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PhD THESIS

CONTRIBUTION OF RADIO-IMAGING TECHNIQUES IN DIAGNOSIS OF LUMBAR SPINAL STENOSIS

- A B S T R A C T -

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T i m i ș o a r a

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Stenosis of the vertebral canal is a degenerative condition in which changes in the vertebral bodies, intervertebral discs, ligamentum flavum, and interapophyseal joint surfaces that occur with aging lead to the narrowing of spaces around the neurovascular structures of the spinal column. These changes result in pain in the lower limbs and lumbar region, limited mobility, as well as other disabilities.

Stenosis can be classified as primary, caused by congenital anomalies or postnatally developed, or secondary, resulting from degenerative alterations or because of infections, traumas, or surgical interventions. Degenerative stenosis may involve the central canal, lateral recess, foramen, or a combination of these and is the most common cause of acquired stenosis, affecting primarily adults and the elderly [1, 5]. There is a continuous increase in life expectancy, leading to a concomitant rise in the occurrence of this condition. Although the exact incidence is not known, it has been estimated that lumbar stenosis affects between three and twelve patients per 100,000 inhabitants annually over the age of 65 [5, 6].

However, there is no single objective standard for identifying this pathology, and diagnosis relies on a comprehensive analysis that includes symptoms, clinical signs, radiographic appearance, and associated comorbidities of each patient.

The natural history of lumbar spinal canal stenosis remains a challenge. The existence of triarticulate mobility as a functional unit and its close contact with neural structures, along with the presence of an avascular main structure (intervertebral disc), are responsible factors in the development of degenerative changes. Central stenosis results from a decrease in the canal diameter in the anteroposterior, transverse, or a combination of these directions, secondary to the loss of intervertebral disc height, fibrous ring injury, and peri-somatic osteophyte formation, leading to instability and hypertrophy of interarticular facets and the ligamentum flavum (3). Intervertebral disc degeneration results in reduced relative stability, leading to facet hypermobility. A cadaver study suggested that pressure on the facets increases with disc height reduction and spinal extension. This would lead to facet joint hypertrophy, especially at the level of the superior articular process. Due to this degeneration, calcifications, and hypertrophy of the ligamentum flavum occur. The result is a reduction in canal dimensions and compression of neural elements.

The complexity of the condition and the lack of standard diagnostic criteria make the clinical and surgical management of the patient challenging, as well as the consolidation of existing research in the literature. According to data published by the National Spine Network in the United States, approximately 13%-14% of patients consulting a specialist for low back pain have evident imaging findings of spinal canal stenosis, and only 3%-4% are diagnosed by a physician.

Several classification systems and radiological measurements have been proposed by Meyerding and Wiltse et al. to describe regional sagittal deformity in degenerative spondylolisthesis, but none of these systems are reliable in predicting the natural history of the disease and postoperative outcomes.

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Neurogenic claudication represents the cardinal manifestation and the most specific symptom, the determining reason why the patient seeks medical attention. It involves the progressive onset of pain, paresthesia, weakness, a burning sensation, and tingling in the lower lumbar region, buttocks, and legs; it is accentuated by prolonged walking, standing, or lumbar extension.

Magnetic Resonance Imaging (MRI) is currently the recommended method for evaluating and confirming the diagnosis of vertebral canal stenosis; it allows assessment of the size, shape, and anatomical and functional relationships of spinal structures. MRI has a sensitivity of 87-96% and specificity of 68-75% for diagnosing vertebral canal stenosis.

Vertebral canal stenosis is a clinical syndrome, not always an anatomical or radiological finding. It is estimated that 21% of individuals with imaging-identified stenosis are asymptomatic.

RESEARCH MOTIVATION

Although numerous retrospective studies have demonstrated the accuracy of magnetic resonance imaging in diagnosing and staging lumbar spinal canal stenosis, more data are needed to validate the use of imaging as part of an algorithm in the management of patients with spondylolisthesis.

In our studies, we aimed to update current evidence regarding the accuracy of magnetic resonance imaging in diagnosing lumbar spinal canal stenosis and optimizing the choice of surgical treatment techniques.

The anticipated results of the study seek to enrich the data available in the literature to date and improve the management protocol for patients with lumbar spinal canal stenosis using clinical signs, physical examination, and radiographic criteria.

The primary aim of the first study is to incorporate imaging assessment of lumbar spinal canal stenosis both in preoperative planning and in the management of intra- and postoperative complications. Additionally, the study aims to evaluate the role of Anterior

Lumbar Interbody Fusion (ALIF) in correcting sagittal balance in patients with degenerative spondylolisthesis.

Incorporating sagittal balance into the radiological evaluation of spondylolisthesis could be valuable for the spinal surgeon in preoperative planning for patients who may benefit from reduction and fusion [5]. Numerous studies have demonstrated that lumbar lordosis is increased in patients with high-grade spondylolisthesis to balance the trunk's position in an upright stance.

In the second study, we conducted a retrospective study that included patients diagnosed with lumbar spinal canal stenosis without prior spinal surgery history. We performed MRI with a lumbar spine evaluation protocol, focusing on the qualitative assessment of the degree of fatty degeneration of the lumbar paravertebral spinal muscles according to the Goutallier classification. Additionally, we assessed the "rising psoas" sign, as this specific morphology of the psoas could influence the results.

The introduction of spino-pelvic parameters by Duval-Beaupere has led to numerous studies investigating their role in lumbar spinal stenosis (LSS). It has been demonstrated that spino-pelvic parameters play an important role in the pathogenesis and quality of life in both adult and pediatric populations. Spino-pelvic parameters can be influenced by the fatty infiltration of the lumbar paravertebral spinal muscles.

Functional outcomes following surgery are traditionally evaluated using patient-reported outcome measures (PROMs), such as the Oswestry Disability Index (ODI). The third retrospective study aims to investigate the relationship between preoperative MRI measurements (cross-sectional area of the psoas muscle, central stenosis, and facet joint degeneration) and preoperative and postoperative ODI values (follow-up at 1 year). By examining these correlations, this study aims to contribute valuable information regarding prognostic factors affecting functional recovery after surgery for lumbar spinal stenosis (LSS).

The results of our studies aimed to assess the role of imaging investigations in the diagnosis, monitoring, and long-term prognosis evaluation of patients with degenerative lumbar spinal canal stenosis. This aspect is valuable in the preoperative management of patients with lumbar spinal stenosis (LSS) who may benefit from surgical treatment. With the information obtained, we hope to contribute to the advancement of this research field and achieve an optimization of the management protocol for degenerative lumbar spinal canal stenosis.

RESULTS

I. REDUCTION OF SPONDYLOLISTHESIS AND SAGITTAL BALANCE CORRECTIONBY ANTERIOR LUMBAR INTERBODY FUSION (ALIF)

Twenty patients (8 males and 12 females) aged between 47 and 70 years (mean age 60.7±9.82) underwent surgery for degenerative spondylolisthesis through Anterior Lumbar Interbody Fusion (ALIF) between July 2011 and September 2014. The indications for ALIF were degenerative spondylolisthesis with sagittal imbalance. Patients with lateral listezis and degenerative scoliosis were excluded.

Preoperative and postoperative standing full-spine radiographs were retrospectively reviewed, recording the lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS) values. Radiographs were considered valid if both hip joints, the lower S1 vertebral plateau, the upper L4 vertebral plateau, and the upper L1 vertebral plateau were visible. The minimum postoperative follow-up was five years.

Patient data regarding the history of previous spinal surgeries, previous spinal fusion, number of ALIF levels, and lordotic angle of the intervertebral cage were recorded. Five out of twenty patients (25%) had at least one previous spinal surgery. All patients were operated on by the same surgical team. Fifteen patients (75%) underwent single-level ALIF, and five patients (25%) underwent two-level ALIF. In total, ten levels (40%) were treated at L5-S1, ten levels (40%) at L4-L5, and five levels (20%) at L3-L4. All ALIF cages were supplemented with posterior screw fixation.

All radiological parameters were calculated using specific validated quantitative analysis software, SpineView 2.1. Clinical and radiological evaluations were performed preoperatively, one year postoperatively, and at five years postoperatively.

II. COHORT STUDY ON THE RELATIONSHIP BETWEEN MORPHOLOGIC PARAMETERS OF PARAVERTEBRAL MUSCLES, BMI AND LUMBAR LORDOSIS ON THE SEVERITY OF LUMBAR STENOSIS

For data collection, a total of 124 medical records corresponding to patients diagnosed with lumbar spinal canal stenosis, coded as ICD: M48.06, were analyzed. All patients had been previously admitted for surgical treatment at our hospital between January 2018 and January 2022. Inclusion criteria were a clear diagnosis of symptomatic lumbar spinal stenosis, age over 18 years, no history of spine surgery before the current hospitalization, complete medical records, and an MRI with a protocol for lumbar spine evaluation. A total of 124 patients were included in the study (52 males and 72 females).

MRI images were independently analysed by two authors, a radiologist and a spine surgeon, using DICOM software Horos (version 3.3.6 for OsX). On the sagittal T2 sequence, lumbar lordosis was measured using the Cobb angle between the S1 plateau and the upper L1 plateau. The technique of measuring lumbar lordosis on MRI images was chosen because previous studies have shown that the difference between results obtained using this technique and those obtained by measuring on lumbar spine radiography (in lateral incidence), in an upright position, is approximately 2.9°. The cross-sectional area (CSA) of the psoas muscle was measured on axial T2 images at the L4-L5 intervertebral disc level by manually contouring the fascial boundary of the psoas. The obtained values were recorded, and their average was used for further investigations. Relative CSA (rCSA) was defined as the ratio between the average CSA and the area of the inferior vertebral plateau of L4 (measured using a similar technique). Although several studies have used the intervertebral disc area (IVD) as a reference, in this study, the decision was made to measure the inferior vertebral plateau of L4 since the IVD could have been degenerated (reduced in size), potentially introducing errors.

Additionally, we also examined the "rising psoas" sign, as this special morphology of the psoas could influence the results. The "rising psoas" sign was diagnosed when the most posterior part of the psoas was anterior to a horizontal line defining the most posterior appearance of the disc or vertebral body. Also, the most anterior part of the psoas should no longer be in contact with the vertebrae and should appear as if detached [18]. If the "rising psoas" sign was present either unilaterally or bilaterally, it was considered positive. The number of levels involved in the stenotic process (i.e., from 1 to 5) was also noted. The severity of canal stenosis was scored on axial MRI images according to the Schizas criteria: A-no/minor, B-moderate, C-severe, D-extreme.

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III. CORRELATION BETWEEN PREOPERATIVE MRI PARAMETERS AND OSWESTRY DISABILITY INDEX IN PATIENTS WITH LUMBAR SPINAL STENOSIS: A RETROSPECTIVE STUDY

A retrospective study was conducted on a sample of 86 patients (37 men and 49 women) with an average age of 54.8 years (ranging from 32 to 82 years, std. dev. 14.40), diagnosed with lumbar spinal stenosis (LSS) in a county clinical hospital over a 5-year period (January 2018 - January 2023). Institutional approval was obtained from the Scientific Research Committee (No. 60/22.12.2021).

Upon admission, all patients underwent preoperative lumbar spine MRI. MRI measurements were performed and recorded as follows: cross-sectional area of the psoas muscle, the region of the highest degree of lumbar canal stenosis (on the T2 sequence in the axial plane), the area of neural foramina (on the T2 sequence in the sagittal plane), and degeneration of the facet joints (n = 516).

MRI images were independently analysed by two authors, a radiologist and a spine surgeon, using DICOM Horos software (version 3.3.6 for OsX). In this study, the relative cross-sectional area of the psoas muscle (rCSA) was used as previously described in another study by the researcher [13]. These values represent a ratio between the average cross-sectional area of the psoas muscle and the cross-sectional area of the lower L4 endplate [13]. The neural foramen area was measured bilaterally (from L3-L4 to L5-S1) by manually removing fat and neural structures. The smallest value was chosen for further investigations. Osteoarthritis of the facet joint was assessed bilaterally from L3-L4 to L5-S1 following Weishaupt et al.'s description in a 4-grade manner, and the highest observed grade was noted. All manually measured values by the two investigators were summed, and their average was used for further investigations.

Additionally, the number of levels involved in the stenotic process was also noted (ranging from 1 to 5). The severity of canal stenosis was scored on axial MRI images according to the Schizas criteria.

Patients were assessed preoperatively and postoperatively (1-year follow-up) through the Oswestry Disability Index (ODI) questionnaire. ODI is a widely used self-administered questionnaire that quantifies the perceived level of disability in various aspects of daily life. It provides a multidimensional approach to assessing pain, function, and health status, thus offering a comprehensive view of a patient's disability level. The preoperative functional status was evaluated using the ODI questionnaire by the overseeing physician together with the patient. Questions addressed pain intensity, the ability to lift weights, self-care ability, walking capacity, ability to sit, ability to stand, social life, sleep quality, and travel capacity.

GENERAL CONCLUSIONS AND ORIGINAL CONTRIBUTIONS

The first study includes patients diagnosed with degenerative spondylolisthesis, with sagittal imbalance, indicated for Anterior Lumbar Interbody Fusion (ALIF), where pre- and post-operative spinal X-rays were performed, recording the values of LL, PI, PT, and SS. ALIF was performed at one level in 75% of patients, and at two levels in 25% of patients. Postoperative radiological data at one year showed that 90% of patients presented with Grade I fusion, and 10% of patients presented with Grade II. At the 5-year postoperative evaluation, all patients showed solid fusion, and sagittal balance correction was maintained. No mechanical complications were identified at 5 years postoperatively.

The second study examines the relationship between morphological parameters of paravertebral muscles, Body Mass Index (BMI), and lumbar lordosis, related to the severity of lumbar spinal canal stenosis. There is an increasing interest in the literature highlighting the negative impact of increased body mass index on the quality of life in patients with lumbar spinal canal stenosis. Patients with lumbar spinal canal stenosis associated with obesity frequently report lower scores on quality-of-life questionnaires and those assessing the ability to perform daily activities without symptoms. Lack of physical activity can lead to muscle atrophy and fat infiltration. These changes can also affect paravertebral muscles, altering their role as dynamic stabilizers of the spine and compromising their ability to maintain optimal lordosis.

These findings support the hypothesis that changes in paravertebral muscles may be consequences of degenerative disease, although it is important to approach this statement with caution, considering that lumbar spinal stenosis is caused by various factors such as hypertrophy of the ligamentum flavum, facet joint arthrosis, or degenerative disc disease. In the study, the analysis of two parameters of fat infiltration in paravertebral spinal muscles, both in the anterior (APVM) and posterior (PPVM) regions, revealed that the latter is more sensitive. This conclusion could be helpful in future research, as the authors believe that the Goutallier Score may not be sensitive enough to accurately detect and classify subtle changes in the psoas muscle.

Regarding the association between obesity and low back pain, previous studies have often reported a correlation, indicating lower scores in general health and activity-related questionnaires. However, in contrast to these findings, the presented study did not observe such an association, even though the average age of the subjects was 54.8±14.4 years. The mean BMI values among patients (29.04 kg/m2±6.86) indicate the presence of overweight or

obesity. It is essential to emphasize that the study group does not represent the general population, consisting of patients with lumbar spinal stenosis (LSS) who underwent spinal surgeries. Although BMI is considered a modifiable factor, its correlation with the severity of LSS, even after adjusting for age and gender, supports the idea that weight reduction can improve the overall condition of these patients.

The third retrospective study aims to investigate the relationship between preoperative MRI measurements, such as the cross-sectional area of the psoas muscle, central stenosis, and facet joint degeneration, and Oswestry Disability Index (ODI) values reported both preoperatively and postoperatively (at the 1-year follow-up). By analysing these correlations, the goal of this study is to make significant contributions to understanding prognostic factors that influence functional recovery after surgery for lumbar stenosis.

According to the results of our study, certain imaging indicators, such as the severity of lumbar spinal stenosis and the relative cross-sectional area of the psoas muscle, exhibit weak to moderate correlations with both preoperative and 1-year follow-up Oswestry Disability Index (ODI) scores. The investigation revealed that, despite a weak correlation between the severity of canal stenosis, measured according to Schizas criteria, and initial ODI scores, it did not serve as a significant predictor of postoperative ODI scores at 1 year. This finding underscores the limitations imposed by the exclusive reliance on radiological assessment of severity in anticipating functional outcomes in lumbar stenosis cases.

Furthermore, it was observed that other imaging parameters, such as the sagittal area of the neural foramen and the degree of facet joint osteoarthritis, did not show statistically significant correlations with ODI scores. This suggests that the exclusive evaluation of these imaging parameters may be limited in its ability to predict the functional progression of patients with lumbar spinal stenosis.