



A narrative review and scoring proposal for secondary lumbar instability after lumbar decompression surgery

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Abstract

Purpose Lumbar spinal stenosis (LSS) is a common condition in the aging population, where decompressive surgery (DS) is widely regarded as the gold standard due to its effectiveness in relieving symptoms. However, DS carries the risk of secondary lumbar instability (SLI), while fusion surgery, although mitigating this risk, may lead to overtreatment and complications such as adjacent segment disease. The aim of the present study was to review the current literature on preoperative radiological and clinical variables, thus accounting for SLI after lumbar decompression surgery and to derive a score for SLI risk prediction.

Methods A literature review using online databases was performed in order to identify risk factors for the emergence of SLI. Risk factors were then graded for relevance. Consequently, a risk score for predicting SLI was developed from these results.

Results 25 studies including 9754 patients were identified. The most commonly described predictors for SLI were preoperative instability, disc height > 6.5 mm, surgical invasiveness as well as patient-related risk factors such as BMI, age, gender and presence of mechanical low back pain. Based on these results, a 14-point scale was created using the most relevant risk factors selected by the research group using a peer-review process.

Conclusion The proposed score identifies known risk factors for SLI, rated according to their importance on clinical decision making. This represents an initial theoretical approach that has to be validated by prospective clinical studies. Nevertheless, decision making may already be supported by the awareness of the characterized risk factors.

Keywords Secondary instability · Postoperativeolisthesis · Lumbar decompressive surgery · Postoperative slippage

Introduction

Lumbar spinal stenosis (LSS) is a common disease in the aging population with a growing socioeconomic importance [2, 60]. Typical symptoms include neurogenic claudication, low back pain (LBP) and radiating pain, characteristically increasing when standing and walking, and showing significant impact on mobility and quality of the patient's life. Treatment options include conservative management, as well as surgery, primarily aiming at decompression of neural structures. Previous research clearly demonstrated the superiority of surgical over conservative treatment [3, 4, 16, 26, 56, 70–72]. Decompression surgery of LSS has been considered the “gold standard” [58]. The traditional laminectomy technique allows an extensive decompression

of neural structures, but carries well reported disadvantages due to extensive muscle trauma and the risk for secondary lumbar instability (SLI), contributing to a poor outcome in up to 50% of patients [21, 52, 68, 75]. Some landmark studies recommended additional fusion and since then the annual rate of fusion surgeries has increased significantly [6, 11, 17, 35]. To overcome the outlined disadvantages of laminectomy, less invasive microsurgical decompression techniques have been developed [18, 68]. These techniques, however, also differ and have a varying impact on segmental stability [36, 42]. Reoperation rates and the likelihood of secondary fusion procedures cannot be neglected, especially in patients with degenerative spondylolisthesis [5]. Nevertheless, management protocols for LSS and accompanying degenerative fixed or low-grade spondylolisthesis are still controversial, and standard guidelines favoring a decompression or fusion procedure are lacking. While lumbar decompression surgery (LDS) as a “stand-alone option” is associated with significantly lower costs and decreased invasiveness compared to lumbar instrumentation surgery, the failure of

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decompression in terms of SLI with need for subsequent fusion may alter the financial burden for the healthcare system significantly. On the other hand, the initial fusion without prior lumbar decompression reduces the risk of SLI, but at the same time may lead to a higher rate of adjacent segment disease (ASD) in addition to the higher invasiveness and more complications of surgery thus remaining a daily challenge. Furthermore, the definition of spinal instability often relies on low back pain, a highly subjective symptom, or radiological findings, which may not always correlate with the patient's clinical presentation. This further complicates planning the adequate surgical treatment of patients with lumbar spinal stenosis.

In the last decade, a vast collection of clinical, radiological and technical factors, potentially influencing stability and decision-making, were identified [31, 41, 67]. Clinical findings, such as the presence of mechanical LBP, a high Body Mass Index (BMI) and previous lumbar surgery, as well as radiological factors, such as dynamic instability, disc height, facet joint angle and effusion have been discussed to account for a higher risk of SLI [40, 51, 62]. However, to date, no clear consensus in determining instability has been achieved in regard to the relative importance of these parameters. Therefore, the purpose of the present study was to review the current literature and to identify measurable preoperative radiological and clinical variables, accounting for SLI after LDS. Accordingly, a score for SLI risk prediction was generated to better identify the appropriate surgical technique in managing LSS patients with or without LDS.

Material & methods

Search methodology and selection criteria for detailed review

A structured narrative literature review was conducted using PubMed and Google Scholar. While not adhering to systematic review protocols (e.g., PRISMA, PROSPERO registration), we aimed to capture a broad overview of known risk factors for secondary lumbar instability. Although PubMed and Google Scholar were the primary search platforms, the included articles span key journals indexed in major databases such as MEDLINE and EMBASE. Additional references were identified through manual reference screening. The predefined search string consisted of the following keywords: “post-decompressive spinal instability”, “secondary lumbar instability”, “iatrogenic spondylolisthesis” and “postoperative spondylolisthesis”. The results of the keyword research were included for a more detailed assessment. In this study, we define “secondary lumbar instability” (SLI) as a postoperative deterioration in segmental alignment or stability following decompressive surgery for lumbar spinal

stenosis, typically characterized by new or progressive spondylolisthesis, worsening low back pain, or new neurological symptoms, and corroborated by dynamic imaging findings. During the initial screening, full-text articles in German and English language were included, if the abstracts were suitable for the literature review. Due to the limited number of articles for this specific research question, no consideration was given to the year of publication. Articles without full text availability or articles including revision surgery due to complications other than SLI were excluded. After exclusion of unsuitable literature, proof-reading of the full-text articles was performed. Additionally, the literature references of the selected articles were also screened. Reviews, meta-analyses and pre-clinical studies were excluded (Fig. 1).

SLI scoring system

The previously identified risk factors for the development of SLI were recorded in a descriptive manner. Study type and quality as well as statistical data including possible risk factors were extracted and used for the categorization of the novel SLI risk assessment classification. Subsequently, a peer-review process within the spine surgery research group was initiated to assess the importance of individual risk factors and to assign the appropriate point weighting.

Results

The initial database research identified 1255 papers, 1176 articles were excluded, and 79 full-text articles were reviewed, identifying 10 prospective and 15 retrospective studies suitable for the research purpose (Fig. 1). Altogether, data of 9754 patients were included and evaluated accordingly (Table 1).

Patient-related risk factors

Patients presenting without degenerative low-grade spondylolisthesis undergoing LDS for lumbar spinal stenosis carry a 2% risk for SLI [29, 45]. In contrast, patients carrying preoperative risk factors (radiologic, surgery- or patient-related) show SLI rates of up to 70% [9, 12, 28]. Younger patients have been reported to be at higher risk for SLI after LDS [69, 75]. Recent studies revealed a roughly 40% higher risk of SLI for younger patients with a cut-off set at 70 years (hazard ratio [HR] 1.37, CI 1.11, 1.70, $p = 0.004$) [69]. Furthermore, women had a 5 times higher likelihood of being affected by postoperative slip progression than men (SLI prevalence in men vs. women: 75.0% vs. 15.8%) [20, 27, 75]. Patients presenting with postoperative slippage had a significantly increased BMI compared to patients without SLI [27, 59, 75]. A retrospective analysis of 163 patients with

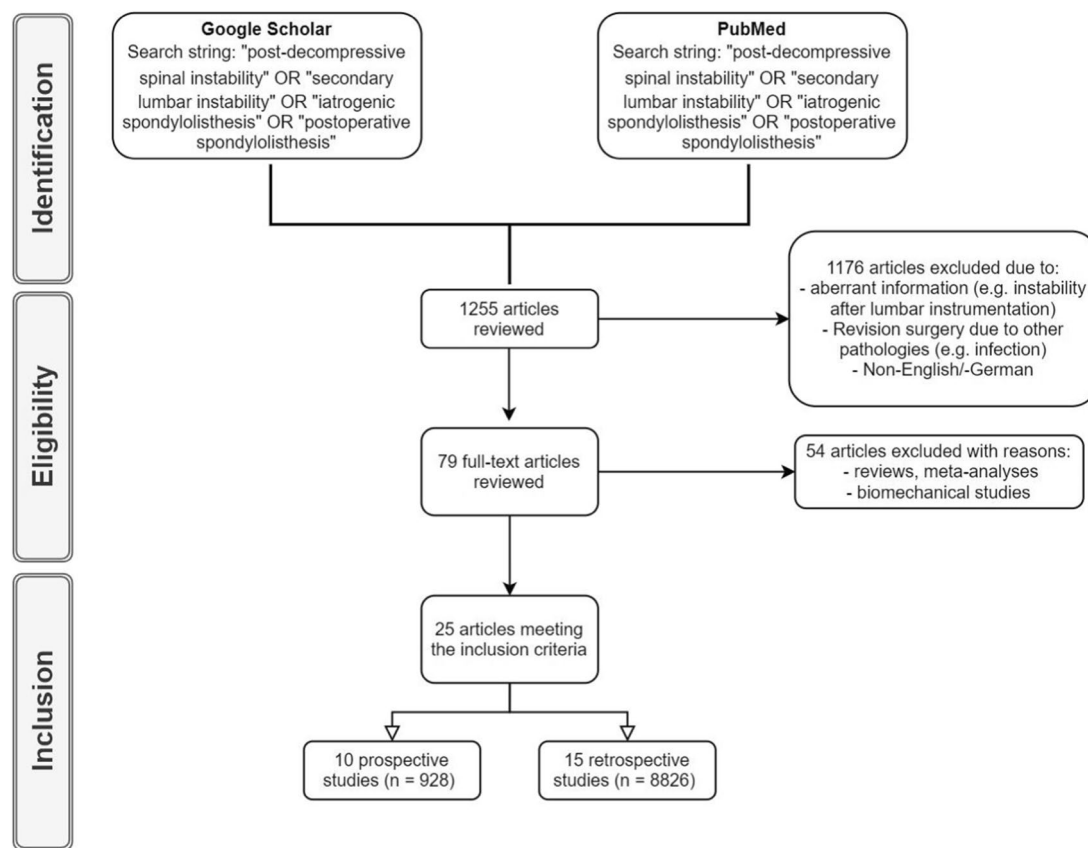


Fig. 1 Flowchart of the study selection and literature review process

degenerative spondylolisthesis treated with LDS revealed that overweight patients had a fourfold higher likelihood to receive revision surgery based on SLI compared to normally weighted patients (Odd's Ratio [OR] 4.11, confidence interval [CI] 1.29–13.11) [59]. Even the presence of rheumatoid or vascular diseases in patients with preoperative low-grade spondylolisthesis led to a significant higher risk of postoperative SLI (HR1.53, CI 1.13–2.06, $p = 0.006$) [69].

Persistent mechanical LBP as a clinical sign for facet joint affection was reported as one of the most significant predictors for postoperative instability, with cut-off values for dynamic slippage of 3 mm [14, 17, 28, 29, 34, 39, 49, 54]. Prospective study cohorts have shown an incidence of mechanical LBP of up to 62% in patients suffering from SLI due to LDS ($p < 0.001$). Moreover, LBP had a significant impact on the patient's ability to work (return to work: 85% vs. 47%, $p = 0.001$) and the overall functional outcome (Oswestry Disability Index (ODI) 34 vs. 17 in patients with compared to patients without SLI, respectively [$p = 0.002$]) [39]. The presence of postoperative neurogenic intermittent claudication was associated with a 50% higher risk of postoperative slippage in patients with preoperative already existing degenerative or isthmic spondylolisthesis leading to fusion surgery (HR1.53, CI 1.13–2.06, $p = 0.006$) [69].

Given the prevailing ambiguity in defining LBP and its inherently subjective nature, our study endeavors to establish a more concrete and clinically applicable criterion, aiming to standardize its identification and enhance the reliability of SLI diagnoses. In this study, LBP is defined by either of the following conditions: VAS greater than 5 or the predominance of low back pain. In both scenarios, the definition additionally requires an exacerbation of symptoms upon axial loading. This dual-criterion approach aims to comprehensively encompass the varying presentations of LBP in SLI cases.

Radiographic risk factors

Preoperative instability indicated by spondylolisthesis of 2–3 mm in dynamic lateral radiographs has been reported as a significant predictor for a postoperative deterioration resulting in SLI [5, 17, 25, 27, 29, 65, 74]. Patients with preoperative dynamic instability suffered from 2.65-fold higher risk of SLI (OR 2.65, CI 1.08–6.46, $p = 0.033$) compared to stable spondylolisthesis [5, 49]. Even the presence of a stable spondylolisthesis grade I according to Meyerding was found to be a significant predictor with a nearly threefold higher risk of SLI compared to patients without spondylolisthesis

Table 1 List of studies incorporated for the review process and development of the SLI score

Author	Year	Patient cohort	Design	Aim of the study	Findings
Lombardi et al. [45]	1985	47	Retrospective*	Facet-sparing vs. wide DS vs. fusion for degenerative listhesis	Predictor for SLI: Postoperative disc height > 6 mm
Johnsson et al. [28]	1986	45	Retrospective	Risk of SLI after DS	SLI prevalence 65% vs. 20% in patients with vs. without preop listhesis ($p < 0.01$), SLI led to a worse clinical outcome ($p < 0.01$)
Hopp et al. [20]	1988	344	Retrospective*	Evaluation of the postop development of SLI	Incidence of revision surgery due to SLI: 4.7%, women more often affected
Johnsson et al. [27]	1989	61	Retrospective	Impact of surgery extent and preop predictors for SLI	SLI occurrence men vs. women = 1:1.6 ($p < 0.01$), significant predictors: age, preop instability, surgical invasiveness, degenerative listhesis ($p < 0.05$)
Herkowitz et al. [17]	1991	50	Prospective	Evaluation of indication criteria for additional fusion in DS	Patients with DS and postop listhesis had higher postop LBP scores (2.5 vs. 1.3, $p < 0.01$) and increased need for daily pain medication
Jönsson et al. [29]	1992	60	Prospective*	Incidence of SLI in facet-joint sparing DS	SLI incidence: 2% (no preop listhesis) vs. 30% (preop listhesis)
Kotilainen et al. [39]	1993	190	Prospective	Impact of SLI on long-term HRQoL outcome	Incidence of LBP: 62% vs. 20% in patients with vs. without SLI ($p < 0.001$), ODI: 34 (w/SLI) vs. 17 (w/out SLI) ($p = 0.001$), 47% of patients w/SLI vs. 85% of patients w/out SLI have returned to work ($p = 0.002$) at 2y FU
Schulitz et al. [63]	1995	46	Prospective	Influence of DS on SLI and impact on outcome	Hemi-facetectomy leads to increased rate of SLI, SLI incidence 30%
Fox et al. [12]	1996	124	Retrospective*	Incidence of SLI, predictors, impact on outcome in DS	SLI prevalence: 53.3%; predictors: postop physiologic disc height, higher facet joint angle (65.8° vs. 50.4°), multilegmental decompression (13% [monosegmental] vs. 59% [3-level decompression]), preop listhesis
Iguchi et al. [23]	2000	37	Retrospective	Long-term outcome of laminectomy as DS	Postop vertebral angulation of > 10° has shown with significant impact on clinical outcome (Rate of improved JOA score: 42.7 ± 31.6% (> 10°) vs. 78.5 ± 27.4% (< 10°), $p = 0.014$)
Ghogawala et al. [15]	2004	34	Prospective	Comparison of DS ± fusion in Grade I spondylolisthesis	SLI incidence in DS patients was 15%, lower postop SF-36 in DS (27.5 vs. 13.6, $p = 0.02$)
Thomé et al. [68]	2005	120	Prospective	Uni- vs. bilateral laminotomy vs. laminectomy	No significant differences regarding the SLI rate for patients treated with uni-/bilateral laminotomy or laminectomy as DS
Fu et al. [14]	2008	152	Prospective	Modified laminoforaminotomy vs. laminectomy	SLI incidence: 8% (laminectomy) vs. 0% (laminoforaminotomy), SLI was associated with increased LBP (0.05 ± 0.22 vs. 0.63 ± 1.07, $p < 0.001$)
Celik et al. [8]	2010	71	Prospective	Bilateral laminotomy vs. total laminectomy	SLI incidence in total laminectomy was 9% vs. 0% in bilateral laminotomy cohort ($p < 0.05$)
Kelleher et al. [34]	2010	75	Retrospective	Postop outcome for facet-preserving DS	Preop listhesis did not show as a significant predictor for SLI ($p > 0.05$)
Hong et al. [19]	2011	53	Retrospective	Uni- vs. bilateral DS	Significant increase of sagittal translation in patients without preop listhesis treated with bilateral DS (1.69% vs. 4.07%, $p < 0.001$), significant difference in postop sagittal translation in uni- vs. bilateral DS (2.4% vs. 4.08%, $p = 0.047$)

Table 1 (continued)

Author	Year	Patient cohort	Design	Aim of the study	Findings
Lattig et al. [41]	2012	160	Retrospective	Correlation between facet joint effusion in MRI and SLI	Facet joint effusion in MRI was significantly associated with SLI ($r = 0.64$, $p < 0.001$)
Blumenthal et al. [5]	2013	40	Prospective	Identification of radiographic risk factors for SLI	Significant predictor: Preop motion at spondylolisthesis (OR 2.65; CI 1.08–6.46; $p = 0.033$), disc height > 6.5 mm (OR 4.1, CI 0.75–22.31), facet angle $> 50^\circ$
Yang et al. [75]	2013	42	Retrospective	Risk factors for SLI	Incidence of SLI: 35.7%; Significant predictors: Asymmetrical paraspinal muscle volume, physiologic lordotic angle, facet joint tropism, smoking history
Chang et al. [9]	2014	165	Prospective	Postop outcome in patients w/or w/out preop listhesis and DS	8% overall SLI incidence at 60 months-FU; no significant SLI predictors in both cohorts, no significant differences regarding SLI
Sato et al. [59]	2015	163	Retrospective	Reoperation rate after DS, risk factors for ASD/SSD	Predictors for SLI: BMI (OR 4.13, CI 1.3–13.06, $p = 0.02$), disc height > 10 mm (OR 3.18, CI 1.03–9.82, $p = 0.04$)
Jang et al. [25]	2016	21	Retrospective	3y postop outcome in patients treated with DS for DLS	Incidence of SLI: 45%, predictor: preoperative sagittal motion ($p < 0.01$)
Ramhmdani et al. [53]	2018	105	Retrospective	Evaluation of iatrogenic spondylolisthesis	Higher preop disc height in patients with SLI at L4/5 (10.4 mm vs. 8.5 mm, $p = 0.036$)
Minamide et al. [49]	2019	218	Retrospective	Postop outcome after DS	Patients requiring subsequent fusion surgery had $> 2/3$ disc height loss and/or dynamic slippage of ≥ 3 mm
Urakawa et al. [69]	2020	7331	Retrospective	Rate and timing of subsequent fusion after DS and risk factor evaluation	Subsequent fusion in 6.3% vs. 14.5% of degenerative vs. isthmic spondylolisthesis at 5 years FU ($p < 0.001$); Risk factors: < 70 years (HR 1.37, CI 1.11, 1.70, $p = 0.004$), Neurogenic claudication (HR 1.53, CI 1.13, 2.06, $p = 0.006$), RA/CVD (HR 1.57, CI 1.27, 1.94, $p < 0.001$)

*no statistical analysis, descriptive design; SSD same segmental disease, ASD adjacent segmental disease, DS decompressive surgery, DLS degenerative lumbar spondylolisthesis, FU follow-up, SLI secondary lumbar instability, HRQoL health-related quality of life, HR hazard ratio, RA rheumatoid arthritis, CVD collagen vascular disease, LBP low back pain, y years

[27, 28]. A retrospective, large-cohort evaluation of long-term revision surgery rates for lumbar spinal surgical interventions revealed a roughly 10% difference in revision rates for patients treated with fusion surgery vs. LDS for degenerative spondylolisthesis (17.1% vs. 28.0%) [47]. SLI rates do not only depend on the presence of spondylolisthesis but also the type of olisthesis (degenerative vs. isthmic). Recent studies showed significant differences in subsequent revision rates at 5 year follow-up for patients with isthmic (14.5%) and degenerative spondylolisthesis (6.3%; $p < 0.001$) treated initially with LDS [69]. Further factors leading to an increased risk of postoperative instability are a sagittal facet joint angle of $> 50^\circ$ as well as facet joint effusion in T2-sequenced MRI as a sign of increased load bearing [5, 41]. A retrospective comparison of 124 patients treated with LDS without fusion at the level L3/4 showed significantly higher facet joint angles for those suffering from SLI (65.8° vs. 50.4°) [12]. The presence of segmental kyphosis at the index segment was associated with a significantly higher risk of a postoperative SLI deterioration (OR 0.87, CI 0.76–0.97, $p = 0.01$) [17, 23, 24]. Patients at younger age (< 70 years) and/or patients with active smoking history were at an increased risk for higher postoperative segmental kyphosis [69, 75]. A postoperatively well-preserved disc may become a risk factor for SLI, hence a retrospective analysis of predictors for SLI in 163 patients treated with LDS showed a significant impact of disc height > 6.5 mm on postoperative deterioration and revision surgery (OR 4.1, CI 0.75–22.31) [5]. This was also highlighted by another prospective study with a disc height cut-off set at 10 mm (OR 3.18, CI 1.03–9.82, $p = 0.04$) as well as several retrospective studies [12, 53, 59].

Surgical risk factors

Multiple decompressive surgeries at the same segment accounts as a significant risk factor for postoperative SLI (OR 2.64, CI 1.13–6.17) [61]. The decompression of two or three adjacent lumbar levels resulted in a fourfold increased risk of SLI (13% in monosegmental vs. 53% and 59% in two- and three-level LDS, respectively) [12]. A comparison of uni- versus bilateral LDS showed significantly increased postoperative sagittal translation in patients without spondylolisthesis treated with bilateral LDS compared to those treated with unilateral LDS (2.4% vs. 4.1%, $p = 0.047$) [8, 14, 19].

SLI-score

Based on the results of this review as well as the peer-review process of the authors' spine surgery research group, the 12 most important predictors for SLI after monosegmental unilateral "over-the-top" decompression were selected and

categorically divided into clinical ($n = 6$; mechanical LBP, age < 70 years, BMI > 30 kg/m², female gender, smoking history, previous lumbar surgery [at index segment]) and radiographic risk factors ($n = 6$; presence of olisthesis > 5 mm, dynamic olisthesis > 3 mm, disc height > 6.5 mm, segmental kyphosis $> 10^\circ$, facet joint angle $> 50^\circ$, bilateral facet joint effusion > 1 mm). Mechanical LBP as well as disc height were weighted with 2 points each, as these were found to be the most important factors in both the internal peer-reviewed process and the reviewed literature. The remaining risk factors were weighted with one point each. Therefore, the SLI-score reaches a maximum of 14 points (Table 2).

Discussion

The study aimed to identify risk factors for SLI from the published literature. Based on these results a predictive score of SLI, including the 12 most relevant risk factors reported, was created.

Patient-related risk factors

BMI and gender are commonly reported risk factors for perioperative complications and/or inferior outcome in spinal surgery. Previous studies report a significantly higher risk to develop degenerative spinal diseases in case of obesity [13, 43, 66]. Furthermore, high body weight shows a negative impact on postoperative regeneration and patient satisfaction. Reasons include increased biomechanical stress on the spine and reduced capacity for perioperative physical activity [62], as well as chronic inflammatory processes and reduced effectiveness of pain medication. Overall, these factors lead to a reduced overall outcome with an additional

Table 2 The SLI score

Clinical Factors	Score
Mechanical low back pain (VAS > 5 OR predominant LBP AND worsening upon axial loading)	2
Age < 70 years	1
BMI > 30 kg/m ²	1
Female gender	1
Smoking history	1
Previous lumbar surgery (at index segment)	1
Radiologic Factors	Score
Disc height (> 6.5 mm)	2
Dynamic olisthesis (> 2 mm)	1
Presence of olisthesis (> 5 mm)	1
Segmental kyphosis ($> 10^\circ$)	1
Facet joint angle ($> 50^\circ$)	1
Bilateral facet joint effusion (> 1 mm)	1

higher morbidity [7, 57]. The same may account for patients presenting with a smoking history [43].

Additionally, previous studies reported on a negative impact on the overall outcome measured by the Beaujon score in case of female gender as a risk factor for SLI. This includes pain values, pain medication usage and disability [46]. Explainable reasons may include a more advanced stage of the disease at the time of surgery most likely as a result of unspecific symptoms in female patients compared to their male counterparts. This can delay in diagnosis and treatment for female patients [33]. Furthermore, postoperative pain management is known to be more challenging in females [48, 55].

Also, various previous studies reported the patient's age may play a role in the risk for development of SLI [62]. Investigated age-cut offs may be variable and range from 65 to 75 years [1, 69]. Factors, which may be causative for the higher SLI rates in younger patients are the cascade of limited mobility, increased degeneration and vertebral auto-fusion, which tends to occur at higher age thereby decreasing the risk of a SLI [40]. The degeneration process of the lumbar spine has been categorized by Yong-Hing et al., in which the initial change of mostly discoligamentous structures (level 1) leads to an altered mobility of the spinal segment causing pain and impairment (level 2), which is then followed by a restabilization process as shown by formation of vertebral auto-fusion and osteophytic attachments (level 3) [77].

The presence of mechanical LBP was reported as a significant patient-related risk factor for SLI, yet other factors, such as concomitant osteochondrosis or ligamentous overload, should always be considered as causative factors for LBP. Spinal instability presents a fairly imprecise clinical definition, so careful clinical examination combined with adequate imaging should be used to define LBP as a potential risk factor for SLI [50].

In the complex area of secondary lumbar instability (SLI) following lumbar decompressive surgery, the significance of mechanical low back pain (LBP) as an indicator is undeniable. Despite its widespread acknowledgment in clinical practice, LBP has been challenging to define and assess precisely. This lack of a universally accepted definition has made it difficult to fully understand its influence on the development of SLI. Addressing this issue, the authors have formulated a clear and quantifiable method to evaluate LBP (VAS > 5/predominant low back pain AND exacerbation upon axial loading). Although a clear, universal definition of LBP has been elusive, it is consistently mentioned as a significant factor in the development of SLI [38, 53]. Hence, in the authors' new scoring system to assess the risk of SLI, LBP is assigned an impactful weight of 2 points out of a total of 14. Other factors in the system are also important but either do not have the same level of empirical support or are not as commonly linked to SLI as LBP. By allocating

more weight to LBP, the authors highlight its crucial role in the postoperative trajectory of patients with SLI.

The last patient-related factor added to the prediction score is represented by the presence of previous lumbar surgery. Many authors report a negative influence on outcome and reoperation rates after LDS, when patients were already treated by any lumbar procedure in the past. This might be explained by an ongoing spinal disease and biomechanical alterations [62]. Accordingly, analysis showed a significant correlation between asymmetric paraspinal muscles (e.g. postoperative scar tissue) and the development of SLI postoperatively has been shown, although further studies are needed for confirmation [75]. In general, fatty degeneration of the paraspinal musculature may lead to an increased risk of postoperative slippage after LDS as a result of diminished muscular support for segmental stability replaced by scar tissue [30].

In addition, a coronal asymmetrical alignment of the intervertebral disc frequently found in patients with moderate or severe lumbar scoliosis may also play a role in the development of postoperative SLI [17]. The coronal malalignment may also be associated with asymmetrical or unbalanced activity of the paraspinal musculature prior to any operative procedure leading to a negative effect on spinal stability, as proofed in the literature [64].

Nevertheless, these factors still lacking information on exact measurement, clinical applicability and relevance and were therefore not included in the score.

Radiographic risk factors

Whilst the clinical definition of spinal stability or instability is still based on rough estimations and scoring systems with no consensus within the scientific community, the radiographic definition is more advanced. In a landmark study conducted by White and Panjabi, spinal stability was defined as the ability of the spine to withstand displacement under physiological loading that would otherwise result in injury or irritation to the nerve roots or spinal cord. Spinal instability is thus defined as a displacement of the spine with neurological deficit, deformity, or pain [73]. Various studies aiming to show risk factors for SLI used > 3 mm in sagittal radiographic imaging as a cut-off. The most commonly reported radiological risk factors include the presence of spondylolisthesis and, in particular, dynamicolisthesis on standardized lateral x-rays. There are several proposed definitions usually based on changes in angulation or vertebral body translation. Nevertheless, there is no report of the degree of dynamic mobility constituting instability [37]. A cut-off for dynamic instability was reported at a translational movement of > 2 mm in dynamic radiographs [74].

A further factor included into our score is outlined by the presence of segmental kyphosis. This is assessed by

the presence of a change in disc angulation from neutral in extension radiographs to kyphotic in flexion radiographs, accounting for segmental instability [32].

Additionally, a disc height > 6.5 mm is reported to be a significant predictor for delayed instability in the lumbar spine [5]. Presumed reasons include an auto-stabilization of segments with collapsed discs, whereas high discs bear a risk of a progressive slip over time with degeneration [5]. As disc height represents a very individual parameter, an intrinsic modification was developed, measuring disc heights in correlation to the adjacent segment and comparing the relative degree of degeneration. A measured disc height > 50% of the adjacent level was assumed to carry the risk of progressive delayed instability [40]. This fact may also support the risk factor of age < 70 years, as disc height naturally decreases with age as part of the degeneration process [75].

In consideration of the lumbar facet joints and their influence on secondary instability, facet joint angle and effusion were considered relevant factors in the literature [41]. Although the role of facet joint inclination in the development of SLI remains controversial, several studies have indicated an increased sagittal orientation as a risk factor for SLI [44, 76].

Furthermore, fluid-filled distended facet joints (> 1 mm in axial T2 weighted MRI slides) seem to predict SLI. Reasons therefore are biomechanical, as loading of the spine leads to compressive forces on the disc, resisted by the facet joints. Fluid-filled facet joints form an indirect sign for SLI as the accumulation of synovial fluid mainly occurs in patients with spinal instability. Recent studies were even able to show a direct correlation of the amount of facet joint fluid accumulation and the severity of spondylolisthesis [10]. The same accounts for synovial cysts [40, 41].

Another discussed factor in the setting of SLI seems to be presented by increased pelvic incidence (PI). Although previous studies report a positive correlation of lumbar instability and increased PI, there is no data on thresholds predicting instability [22]. Additionally, PI seems to be a very individual component, highly correlating on sagittal imbalance and compensation of the same. Therefore, it was decided not to include PI into the scoring system.

The SLI-score

In a synopsis of all these reported risk factors, a score was assembled, aiming to predict the risk of SLI preoperatively. For the score, the 12 most commonly reported and transparent factors were merged and rated, resulting in a score of maximum 14 points. An additional requirement was constituted by the clinical usability of the score. As Kulkarni et al. [40] and Blumenthal et al. [5] have already characterized, disc height and mechanical LBP showed the most significant impact on SLI and were therefore rated with 2 points each.

Limitations

There are several factors limiting this review. First of all, the definition of lumbar decompressive surgery is based on the authors' standard of procedure, respectively, thereby forming a potential bias in the sense of a retrospective comparison of slightly inconsistent operative techniques with more or less impact on spinal stability. The absence of a professional librarian in the search process and the lack of a systematic review protocol (e.g., PRISMA compliance or PROSPERO registration) may limit reproducibility and comprehensiveness of our literature search. Another major factor is the inconclusive definition of spinal instability itself, which limits the assessment of the severity of each risk factor for the development of SLI. In particular, the clinical factors potentially favoring SLI are largely based on subjective data, which can be easily biased by confounders and thus also affect the validity in this review. The hereby presented score solely constitutes an overview of already described risk factors in the literature and therefore remains a theoretical basis for the concept of SLI. Furthermore, to date there is no existing data depicting the relevance of these factors, and especially on their combination. Moreover, the inclusion of clinical factors to the score may lead to less objective results due to subjective bias of clinical factors. Thus, we are not able to define clearly whether the presence of different parameters would lead to an addition or multiplication of different factors (e.g., obesity ± smoking). Besides, there are no reports on cut-off values for similar scores or expedient treatment recommendations according to when to fuse or when not to fuse, in particular depending on different surgical techniques to achieve decompression.

Conclusion

The findings of this comprehensive review elucidate the prevailing clinical, radiographic, and patient-related risk factors, shedding light on their potential influence on postoperative outcomes in patients undergoing LDS. The introduced scoring system provides a structured framework delineating prominent risk factors for SLI, stratified based on their presumed significance in guiding clinical decision-making. While this conceptual foundation establishes a theoretical framework for understanding SLI, its practical applicability necessitates validation through rigorous clinical investigation. Nevertheless, this preliminary overview of clinically significant factors serves as a valuable resource, offering insight into characterized risk elements that can inform and potentially enhance the decision-making process in the context of LDS.

Author contributions AA: Literature search, scoring, data extraction, manuscript drafting, writing—original draft preparation. SL: Literature search, scoring, data interpretation, manuscript drafting, critical revision. SH: Study conception, methodology, supervision, critical review, writing—review and editing. CT: Study conception, project administration, supervision, critical review, writing—review and editing. All authors have reviewed and approved the final manuscript.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Human ethics and consent to participate Not applicable.

Competing interests The authors declare no competing interests.

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