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

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SUMMARY

Lumbar radiculopathy and neurogenic claudication are among the most common clinical syndromes encountered in spine care. Patients with these clinical syndromes typically present with severe leg pain, back pain, and impaired physical functioning, resulting in reduced quality of life. Despite advances in imaging, interventional pain management, and spine surgery, clinical decision-making remains challenging. Radiological findings do not always correlate with symptoms, treatment effects vary widely between patients, and clinicians lack reliable tools to predict outcomes of conservative or surgical interventions. This thesis aims to optimize care for patients with lumbar radiculopathy and neurogenic claudication by addressing two key domains: (1) the effectiveness and prognostic factors of transforaminal epidural steroid injections (TEI) in lumbar radiculopathy due to disc herniation or degenerative stenosis, and (2) the diagnostic and prognostic evaluation of lumbar spinal stenosis (LSS), with a focus on standardized grading systems and the potential role of artificial intelligence (AI).

Part I: optimizing care for lumbar radiculopathy

Lumbar radiculopathy, often referred to as sciatica, is characterized by unilateral radiating leg pain resulting from dysfunction of a lumbosacral nerve root. Although lumbar disc herniation (LDH) or degenerative stenosis are frequently identified on magnetic resonance imaging (MRI) as underlying causes, symptoms may also arise in the absence of clear compressive pathology, reflecting the complex interplay between mechanical compression, inflammation, and immunological processes. The natural course of lumbar radiculopathy is often favourable, particularly when caused by LDH, but spontaneous symptom resolution may also occur in cases related to degenerative stenosis. Consequently, current Dutch guidelines recommend an initial period of conservative management. However, this “wait-and-see” approach may expose patients to prolonged pain, functional limitations, and reduced quality of life.

Epidural steroid injections (ESI) are a minimally invasive treatment aimed at reducing nerve root inflammation and alleviating pain in lumbar radiculopathy, thereby providing symptomatic relief that makes the waiting period until spontaneous recovery or surgery more tolerable. Transforaminal epidural injections (TEI) are the most common approach, although caudal and interlaminar techniques are also used. Nevertheless, uncertainty persists in the literature regarding their effectiveness, optimal timing, and the patient characteristics that predict benefit. Our systematic review and meta-analysis of randomized controlled trials compared ESI, including all three approaches, with placebo injections in

patients with lumbar radiculopathy and demonstrated superior pain relief and functional improvement at 6 weeks and 3 months, although the magnitude of the difference in clinical effect was modest. The treatment effect was larger for TEI and caudal injections than for the interlaminar approach for short-term pain relief. Reported complication rates were low.

The effectiveness of TEI was evaluated in a retrospective cohort of patients who were referred to the outpatient pain clinic due to complaints of lumbar radiculopathy. This study focused on the effectiveness of TEI on pain reduction and whether outcomes depended on the presence of LDH on MRI. Approximately 70% of the 486 patients who underwent TEI experienced at least some short-term pain reduction, and, contrary to the common assumption that imaging-confirmed disc herniation is a prerequisite for benefit, clinical outcomes were comparable in patients with LDH and those with alternative or no clear compressive pathology. This finding challenges the routine reliance on MRI as a decisive factor for TEI eligibility and suggests that clinical assessment may be sufficient to guide initial treatment decisions.

Although the majority of patients benefit from TEI in the short term, the patient characteristics associated with a favourable response remain unclear. Identifying prognostic factors is essential to enable more tailored use of TEI. In our systematic review of prognostic factors associated with TEI outcomes, numerous demographic, clinical, and radiological variables were studied. Shorter duration of symptoms and, interestingly, lumbar radiculopathy secondary to stenosis rather than LDH emerged as potential predictors of a favourable treatment response, although they were not identified as such consistently across studies. In contrast, many commonly cited imaging features showed inconsistent or weak associations with treatment response. Overall, the review highlights the absence of robust, validated predictors and underscores the need for large, well-designed prospective studies to identify patient subgroups that are most likely to benefit from TEI.

One understudied imaging biomarker is the presence of Modic changes (MC). These vertebral endplate alterations are thought to reflect an inflammatory environment: MC type I represents a more acute process, whereas MC type II is associated with a more chronic inflammatory state and is the most prevalent type. In a prospective cohort study, the relationship between MC type II and the effect of TEI in 88 patients with lumbar radiculopathy secondary to LDH was examined, but no correlation was demonstrated. This suggests that this type of endplate change should not affect expectations regarding clinical outcomes

after TEI, further emphasizing the limited predictive value of isolated MRI features.

Considering the potentially limited value of MRI in relation to TEI effectiveness, the TEIAS trial has been initiated to evaluate whether early TEI in patients with acute lumbar radiculopathy provides more rapid and effective symptom relief than usual conservative care. In a subset of patients, symptom burden remains inadequately controlled with standard conservative management. This multi-centre randomized controlled trial investigates whether early administration of TEI, based on clinical assessment without routine pre-treatment MRI, leads to superior symptom control during the early phase of disease compared with continued usual conservative care.

Additionally, the POTEISS study was designed to develop a multivariable prediction model for TEI treatment success, integrating clinical, demographic, and radiological factors. The results of this large prospective cohort study will aid clinicians in stratifying patients with lumbar radiculopathy due to LDH or degenerative stenosis for treatment with TEI, thereby facilitating more tailored treatment strategies.

Part II: improving diagnosis and prognosis in lumbar spinal stenosis

Lumbar spinal stenosis (LSS) is a degenerative condition characterized by narrowing of the spinal canal, lateral recess, or neuroforamen, often leading to neurogenic claudication. It represents one of the most common indications for spine surgery in older adults, yet postoperative outcomes and patient satisfaction vary widely. A major obstacle in the management of LSS is the lack of a universally accepted, clinically meaningful grading system that reliably correlates imaging findings with symptoms and outcomes.

Numerous grading systems for LSS have been proposed that assess the different anatomical regions of the lumbar spine contributing to this disease. The majority of grading systems are based on MRI examination. However, most systems assess only one anatomically relevant region, are subject to considerable intra- and inter-reader variability, and lack correlation with clinical parameters. A novel grading system was introduced by Miskin et al., assessing central canal stenosis (CCS), lateral recess stenosis (LRS), foraminal stenosis (FS), and facet arthropathy (FA). Using an independent cohort of patients with neurogenic claudication due to LSS who underwent surgery, the reliability and correlation with clinical data were evaluated. Substantial inter-reader agreement was demonstrated for CCS and LRS, while agreement for FS and FA remained limited.

Importantly, higher grades of CCS were independently associated with greater postoperative improvement in pain and disability, whereas LRS and a combined grading construct showed weaker clinical correlations. These findings suggest that CCS remains the most clinically relevant imaging parameter and that the proposed grading systems for FS and FA require refinement or substitution before broader implementation.

Recognizing the inherent variability and time burden of manual MRI grading, artificial intelligence (AI) has substantial potential to enhance LSS diagnostics. AI is capable of processing high-volume data in a short amount of time, detecting patterns that are difficult for humans to discern, and eliminating inter-reader variability. This makes AI particularly valuable in medical imaging, where it can improve diagnostic precision. A systematic review of existing algorithms was conducted to provide an overview of conventional machine learning (ML) and deep learning (DL) approaches for automated segmentation and classification of LSS. DL models demonstrated excellent capability in both segmentation and classification tasks, outperforming conventional ML methods, and nearing human-level performance. Moreover, these DL models can perform classification tasks without a separate segmentation step. However, the review also identified important limitations, including heterogeneity in outcome metrics, limited use of external validation, and lack of standardized test datasets. These shortcomings currently hinder clinical translation, despite the clear technical potential of AI-based tools.