n=5). DSLS classification demographics were respectively: type 1A (n=73), type 1B (n=3), type 2a (n=8), type 2B (n=22), type 3 n=60). The mean BMI was 26.14 ± 5.05 kg/m^2.

The demographic distribution of spondylolisthesis types is reported in Table 1.

Preoperative clinical parameters

The mean LP-VAS and BP-VAS were respectively 6 ± 2 and 7 ± 2; pain did not correlate with any other parameter. The mean ODI was 48 ± 15. The mean SF-12 PCS was 31 ± 8.

Clinical parameter data classified by type are reported in Table 2.

Radiographical parameters

The Meyerding grading was the following: grade 1 (n=124), grade 2 (n=24). The mean slippage percentage was 15% ± 7.6%. The mean values of spinopelvic parameters were: PI (59.3° ± 11.9°), PT (24.3° ± 7.6°), SS (35° ± 9°), PI-LL (9° ± 12°), SL (18.2° ± 8.1°), LL (51.3° ± 13.1°), TK (41.0° ± 13.9°), SVA (29.1 mm ± 42.2 mm).

Radiographical parameter values are reported in Table 3.

PI-LL was correlated with ODI (rho = 0.24, p=0.002). SVA was correlated with ODI (rho = 0.3, p = 0.0002) and SF12-PCS (rho = -0.18, p = 0.02). PT, PI, LL, TK and SL were not correlated with HRQOLs.

Relationships between spondylolisthesis types, clinical and radiographical parameters

DSLS types were correlated with age, ODI and SF-12 PCS (rho= 0.34, p<0.05; rho= 0.33, p<0.05; rho= -0.20, p=0.01, respectively). Type 3 patients had a significantly higher ODI than type 1A and 1B patients (p=0.0002), while SF-12 PCS was significantly lower in type 3

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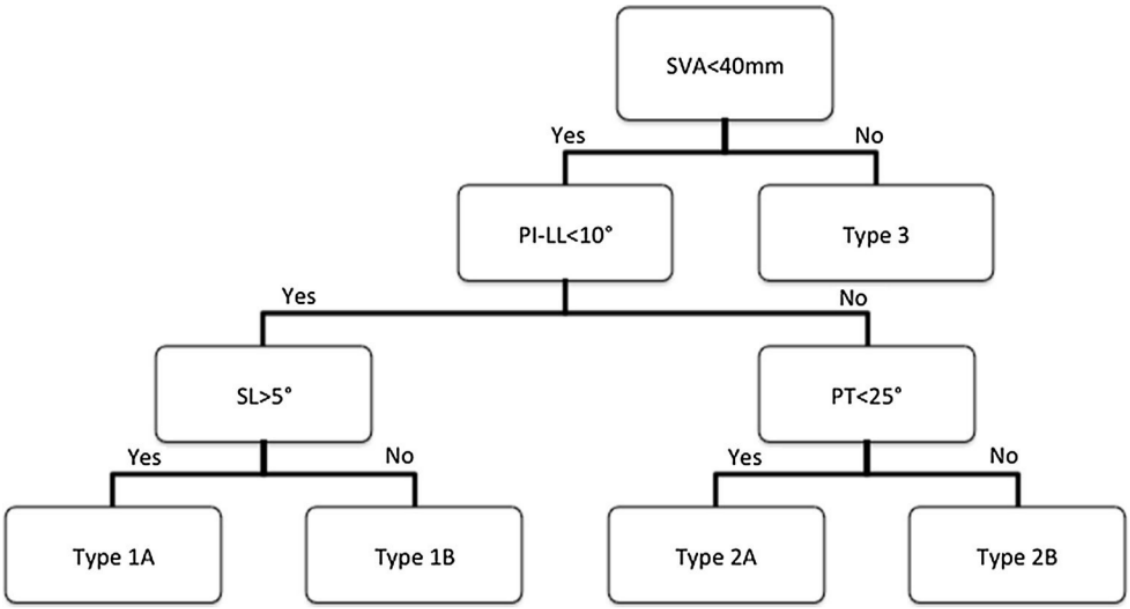

Fig. 4 Decision-tree algorithm

than type 1A and 1B patients (p = 0.03), demonstrating a quality of life degradation with increased type severity. BP-VAS and LP-VAS did not vary with types. Low SL did not influence HRQOLs.

Relationships between the spondylolisthesis classification, age and HRQOLs are reported in Figure 5 while effect of age on spinal parameters are detailed in Figure 6. Trends were observed between segmental parameters (SL and slippage percentage) and classification types. SL decreased with increasing types, with a significant difference between Type 1 and type 3 (p = 0.02, Figure 6), while slippage percentage increased with increasing types, again with a significant difference between Type 1 and type 3 (p = 0.01, Figure 6). Furthermore, LL decreased with increasing types. Differences between type 1 and type 3 were statistically significant (p<0.001, Figure 6). Mean PI in type 1 patients was physiological (56.3° ± 9.4°) while it was significantly increased in type 2 (63.9° ± 12°, p<0.001) and type 3 (69° ± 13.7°, p<0.001). Mean PT was the highest

Table 2. Clinical characteristics by type

	LP-VAS	BP-VAS	ODI	SF12 PCS
Type 1A	6 ± 2	7 ± 2	0.42 ± 0.12	39 ± 11
Type 1B	5 ± 1	6 ± 1	0.39 ± 0.14	42 ± 1
Type 2A	7 ± 1	8 ± 1	0.49 ± 0.17	35 ± 12
Type 2B	6 ± 2	7 ± 2	0.45 ± 0.16	37 ± 10
Type 3	6 ± 2	6 ± 2	0.52 ± 0.15	39 ± 10
Mean ± SD	6 ± 2	7 ± 2	0.46 ± 0.15	31 ± 8

Quality of life assessments: Short Form-12 questions physical composite scale (SF-12 PCS), Oswestry Disability Index (ODI), low back and leg pain visual analog scale (BP-VAS, LP-VAS).

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Table 3. Radiological characteristics by types

	PI [°]	LL [°]	PI-LL [°]	PT [°]	SS [°]	SL [°]	SVA [mm]	TK [°]	Slippage [%]
Type 1A	57 ± 9	57 ± 9	1 ± 6	21 ± 5	36 ± 8	21 ± 7	11 ± 17	44 ± 11	13 ± 8
Type 1B	45 ± 9	40 ± 9	6 ± 1	17 ± 5	28 ± 4	3 ± 1	13 ± 4	36 ± 15	12 ± 7
Type 2A	57 ± 11	46 ± 17	11 ± 10	22 ± 1	35 ± 11	19 ± 11	18 ± 15	30 ± 21	12 ± 6
Type 2B	67 ± 12	49 ± 14	18 ± 6	33 ± 5	34 ± 10	16 ± 8	14 ± 17	33 ± 10	16 ± 6
Type 3	61 ± 14	47 ± 15	16 ± 13	26 ± 9	35 ± 11	16 ± 8	73 ± 34	42 ± 15	17 ± 8
Mean ± SD	59 ± 12	51 ± 13	9 ± 12	24 ± 8	35 ± 9	18 ± 8	34 ± 38	41 ± 14	15 ± 8

in type 2 (29.7° ± 6.3°, $p<0.05$). SVA expectedly tended to increase with increasing types. Type 2 patients had significantly lower TK (32.3° ± 13.5°) than type 1 (43.9° ± 11.3°, $p = 0.00002$) and type 3 patients (41.8° ± 15.4°, $p = 0.004$).

Relationships between classification types and radiographical parameters are reported in Figure 6.

Discussion

DSLS is a common cause of lower back pain and leg pain with or without neurogenic claudication. It is caused by several degenerative modifications [5]. The prevalence of patients with symptomatic DSLS is expected to rise as the population ages. The other known causes of spondylolisthesis (isthmic, congenital, traumatic, iatrogenic) are not considered here.

To our knowledge, there is no classification system or tool providing surgeons with a comprehensive analysis of sagittal alignment in DSLS. In this framework, we proposed a new classification system based on sagittal alignment with three main types.

The management of DSLS requires a holistic and comprehensive analysis of each case. Recently, different studies reported that spinopelvic sagittal malalignment played an important role in multiple spinal conditions [15],[16],[17] and especially in the management of DSLS [11],[12]. Standing lateral radiographs are the most appropriate, noninvasive test to detect degenerative DSLS [21]. However, the analysis of sagittal spinal alignment seems to be an important factor for the full assessment of DSLS [22]. Indeed, our own experience with the treatment of spondylolisthesis is that neglecting the role of sagittal alignment in DSLS, as shown by Kumar et al., may lead to poor clinical outcome and patient satisfaction [23]. We observed that patients mistreated as type 1 with a single-level posterior fusion while they actually were type 2 or 3 required revision surgery to prolong constructs more frequently.

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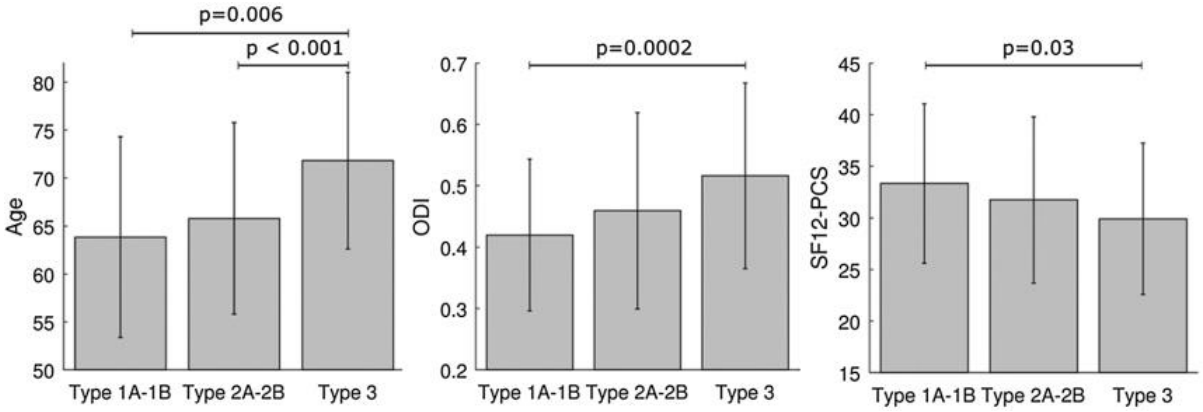

Fig. 5 Relationship between degenerative spondylolisthesis types, age, and quality-of-life indexes. ODI Oswestry Disability Index, SF-12 PCS Short Form-12 Questionnaire Physical Composite Scale

However, this reflects our local experience and is not supported by clinical evidence; a longitudinal study is currently under way.

Our data were similar to literature findings. Typically, the slippage was less than 30% [24]'[3]'[4]'[5]'[25]. In the present study, the sex ratio was 2.5. The mean age was 67.1 ± 11 years. Mean slippage was 14.6 ± 7.6 %. Patients were older and the sex ratio was comparable to results from other studies. The mean PI was 59.3° ± 11.9°, which is higher than in the general population (52.6° ± 10.4° according to Mac Thiong et al. [26]) but comparable with other DSLS cohorts[18]. Indeed, patients with a high PI are predisposed to the development of DSLS [27]'[15].

This classification system was consistent with age, ODI, and SF-12 PCS (rho= 0.34, $p<0.05$; rho= 0.33, $p<0.05$; rho= -0.20, $p=0.01$, respectively). Aging is responsible for increasing clinical and radiographical DSLS severity and was therefore associated with increasing types. Indeed, compensatory mechanisms are progressively overrun due to muscular degeneration and osteoarthritis as they become unable to restore sagittal imbalance. Furthermore, HRQOLs decreased with increasing types: the type definition was entirely based on X-ray measurements and had no direct link with age or HRQOL scores, which reduces the risk of bias. ODI and SF-12 PCS showed significant correlations, albeit weak, with several sagittal parameters (PI-LL correlated with ODI, $p<0.05$ while SVA correlated with ODI and SF-12 PCS, $p<0.05$). It should be noted that low SL did not influence HRQOLs. This may be explained by the low number of patients with SL < 5° (three patients). Classification types were not correlated with LP-VAS, BP-VAS and SF-12 MCS. In fact, these parameters are known as highly subjective and their value was limited in the absence of a comparison with postoperative values.

Our results support the well-described natural history of DSLS featuring decreasing SL and disc height loss in parallel with increasing slippage. Indeed, type 3 presented a lower SL and

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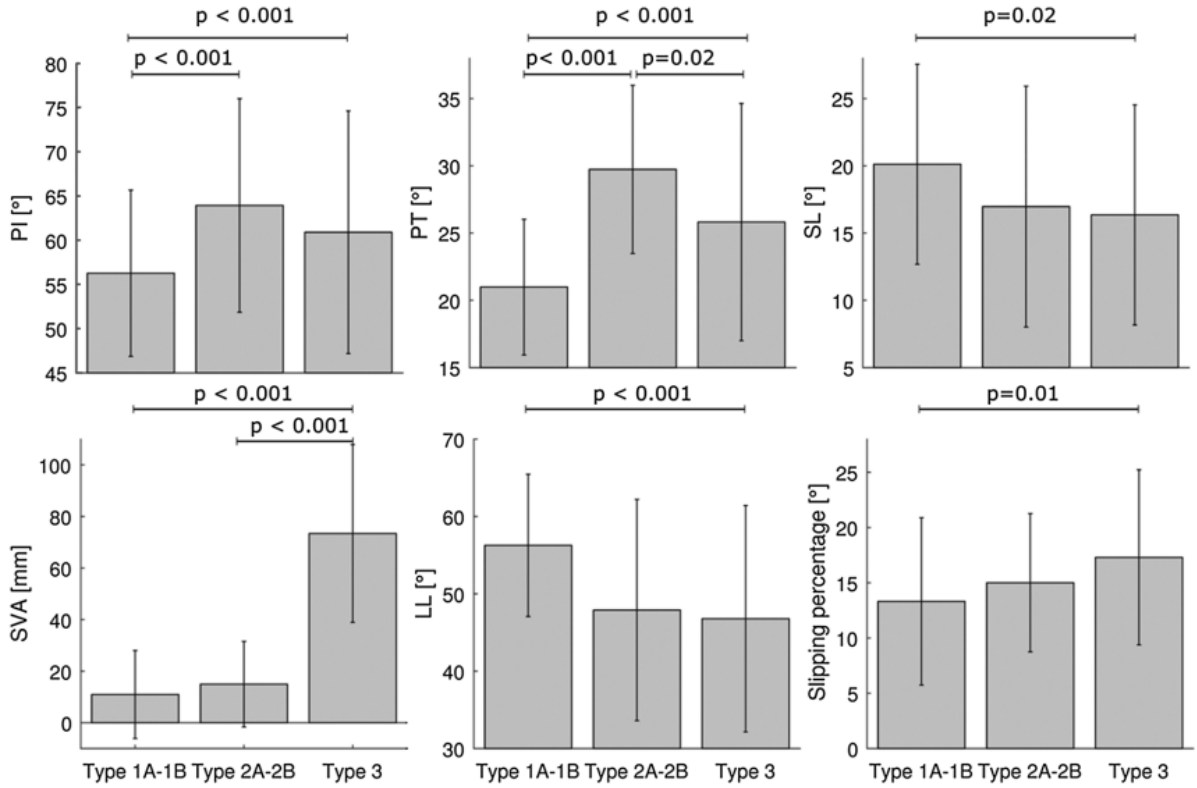

Fig. 6 Relationships between degenerative spondylolisthesis types and radiographical spinal characteristics: Pelvic incidence (PI), pelvic tilt (PT), segmental lordosis (SL), sagittal vertical axis (SVA), L1–S1 lumbar lordosis (LL), and slippage

LL compared to type 1 (p=0.02) with a linear decreasing trend. The slipping percentage significantly increased with types. Furthermore, PT was increased in types 2 and 3 compared to type 1. This increase was predominant in type 2, in accordance with the classification definition. This may be explained by overrun compensatory mechanisms in type 3. Type 2 patients managed to keep a "subnormal" SVA (<40mm) by a PT increase. PT is the key of pelvic adaptation [28].

We hypothesize that there is a dynamic continuum from type 1 to type 3, which is yet to be proven following the same patients over time. Type 1A corresponds to balanced spines with preserved local and global sagittal balance. Type 1B includes a local compensation with disc flexion and loss of segmental lordosis. Type 2A and 2B include a PI-LL mismatch. This is due to multi-segmental degenerative disc disease responsible for a loss of LL. Type 2A (PI = 57°) presented a lower PI than type 2B (PI = 67°); in that sense, in these unbalanced but compensated subgroups, type 2A grossly corresponded to a flat lumbar spine with a mainly thoracic adaptation in hypokyphosis and type 2B corresponded to a dynamic lumbar spine with overrun thoracic adaptation in hypokyphosis and a mainly pelvic adaptation in retroversion. Indeed, patients in type 2 group displayed significantly lower thoracic kyphosis (32.3° ± 13.5°) than patients in type 1 (43.9° ± 11.3°) and type 3 (41.8° ± 15.4°). These compensatory mechanisms display specific limits with aging (thoracic extension muscular fatigability, pelvic maximum retroversion impaired by hip osteoarthritis). Type 3 represents

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significant global malalignment resulting from overrun local and regional compensatory mechanisms (thoracic and pelvic); patients therefore commonly use walking canes.

Several authors extensively described the biomechanics of DSLS [11],[12],[15]. It appeared that patients with a dynamic lumbar spine and high PI (Roussouly 3 or 4) were prone to developing slippage [29],[13]. A high PI is therefore the initial driving force behind the development of DSLS, supported by the high mean PI observed in types 2 and 3 (Figure 6). Thus, we believe that degenerative disc disease occurs later in the natural history of DSLS, resulting either in single-level disc degeneration with local kyphosis (type 1B) or multi-level disc degeneration with global hypolordosis (type 2). Type 1B seemed to be an isolated and rare (three patients) entity due to its lower PI compared with all other types (PI=45° ± 9°). This may be explained by the very nature of the process behind the development of DSLS. Indeed, static spines (Roussouly 1 and 2) with low PI and low SS are less frequently responsible for DSLS. Type 2A only represented 4.8% of the population in the present study. Indeed, according to Liu et al. [15], increased lumbar lordosis and pelvic incidence account for the high sheering forces responsible for the development of spondylolisthesis. This may explain the higher prevalence of type 2B (13.25%) over type 2A (4.8%). Type 3 represents the final stage of DSLS and occurs in significantly older patients (72 ± 9 years, p=0.006).

One of the limitations of this study was the absence of evaluation of the impact of spinal stenosis on posture. MRI analysis seems mandatory and could prevent to over treat type 2, as deformity cases. Discerning the implication of spinal stenosis on posture would require a control group with no spinal stenosis. However, all patients suffered from neurological symptoms and if postural factors intervened, the distribution of postural factors was also assumed uniform in the studied population since there was no control group without spinal stenosis. Since the surgical treatment of DSLS with isolated back pain and no symptomatic spinal stenosis (no neurogenic claudication or radiculopathy) remains highly controversial, we believe that this classification should not be used in such cases. Spinal stenosis has been demonstrated to be a cause of reversible lumbar kyphosis [30]. Buckland et al. studied different posture patterns between patients with either ASD or degenerative lumbar stenosis (DLS) and concluded that they engaged different compensatory mechanisms [30]. Indeed, according to Buckland et al., patients attempt to decompress neural elements by permitting truncal sagittal malalignment driven by a posterior pelvic shift. The latter was recruited earlier in patients with DLS compared with patients suffering from ASD. Besides, patients in mild to moderate malalignment did not recruit PT until moderate to severe malalignment was present. They also showed that increasing SVA before recruiting PT was the preferable mode of compensation for patients with DLS. Those fundamental differences in terms of compensation behavior advocate the use of this classification for DSLS with spinal stenosis only.

Considering solely PI and other sagittal lumbar parameters for an optimal surgical management of DSLS occults fundamental regional and global dynamic compensatory mechanisms. This classification proposes to fully integrate sagittal spinal balance and pelvic

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parameters taking into account commonly used preoperative criteria. Furthermore, Smith et al. showed that patients with improved spinopelvic sagittal modifiers (PI-LL, PT, or SVA) after surgical correction had significantly higher HRQOLs than those whose modifiers deteriorated or remained the same [29]. However, the therapeutic impact of this classification has to be validated.

A therapeutic guidance can be proposed according to this classification. The ideal goal of surgical management is to maintain, approach or restore a physiological postoperative spinal balance:

- Type 1: a segmental approach is advised: decompression and fusion alone with no correction or dynamic stabilization (type 1A) [31]. Type 1B incudes segmental kyphosis (SL<5°) and we believe that it is preferable in that case to restore SL using an intersomatic device, through an anterior or posterior approach.

Treatments for type 2 and 3 are similar to strategies developed for ASD: regional correction becomes essential to reach a satisfying postoperative global alignment.

- Type 2: there is PI-LL mismatch. Patients compensate with thoracic spine extension (flat back appearance) (Type 2A, PT<25°) or with pelvic retroversion (type 2B, PT>25°). The aim in these cases is to restore a harmonious spine with a LL adapted to PI.

- Type 3: sagittal imbalance prevails (SVA> 40 mm). More aggressive surgical treatment may be considered to correct sagittal malalignment especially in case of significant clinical sagittal imbalance. Treating only the slippage level may lead to a poor clinical outcome.

Conclusion

This classification fully combines segmental, regional and global analysis of sagittal balance with regard to DSLS. Classification types were consistent with age and HRQOLs (ODI, SF12-PCS). This classification potentially represents a useful tool for comprehensive analysis of DSLS before surgical treatment taking into account sagittal balance. Further clinical evidence is currently being collected to validate its therapeutic impact.

Disclosure:

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