Neurochirurgie 65 (2019) 75–82

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Original article

# History of degenerative spondylolisthesis: From anatomical description to surgical management

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ARTICLE INFO

*Article history:*
Received 26 December 2018
Received in revised form 26 January 2019
Accepted 20 March 2019
Available online 2 April 2019

*Keywords:*
History
Degenerative Spondylolisthesis
Spine
Surgery
Anatomy
Review

ABSTRACT

This review of the historical medical literature aimed at understanding the evolution of surgical management of degenerative spondylolisthesis over time. The Medic@, IndexCat and Gallica historical databases and PubMed and Embase medical databases were used, with several search-terms, exploring the years 1700–2018. Data from anatomical, biomechanical, pathophysiological and surgical studies were compiled. In total, 150 documents were obtained, dating from 1782 to 2018: 139 from PubMed, 1 from Medic@, 7 from IndexCat, and 3 from Gallica. The review thus ranges in time from (1) description of the first clinical cases by several authors in Europe (1782), (2) the identification of a distinct entity by MacNab (1963), and (3) surgical management by the emerging discipline of minimally invasive spine surgery, to its subsequent evolution up to the present day. Spondylolisthesis is a frequent condition potentially responsible for a variety of functional impairments. Understanding and surgical management have progressed since the 20th century. Historically, the first descriptions of treatments concerned only spondylolisthesis associated with spondylolysis, especially in young adults. More recently, there has been progress in the understanding of the disease in elderly people, with the recognition of degenerative spondylolisthesis. New technologies and surgical techniques, aided by advances in supportive care, now provide spine surgeons with powerful treatment tools. Better knowledge of the evolution of surgery throughout history should enable better understanding of current approaches and concepts for treating degenerative spondylolisthesis.



## 1. Abbreviations

| | |
|---|---|
| ALIF | anterior lumbar interbody fusion |
| CT | computed tomography |
| DS | degenerative spondylolisthesis |
| MIS | minimally invasive surgery |
| PLIF | posterior lumbar interbody fusion |
| PRISMA | preferred reporting items for systematic reviews and meta-analyses |
| TLIF | transforaminal lumbar interbody fusion |

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https://doi.org/10.1016/j.neuchi.2019.03.006


## 2. Introduction

Degenerative spondylolisthesis (DS) is one of the most commonly encountered spine conditions. It was the object of increased research interest during the 20th century (Fig. 1). DS appeared in the literature decades earlier under a different name, but the term was first used in the 1960s by Newman and Stone [1]. Spondylolisthesis is derived from the Greek terms "spondylos" meaning vertebra and "olisthesis" meaning to slip forward.

This condition probably includes different pathophysiological entities [2–6]. DS, also known as arthritis spondylolisthesis, is differentiated from isthmic spondylolisthesis by pars interarticularis disruption [7]. Despite its frequent occurrence, the pathophysiology of the vertebral slippage remains controversial, and numerous treatment options are available. Symptomatic DS can be due to either spinal stenosis, typically causing lower-limb symptoms, or mechanical low-back pain, impairing quality of life [7]. This pattern typically associates lower limb pain, paresthesia, and a sensation of

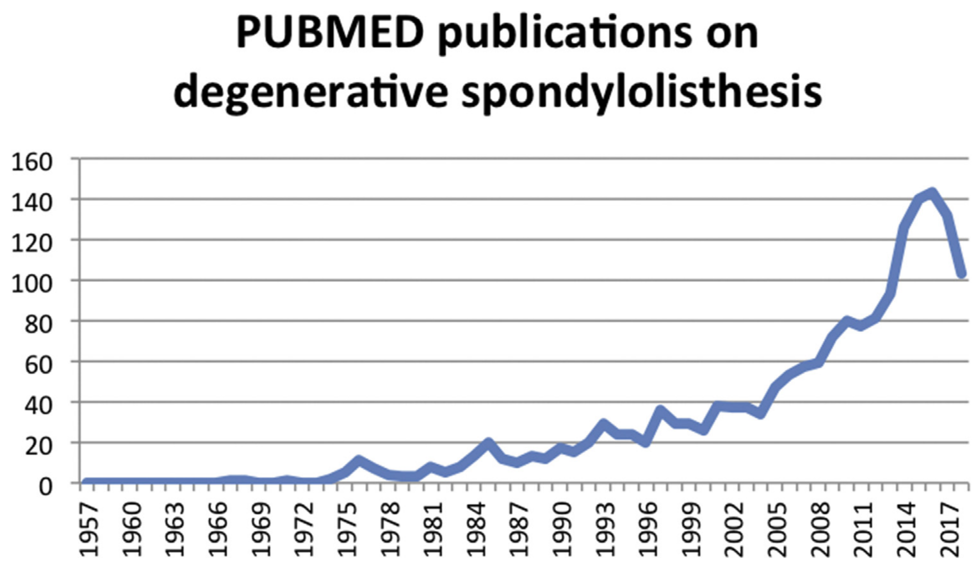


**Fig. 1.** Chart of PubMed publications on "degenerative spondylolisthesis" over time from 1957 to 2018.

heaviness or weakness walking or standing. These aspects are well documented and have previously been reviewed (see, for example [8–10]).

However, historical references are scarce in the literature and generally limited to a few lines in review articles, usually recent and including only English-language sources. Thanks to the new online availability of previously unpublished source articles, we know that this condition was previously described in the French and German literature. These historical data can improve understanding of the historical construction of the concept of DS and provide insight into clinical and therapeutic practices currently proposed in different medical specialties and countries.

The aim of this paper was to carry out a systematic review of the medical literature. We focused on the presence of the condition in the literature and on means of surgical management, seeking to understand the mechanisms that governed their evolution.

## 3. Methods

PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) consists in a minimum set of items for reporting in systematic reviews and meta-analyses. It focuses on the reporting of reviews evaluating randomized trials, but can also be used as a basis for reporting systematic reviews of other types of research [11].

### 3.1. Bibliographic databases

The following databases were examined:

- literature before 1946: Medic@ Library (BIU Santé Paris, 2017); IndexCat (Index-Catalog of the Library of the Surgeon-General's Office, US National Library of Medicine, 2017); and Gallica (Bibliothèque Nationale Française, 2017);
- literature published since 1946 was accessed via Internet and database searches of both public and academic literature (PubMed, PubMed Central, and MEDLINE).

### 3.2. Keywords

The search-term used for all databases was "degenerative spondylolisthesis". As this term was introduced by Newman only in 1963; other search-terms were also used: "pseudospondylolisthesis" and "listhesis".

### 3.3. Exclusion criteria

The search tools provided a first set of sources that were more or less relevant and therefore required additional sorting. Exclusion criteria were as follows:

- study not focusing on degenerative spondylolisthesis (spondylolisthesis with spondylolysis, lumbar spinal stenosis, infectious spinal disease, etc.;
- off topic: indexing error or aberrant result (non-spinal cases, such as obstetric);
- duplicate;
- review article.

### 3.4. Final sample

After examination of Abstracts based on the inclusion and exclusion criteria, 150 articles were chosen for full-text examination, 49 of which finally fulfilled the inclusion criteria. Fig. 2 is a PRISMA flow diagram, which illustrates the number of articles at each data acquisition level, the number of excluded articles, and the reasons for exclusion.

## 4. Anatomy of degenerative spondylolisthesis

### 4.1. First anatomical descriptions

Spondylolisthesis was first described in 1782 by Herbiniaux, a Belgian obstetrician. In his *Traité pour divers accouchements laborieux* [12], he describes a case of "spondyloptosis" (corresponding to Meyerding grade IV spondylolisthesis [13]) as a factor of mechanical obstruction to delivery. In Herbiniaux's case report, the affected vertebral body decreased the diameter of the pelvic inlet (Fig. 3). Secondly, in an anatomical work, Robert de Koblenz, professor of medicine at the University of Marburg, described the notion of posterior vertebral instability and underlined the involvement of posterior arch instability in the genesis of L5-S1 spondylolisthesis [14]. After successively sectioning posterior arches, discs and intervertebral ligaments, he emphasized the importance of posterior arch integrity in the

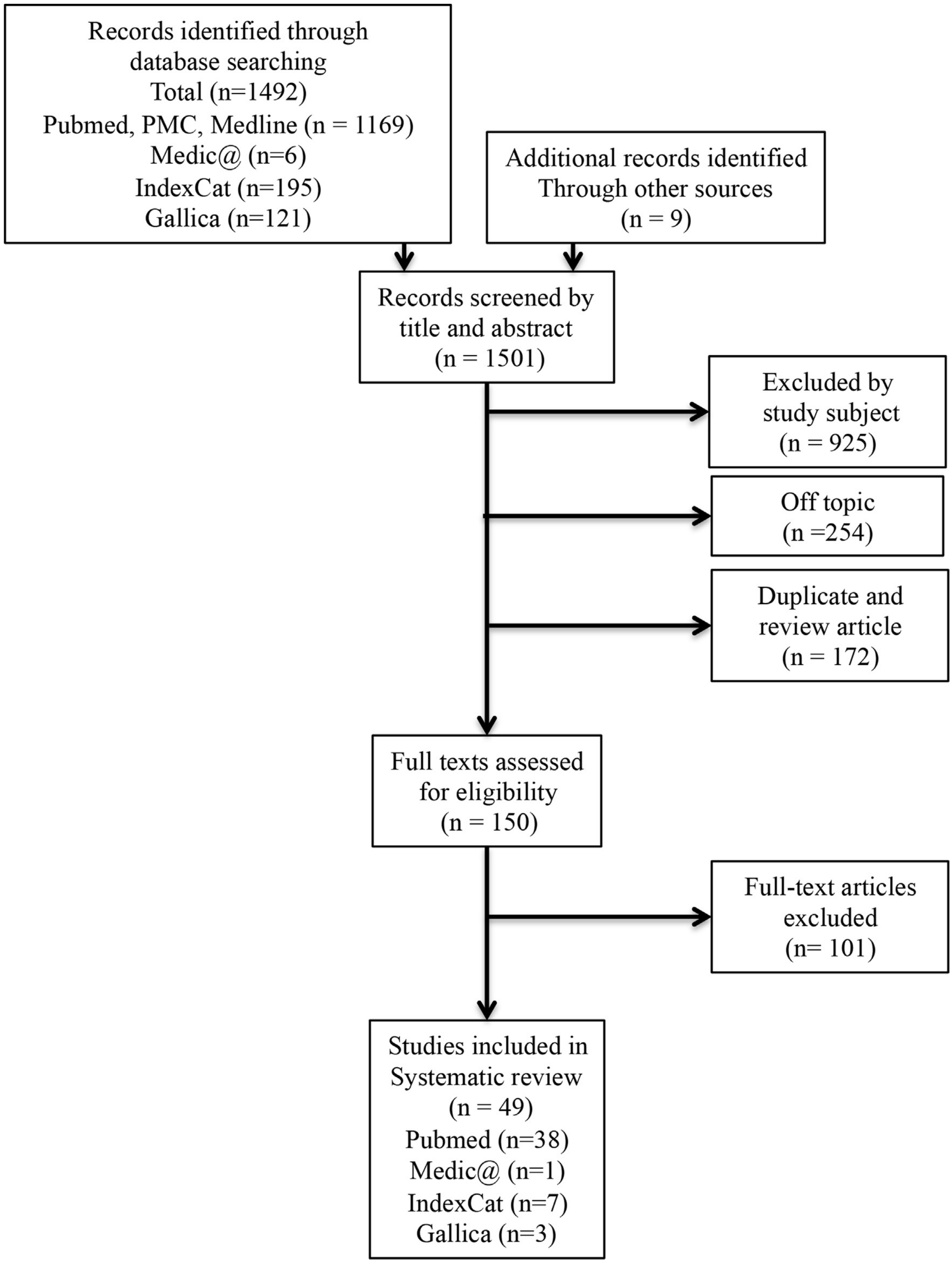


**Fig. 2.** PRISMA flowchart showing the flow of information through the different phases of the systematic review.

prevention of spondylolisthesis. In 1865, he performed osteoligamentous resections of the lumbar spine, and for the first time described acquired iatrogenic instability by posterior destabilization [15].

### 4.2. *Toward a new entity*

The terms spondylolisthesis and spondylolysis were confused until 1930 [15]. Spondylolisthesis was first understood as an acquired pathology resulting from spondylolysis, concerning mostly the pediatric population or young adults. In 1930, Junghanns and Schmorl introduced the term "pseudospondylolisthesis", corresponding to spondylolisthesis without isthmic lysis [8,16,17]. In 1950, MacNab (Fig. 4F) referred to this as intact neural arc spondylolisthesis [18]. Finally, in 1963, Newmann first used the term "degenerative spondylolisthesis", concerning an elderly female population [1]. Thus, the understanding of DS as a separate pathophysiological entity has evolved.

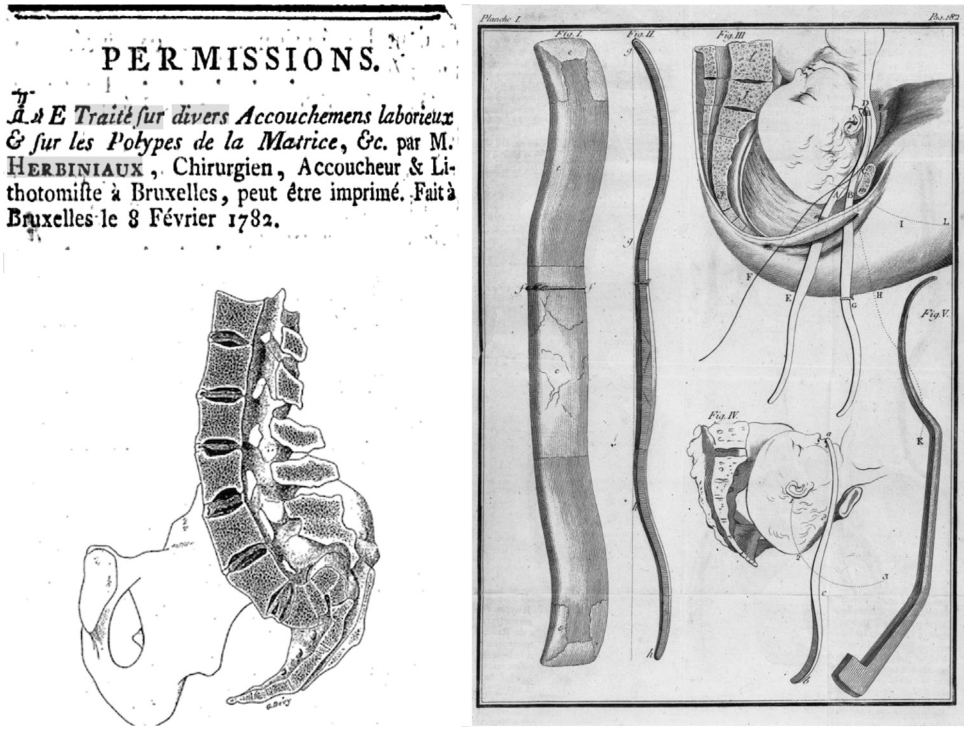


**Fig. 3.** Drawings of first description of spondylolisthesis by Herbiniaux in *Traité pour divers accouchements laborieux, 1782. Source gallica.bnf.fr/Bibliothèque Nationale de France.*

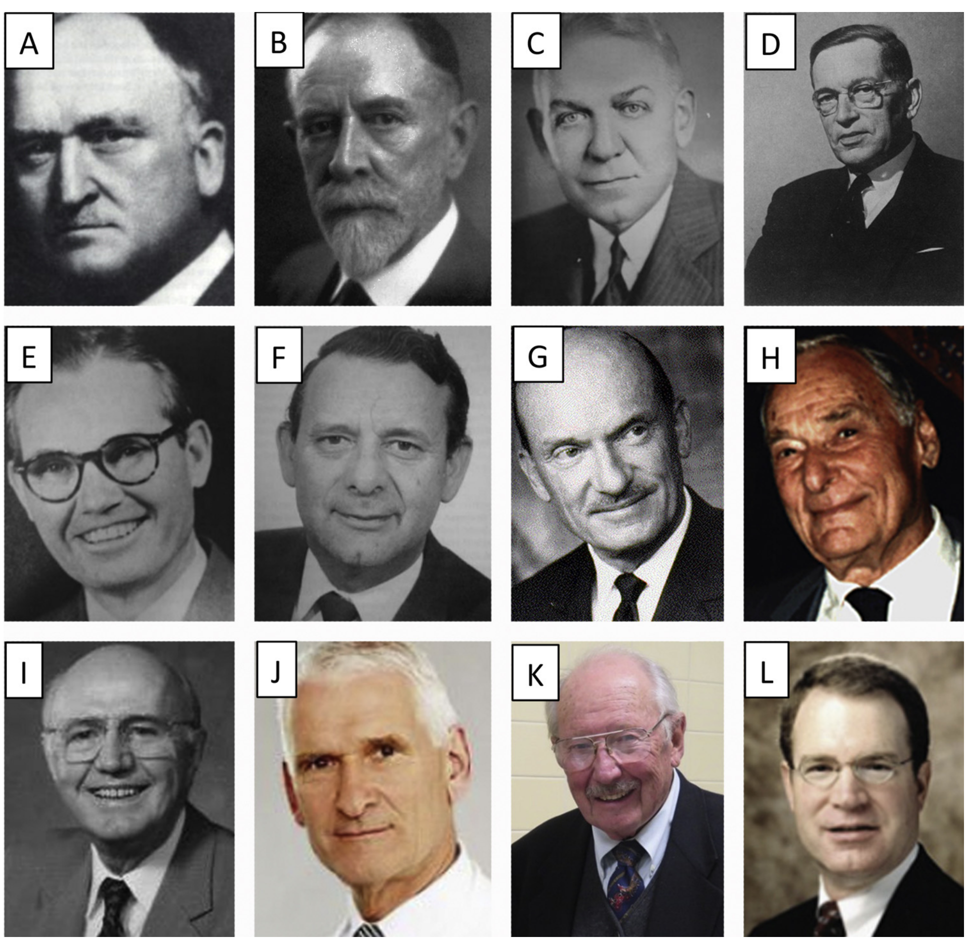


**Fig. 4.** Emblematic figures the degenerative spondylolisthesis in chronological order. A. Fred H. Albee (1876–1945). B. Russell A. Hibbs (1869–1932). C. Willis C. Campbell (1880–1941). D. Norman Leslie Capener (1898–1975). E. Donald E. King (1903–1987). F. Ian MacNab (1921–1992). G. Ralph B. Cloward (1908–2000). H. William H. Kirkaldy-Willis (1914–2006). I. Leon Wiltse (1913–2005). J. Jürgen Harms (1944–). K. Arthur S. Stefee. L. Kevin Foley.

### 4.3. Sagittal balance

Several studies reported the close relationship between DS and overall sagittal balance and spinopelvic parameters. Recent studies investigated the relationship between pelvic parameters and the development of DS [19,20]. In 2017, Radovanovic et al. demonstrated an association between sagittal balance and postoperative outcome specific to a DS cohort [21]. This sagittal balance factor should be considered during operative planning and counseling of patient expectations [6,21,22]. For this, preoperative full spine imaging seems crucial.

Since the 1932 Meyerding grading system [23], various classifications attempted to provide further biomechanical understanding of this disease. However, they were based on etiology, topography or slippage grading (percentage), and were restricted to segmental analysis [18,23,24]. The role of regional or global misalignment was not considered. None of these systems provide surgeons with a comprehensive analysis of DS or guidance for optimal care. A new 3-type DS classification based on sagittal alignment was proposed by Gille et al. [6] in 2017, based on rating sagittal full-body standing radiographs (EOS system, EOS Imaging, Paris, France) as used in routine. Type 1 is a harmonious and aligned spine, type 2 is compensated spinal misalignment, and type 3 is impaired global sagittal alignment; severity increases from type 1 to type 3 [6]. As shown by Kumar et al., neglecting the role of sagittal alignment in DS may lead to poor clinical outcome and poor patient satisfaction [25]. This recent classification fully combines segmental, regional and global analysis of sagittal balance in DS, and may prove a useful tool for comprehensive analysis before surgical treatment, taking sagittal balance into account.

## 5. Pathophysiology of degenerative spondylolisthesis

### 5.1. The “three joint complex”

Historically, DS progressively came to be understood biomechanically. In 1978, Kirkaldy-Willis (Fig. 4H) considered DS as a degenerative pathology involving a “three joint complex” comprising the intervertebral disc and two posterior zygapophyseal (facet) joints [26]. Thus, spondylolisthesis gradually came to be understood as a progressive degenerative pathology with gradual destabilization of the spine. DS was increasingly described as a multifactorial process, involving the above causes plus degenerative aging processes, affecting both the intervertebral disc and facet joints.

### 5.2. Age-acquired spinal instability

Although more commonly found in women (female:male sex ratio, 2–3:1), incidence of DS increases with age in both sexes [27]. The fact that women seem to be more affected by the pathology is thought by Bell et al. to be due to greater ligament laxity and to hormonal effects [28]. There increasing evidence that baseline lumbar and pelvic parameters may influence the development of DS. Aono and colleagues recently followed up 142 women without baseline deformity over a mean of 14 years and found an incidence of newly developed DS of 12.7% [29]. The authors reported that high pelvic incidence, L4 vertebral inclination, adjusted vertebral size and facet orientation in the sagittal plane were all independent predictors of the development of DS [29].

The natural history of degenerative spondylolisthesis was described by Matsunaga in 1990 [5], in 145 non-surgically managed patients with a minimum 10 years' follow-up. The authors reported slip progression in 49 patients (34%). Intervertebral disc height in the diseased segment decreased significantly throughout follow-up, with a concomitant decrease in low-back pain. They also concluded that this narrowing of the intervertebral disc, along with spur formation, subcartilaginous sclerosis and/or ligament ossification can prevent disease progression, in a process they called spinal restabilization.

### 5.3. Current theories

In the pathophysiology of DS there are 3 components leading to canal narrowing and foraminal root compression:

- non-specific degenerative lesions (joint hypertrophy, thickening of the ligamentum flavum, disc depression);
- specific degenerative lesions (orientation and morphology of facet joints);
- disc slippage [30].

The major element is facet joint sagittalization, which can be quantified in terms of the transverse/facet angle (normal values, $>40^\circ$) [31,32]. In 1989, Sato described different morphologies of the facet joints [33]. It is not known whether this involvement of posterior masses is due to primary lesions or to disc hypermobility. As well as these biomechanical concepts specific to DS, greater understanding of biomechanics and sagittal balance in general has improved the understanding of this entity.

### 5.4. Other theories

There are many other theories. (1) Muscular theory: in 2001, Ramsbacher et al. performed systematic muscle biopsies in patients after depicting fatty muscle involution, and found alteration of the mitochondrial respiratory chain [2]. This theory has not been further studied by other authors. (2) Disc theory: some authors hypothesized that disc hypermobility causes secondary changes in the entire spine [3]. (3) Hormonal theory: in 1996, Sanderson et al. [4] attempted to explain the female predominance of this disease.

Further studies are needed to know whether these theories contribute to the pathophysiology of DS.

## 6. Surgical treatment of degenerative spondylolisthesis

Early treatment of DS echoed that of dysplastic spondylolisthesis, by decompression, reduction, fixation and fusion. Surgical treatment developed mainly in the second half of the 20th century, with the development of spinal instrumentation and the recognition of DS as an entity. The two aspects of this pathology were treated progressively: direct/indirect root decompression, and spinal stabilization.

### 6.1. Isolated neurologic decompression without fusion

This technique acquired a poor reputation due to reports of increased slippage after decompression laminectomy without fusion used to treat DS. In 1991, Herkowitz and Kurz reported that fusion provided better outcome than isolated decompression [34]. However, the introduction of microsurgical techniques challenged this paradigm. Isolated microsurgical unilateral decompression produced good clinical and radiographic outcomes with no significant increase in slippage [35]. In other studies, however, microsurgical unilateral decompression was associated with a subsequent increase in slippage [36,37]. Jang et al. reported that the risk of increased slippage was greatest in patients whose preoperative dynamic radiographs showed sagittal motion at the spondylolisthesis level [36].

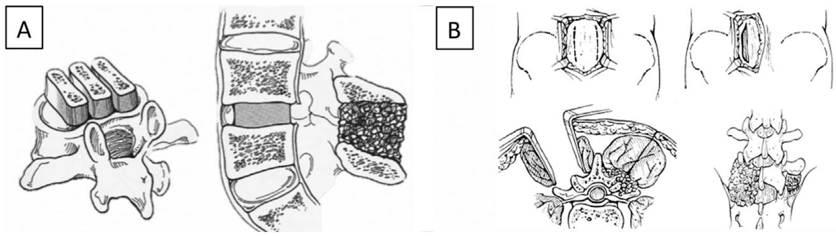


**Fig. 5.** Historical posterior approaches for degenerative spondylolisthesis. A. Posterior lumbar interbody (PLIF) and interspinous fusion without internal fixation. B. Wiltse approach for posterolateral fusion without internal fixation. Source:gallica.bnf.fr/Bibliothèque Nationale de France.

### 6.2. *The beginnings of posterior fusion*

Outside DS, the first posterior arthrodeses were described by Albee (Fig. 4A) (interspinous arthrodesis) and Hibbs (Fig. 4B) (posterolateral arthrodesis with decortication) in 1911 [38,39]. In 1962, Wiltse (Figs. 4I and 5B) described a technique of posterolateral arthrodesis by two paravertebral approaches and iliac bone grafts [40]. The posterior surfaces of the transverse and articular processes were decorticated. Bone grafts produced by laminectomy or taken on the iliac crest were then placed in contact with the sharpened bone. The priority was not to reduce but to secure the vertebrae in position [40]. All these techniques of posterior arthrodesis are associated to direct radicular decompression. The main limitation of the technique is non-union in mobile spinal segments, in an often osteoporotic, female, menopausal population. Posterior lumbar interbody fusion (PLIF) was described by Campbell (Figs. 4C and 5A) in 1925, and implemented in DS by Cloward (Fig. 4G) in 1953[41]. This technique combines direct and indirect radicular decompression with interbody fusion by autologous bone graft. Cloward initially developed the technique using iliac bone grafts after discectomy. He then continued his work by studying the impact of bone graft cuttings on postoperative sagittal balance. He considered his results in 321 patients to be rather favorable with a limited rate of complications and satisfactory results [42]. However this technique was reported by his peers as difficult, due to the risk of nonunion and frequent complications [10].

Internal fixation was therefore associated to arthrodesis to avoid non-union. Advances in spinal instrumentation made it possible to combine fixation and fusion. Transpedicular screwing, described by King (Fig. 4E) in 1944, greatly contributed to the development of this technique, as did the development of spinal instrumentation by Roy Camille (cage, titanium) [43,44]. Harms (Fig. 4J) and Rolinger developed transforaminal lumbar interbody fusion (TLIF) techniques [45]. Steffee (Fig. 4K) and Sitowski in 1988 associated PLIF to posterior fixation [46]. The goal was to achieve direct and indirect radicular decompression and avoid non-union of the bone graft.

### 6.3. *The beginnings of anterior fusion*

Capener (Fig. 4D) in 1932, and Jenkins in 1936 developed anterior lumbar interbody fusion (ALIF) for dysplastic spondyloptosis [47,48]. The patient underwent attempted preoperative reduction using leg skin traction, immediate postoperative immobilization, and then brace [47]. Surgery consisted in corpectomy with tibial bone graft. These deformity surgeries appear to be less applicable to elderly patients, whose tolerance of immobilization does not have the same functional limitations. Anterior fusion in DS is therefore mainly linked to the growth of minimally invasive spine surgery.

### 6.4. *The new era of minimally invasive surgery (MIS)*

Spinal MIS is increasingly used, to minimize skin incision, muscular injury and perioperative pain, achieving early recovery and improved quality of life [49]. The history of MIS on an anterior approach began in 1991 when Obenchain [50] reported the first use of a laparoscopic transperitoneal approach to the lumbar spine for discectomy. Several studies described the technique and reported preliminary results for laparoscopic transperitoneal ALIF [51–53]. The retroperitoneal approach to the lumbar spine was first described by Iwahara [54] in 1963, and was increasingly used for treatment of DS [55–57]. Gaur [58] and McDougall et al. [59] were the first to describe an endoscopic retroperitoneal approach for urological procedures, later applied to treatment of the lumbar spine. Retroperitoneal endoscopic spine surgery has the advantages of not requiring carbon dioxide insufflation or penetration of the peritoneal cavity. It also avoids dissection near the large vessels and hypogastric plexus.

Most clinical DS studies of MIS evaluated posterior approaches. For example, in 2001 Foley et al. [60] introduced a percutaneous pedicle screw insertion and rod assembly system (CD Horizon Sextant, Medtronic, Memphis, TN, USA) for MIS-TLIF (Fig. 4L). After the Sextant system came onto the market, several authors reported their experience of using it for MIS-TLIF [36,61–66] or MIS-PLIF [60,67].

### 6.5. *The new era of stereotactic spinal guidance*

MIS techniques are associated with greater radiation exposure than open techniques [68]. Methods of reducing both radiation dose and duration for both surgeon and patient are critical to minimizing the dangers of overexposure [68]. Intraoperative CT for navigation is a potential solution. Villard et al. demonstrated that radiation exposure using freehand techniques was almost 10 times higher than with navigation-guided techniques in a cohort of patients who underwent posterior lumbar instrumentation [69]. In a cadaver study, Tabaree et al. contrastingly demonstrated that, while use of the O-arm resulted in breach rates similar to the C-arm, radiation exposure, while lower for the surgeon, was higher for the patient [70,71].

Moreover, in both MIS and open surgery, serious complications resulting from screw misplacement or pedicle cortex perforation can lead to devastating neurological or vascular damage. To increase the safety of the procedure, various methods have been progressively developed to better target the pedicle in terms of screw trajectory and depth. Most surgeons use assessments of anatomic landmarks, supplemented by fluoroscopy, to identify the anatomic features of the pedicles before placement of the pedicle screws. Image-guided systems are widely used in intracranial surgery and have been adapted to assist with screw placement since the mid-1990s [49,60,72,73], improving accuracy. The systems rely on precise CT location of the pedicles. CT-guided spinal imaging systems are constantly improving. Better accuracy and ease of use should facilitate the location of pedicles and facets and expedite fixation for cervical, thoracic and lumbar stabilization. With improvements in MIS and image-based guidance, the use of a combination of MIS and image-guided systems for stabilization procedures has been progressively developed.

## 7. Conclusion and future directions

Surgical treatment of DS progressed during the 20th century, in parallel to society. The inversion of the age pyramid has forced us to adapt concepts. Anatomical and biomechanical understanding and progress in spinal instrumentation shed light of the evolution of DS management. DS has come to be considered as a failure of the spinal mobile segment, requiring specific surgical treatment, taking account of age, comorbidities, and the patient's way of life. Surgical techniques applied to the treatment of DS are thus now integrated in an effective therapeutic strategy.

## Disclosure of interest

The authors declare that they have no competing interest.

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