Optimizing care in lumbar radiculopathy and neurogenic claudication: from injection to inference, and from clinician to algorithm

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Part II

Improving diagnosis and prognosis in lumbar spinal stenosis

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General introduction and outline

Lumbar spinal stenosis (LSS) is a degenerative condition characterized by the narrowing of the spinal or nerve root canal, resulting in compression of neural structures. Stenosis is generally classified into three subtypes based on its anatomical location: (1) central canal stenosis (CCS), caused by disc bulging and ligamentum flavum hypertrophy; (2) lateral recess stenosis (LRS), resulting from disc bulging and facet joint arthropathy (FA); and (3) foraminal stenosis (FS), attributed to degenerative changes within the neuroforamen. CCS typically results in neurogenic claudication, characterized by bilateral radiating leg pain that worsens with walking or lumbar extension and improves with sitting or lumbar flexion. In contrast, LRS and FS more frequently present with neurogenic claudication symptoms with a radicular pattern. Often accompanied by back pain, LSS can significantly impair mobility and quality of life [1, 2]. Given its degenerative nature, LSS is most common in the elderly. As such, its prevalence is increasing due to our aging population, and, hence, it is one of the most frequent indications for spinal surgery in older adults [3, 4]. However, despite advances in imaging and surgical techniques, clinical decision-making regarding LSS remains challenging, and postoperative patient satisfaction varies widely, ranging from 27% to 80% [5-7].

One of the significant barriers to clinical decision-making for LSS is the ambiguity in radiological assessment. Magnetic resonance imaging (MRI) is the gold standard for diagnosing LSS, offering high-resolution visualization of soft tissues and neural compression [8]. In addition to MRI, computed tomography (CT) and plain radiography are utilized to evaluate bony structures. Standardized assessment of the severity of LSS on diagnostic imaging is essential for unequivocal communication between radiologists, neurologists and neurosurgeons, and for guiding appropriate treatment strategies. To achieve this, grading systems must be capable of producing high inter-reader agreement, clinically applicable—avoiding excessive complexity while maintaining sufficient detail for meaningful differentiation—and correlate with clinical symptoms [9].

The first widely adopted classification system for LSS, introduced by Lurie et al., categorized CCS as mild, moderate, or severe [10]. Subsequently, more detailed grading systems were developed by Guen et al. and Schizas et al., but these also focused exclusively on the central canal [11, 12]. Although moderate to almost perfect inter-reader agreement has been reported, external validation studies have demonstrated substantial variability in interobserver reliability. Moreover, these grading systems have shown inconsistent correlations with clinical symptoms and do not account for stenosis of the lateral recess (LRS) or neuroforamen (FS). Conversely, grading systems developed specifically for LRS and FS share similar limitations and do not incorporate assessment of CCS. To address these limitations, Miskin et al. introduced a novel, more comprehensive grading system in 2021 [13]. This classification extends assessment beyond CCS to include LRS, FS, and FA for a more complete evaluation of LSS. While this system demonstrated fair to substantial inter-reader agreement, it has yet to undergo external validation or be correlated with baseline clinical symptoms and postoperative outcomes.

Although some grading scales have demonstrated adequate inter-reader agreement, human variability in interpretation can never be completely eliminated. Additionally, certain grading systems are laborious, limiting their utility in the fast-paced clinical environment. Automating the grading process could address both challenges. Artificial intelligence (AI), particularly machine learning (ML) and its subtype deep learning (DL), has shown significant promise in medical imaging applications, including automated image segmentation and classification [14, 15]. In segmentation, each pixel is assigned to a class based on extracted attributes, which are then used as inputs for classification models that predict LSS severity. AI-driven models can rapidly analyze MRI scans with high accuracy and consistency, reducing observer variability and potentially enhancing diagnostic precision. While conventional ML approaches require manual selection of relevant input features for segmentation and classification, DL models can autonomously learn relevant imaging features, obviating the need for a separate segmentation step and making them particularly well-suited for complex image analysis tasks.

Beyond diagnosis, radiological imaging may also aid in predicting patient outcomes following surgical treatment for LSS. Previous research has shown that the grading system by Schizas et al. lacks a strong correlation with postoperative outcomes [11, 16, 17]. While some radiological, demographic, and clinical parameters have been associated with surgical outcomes, they are not considered established outcome predictors [16, 18, 19]. Hence, a reliable grading system that is also clinically relevant is still lacking.

AIMS AND OUTLINE OF THIS THESIS:

1. A comprehensive MRI-based classification of LSS severity requires assessment of stenosis not only in the central canal but also in the lateral recess and neuroforamen. The grading system introduced by Miskin et al. incorporates all these anatomical regions and has demonstrated fair to substantial inter-reader agreement. However, further validation is warranted for broader acceptance. Therefore, the first aim of this study is to evaluate inter-reader agreement of this grading system using an independent dataset, providing insights into its validity, and to determine its correlations with baseline symptoms and postoperative outcomes, thereby assessing its clinical relevance and applicability (Chapter 9).
2. Recent advancements in artificial intelligence (AI) have led to the development of sophisticated machine learning algorithms with potential applications in medical imaging. AI-based approaches could improve LSS diagnostics by improving efficiency, reducing observer variability, and lowering healthcare costs. To explore this potential, the second aim of this study is to conduct a systematic review of studies utilizing conventional machine learning (ML) and deep learning (DL) models for the segmentation and classification of LSS, with a focus on evaluating their diagnostic accuracy and performance (Chapter 10).

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