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Index for static and dynamic measurements of the lumbar foramina in patients with foraminal stenosis

Índice para la medición estática y dinámica de los forámenes lumbares en pacientes con estrechez foraminal

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ABSTRACT. Introduction: lumbar foraminal stenosis refers to the constriction of the lateral canal through which the nerve root exits the spinal canal in the lumbar spine. It occurs in 8-11% of patients aged over 40 years. Failure to detect and alleviate foraminal constriction can contribute to up to 60% of instances of unsuccessful lumbar surgery. This study aimed to develop an index to assess the extent of foraminal narrowing, thereby aiding decisions regarding direct or indirect foraminal decompression. **Material and methods:** a cross-sectional study was conducted, involving 49 patients, wherein measurements of all five lumbar foramina were taken using X-rays and simple magnetic resonance imaging. These measurements primarily focused on the foraminal width and the lower endplate, which were then correlated to establish a foraminal width/lower endplate index. **Results:** the foraminal width/lower endplate index < 10% yielded an odds ratio (OR) of 3.07 on lateral radiography, 3.59 on flexion radiography, and 4.01 on extension radiography. In MRI, an OR of 0.195 was found for the left foramina, while an OR of 3.07 was observed for the right foramina. **Conclusion:** this study paves the way for further exploration of preoperative and postoperative clinical outcomes across various surgical decompression methods guided by the FW/LE index. To enhance decision making, it is recommended to conduct research comparing pre- and postoperative clinical

RESUMEN. Introducción: la estenosis foraminal lumbar se define como el estrechamiento del canal lateral por donde sale la raíz nerviosa del canal espinal en la columna lumbar, ocurre de 8-11% en pacientes mayores de 40 años. El fallo en la detección y descompresión del foramen representa 60% de las causas de cirugía lumbar fallida. Este estudio tuvo como objetivo generar un índice que evalúa el grado de estrechez foraminal y así apoyar la toma de decisiones para una descompresión foraminal directa o indirecta. **Material y métodos:** se realizó un estudio transversal, donde se incluyeron 49 pacientes a los cuales se les midieron los cinco forámenes lumbares con rayos X y resonancia magnética simple. Estas mediciones incluyeron principalmente el ancho foraminal y la plataforma vertebral inferior del cuerpo vertebral superior y se correlacionaron para formar un índice ancho foraminal/plataforma vertebral inferior. **Resultados:** el índice ancho foraminal/plataforma vertebral inferior < 10% tiene un OR de 3.07 en la radiografía lateral, un OR de 3.59 en la radiografía en flexión y un OR de 4.01 en la radiografía en extensión. En la resonancia magnética se obtuvo un OR de 0.195 para los forámenes izquierdos y un OR de 3.07 para los forámenes derechos. **Conclusión:** este estudio abre el camino para una mayor exploración de los resultados clínicos preoperatorios y postoperatorios en diversos métodos de descompresión quirúrgica guiados por el índice FW/LE. Para mejorar la toma de decisiones,

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findings in individual patients, considering their FW/LE index measurements.

Keywords: foraminal stenosis, lumbar spine, magnetic resonance imaging, lateral radiography, cross-sectional study.

se recomienda realizar una investigación que compare los hallazgos clínicos preoperatorios y postoperatorios en pacientes individuales, teniendo en cuenta sus mediciones del índice FW/LE.

Palabras clave: estenosis foraminal, columna lumbar, resonancia magnética, radiografía lateral, estudio transversal.

Introduction

Lumbar foraminal stenosis is defined as the narrowing of the lateral canal (foramen) through which the nerve root exits the spinal canal in the lumbar spine.[1] It can be caused by congenital, developmental, acquired, and inflammatory etiologies.[2] The most common is due to a degenerative process where there is a loss of intervertebral disc height causing anterior and posterior subluxation of the superior articular process of the inferior vertebra, occurring in 8-11% of patients over 40 years.[1,2,3]

Among the degenerative causes are disc herniations, osteoarthritis, spondylolisthesis, scoliosis, and facet joint osteoarthritis, among others.[2]

Clinically, pain may manifest while at rest, such as when sitting, lying supine, or lying laterally, as well as during prolonged standing and/or walking. The pain may present as radicular, radiating towards the affected dermatomes in the lower extremities, or as mechanical discomfort localized in the lumbar or gluteal region, which limits the range of motion, particularly in spine extension where the foramen dynamically narrows. Physical examination findings are typically nonspecific. The positive Kemp sign involves an exacerbation of radicular pain during extension and lateralization of the spine. These movements alter the foraminal space, thereby compromising the exiting nerve root and resulting in radicular pain.[4] Some patients may exhibit reduced strength, altered sensitivity, and/or changes in myotendinous reflexes.[2,3] The average duration of symptoms is usually 43.7 ± 14.6 months for mechanical lumbar pain and 15.3 ± 12.9 months for radicular pain.[5]

As diagnostic tools, lateral and dynamic flexion-extension lumbar radiographs are used, as well as computed tomography and magnetic resonance imaging.[3,6,7] There are various classifications for lumbar stenosis, primarily descriptive and lacking specific guidance on management. For central lumbar canal stenosis, the Schizas classification is used, which assesses compression in axial T2 images.[8] Grade A indicates either no stenosis or minimal stenosis attributed to a homogeneous distribution of cerebrospinal fluid. Grade A is further classified into 4 points based on the position of the roots. Grade B signifies moderate stenosis, characterized by roots occupying the entire dural sac, yet with cerebrospinal fluid still present between them. Grade C denotes severe stenosis, where the roots are indistinguishable from each other, while the posterior epidural fat remains visible. Grade D represents extreme stenosis, akin to type C where the posterior epidural fat is not visualized.[8]

The lateral recess stenosis described by Bartynski in magnetic resonance imaging comprises 4 grades. Grade 0 denotes no compression, while grade 1 indicates a narrowing of the lateral recess without nerve root compression. grade 2 signifies compression of the nerve root. Grade 3 represents severe hypertrophy of the ligamentum flavum and facets, resulting in severe compression of the nerve and absence of cerebrospinal fluid in the lateral recess.[9]

The most used classification for foraminal stenosis is proposed by Lee and colleagues.[10] This classification is derived from magnetic resonance imaging, where grade 0 signifies no foraminal stenosis, and grade 1 indicates vertical or transverse narrowing with fat obliteration. Grade 2 presents vertical and transverse narrowing but without morphological changes in the nerve root. Grade 3 indicates morphological changes to the nerve root.[10]

In the study led by Dr. Hasegawa and colleagues, they discovered that in the subset of nerve roots with compression data, most were linked to foraminal height reduction below 15 mm and a posterior intervertebral disc height of 4 mm or less. With both factors present, they observed a coexistence of facet subluxation and hypertrophy of the ligamentum flavum, both contributing to nerve root compression.[11]

Failure to identify foraminal stenosis and neglecting foraminal decompression could contribute to 60% of unsuccessful lumbar surgeries.[12] This study aimed to establish an index to quantify the extent of foraminal narrowing and based on the findings, recommend either direct or indirect decompression.

Materials and methods

An observational and retrospective study was conducted between the years 2020 and 2023. The present project was submitted to and approved by the Ethics and Research Committees of the ABC Medical Center, with registration number CMABC-23-34. Data were obtained from the electronic medical records of the hospital, as well as from the Picture Archiving and Communication System (PACS) of Carestream.

Patients with lumbar and foraminal stenosis secondary to spondylolisthesis, adult degenerative scoliosis, osteoarthritis, facet joint osteoarthritis, and degenerative disc disease at the levels of L4-L5 and L5-S1 were included. These patients were

Figure 1: Lateral radiograph of the lumbar spine in a weight-bearing position. **A)** Measurement of foraminal height. **B)** Measurement of foraminal width. **C)** Measurement of the inferior endplate. **D)** Index of foraminal width/inferior endplate platform with a result of 10%. **E)** Measurement of posterior disc height.

required to have lumbar spine magnetic resonance imaging, lateral and dynamic radiographs of the lumbar spine in a weight-bearing position. Patients without lumbar magnetic resonance imaging and radiographs, those diagnosed with cancer, rheumatic disease, sepsis, spondylodiscitis, use of antiresorptive calcium medications, history of lumbar vertebral fracture, disorders in calcium metabolism, inability to achieve independent weight-bearing, transitional vertebra, pregnancy, or previous lumbar spine surgery were excluded.

All measurements were conducted by a resident physician in traumatology and orthopedics, who assessed the foramina from L1-S1, and performed the following measurements: 1) **Foraminal height**, measuring the distance between the pedicles; 2) **Foraminal width**, extending from the posterior edge of the vertebral body to the anterior edge of the superior articular process. In cases where there were two posterior edges due to obliquity or rotation of the vertebral body, the most posterior edge of the vertebral body was taken as a reference. 3) **Lower endplate**, measured from its anterior limit to its posterior edge; 4) **Posterior disc height**, measured as the distance between the posterior edges of the vertebral endplates. These measurements are illustrated in *Figures 1 and 2*.

Of these foramina, those of L1-L2, L2-L3, and L3-L4 were considered without reduction, while those of L4-L5 and L5-S1 were considered with reduction.

Following the measurements, the foraminal width/lower endplate (FW/LE) index was calculated. This index is obtained by dividing the measured foraminal width by the lower endplate measurement and multiplying the result by 100 to express it as a percentage.

During this study, a consensus was reached among 3 spine surgeons in the service, establishing that a foraminal width/lower endplate index of less than 10% suggests performing direct decompression. This decision is based on the inference that with a bone distance of less than 4 mm in foraminal width, there will be compression and morphological changes of the nerve, despite the removal of soft structures such as intervertebral disc or ligamentum flavum. This inference is supported by the understanding that the nerve root occupies approximately between 23.89 and 32.18% of the foraminal area depending on the lumbar level.[11,13]

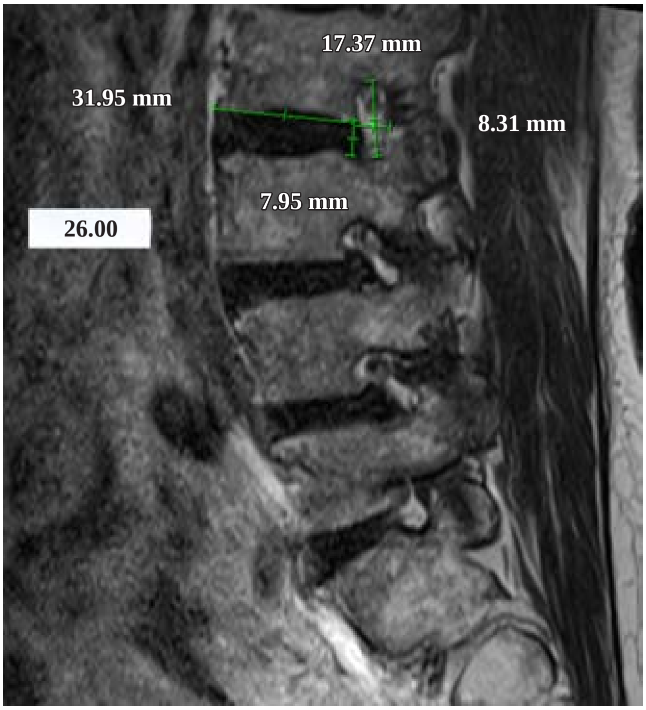

Figure 2: Lumbar plain magnetic resonance imaging in T2 sequence with sagittal view. Combined measurement of foraminal height and width, inferior endplate, index of foraminal width/inferior endplate with a result of 26%, and measurement of posterior disc height.

Moreover, demographic data including age, gender, Oswestry disability index, and body mass index (BMI) for each patient were documented. The information was input into a Microsoft Excel database, and its accuracy was verified by two physicians who underwent prior training.

For statistical analysis, the IBM SPSS v27.0 software was employed. Initially, a descriptive analysis was conducted to delineate the clinical features of the patients. Quantitative data distribution was assessed, and variables with a normal distribution were presented as mean and standard deviation, while those with a non-normal distribution were expressed as median and interquartile range (P25-P75). Additionally, qualitative variables were depicted as frequencies and proportions.

To ascertain heterogeneity among the foraminal width/lower endplate index in the five studied foramina, a Kruskal-Wallis test was performed, where a p-value < 0.05 was deemed statistically significant.

Furthermore, a simple logistic regression analysis was executed to assess the impact of a foraminal width/lower endplate index < 10% as an independent variable, with foraminal reduction (L4-L5 and L5-S1) as the dependent variable. The odds ratio, along with the 95% confidence interval and p-value, were examined.

Results

Forty-nine patients were enrolled, consisting of 26 males and 23 females, with a mean age of 55 years and a median body mass index of 24.5 kg/m^2. The Oswestry Disability Index yielded a mean score of 49%. The population's descriptive analysis is detailed in *Table 1*.

A total of 245 foramina were analyzed, with 49 measurements obtained for each foraminal level, constituting 20% each. Among these, the foramina of L1-L2, L2-L3, and L3-L4 were considered without reduction, representing a frequency of 147 and 60% of the total. Foramina considered with reduction were L4-L5 and L5-S1, accounting for 40%.

Table 1 delineates the results regarding foraminal measurements from lateral, flexion, and extension radiographs. In the flexion radiograph, the foraminal height had a median of 19 mm, while the foraminal width had a mean of 7.1 mm with a standard deviation of 2.8 mm. The lower endplate yielded a median of 39.8 mm. The FW/LE index averaged 17.8% with a standard deviation of 7.21%.

Furthermore, *Table 1* presents the descriptive analysis results of foraminal measurements obtained through magnetic resonance imaging. For the left foramina, foraminal height measured a median of 19.8 mm, and foraminal width recorded a median of 7.5 mm. The lower endplate averaged 31.94 mm, with the FW/LE index averaging 23.3%. The posterior disc height averaged 6.3 mm. For the right foramina, foraminal height reached a median of 19.6 mm, while foraminal width averaged 7.1 mm. The lower endplate measured a median of 39.8 mm, with the FW/LE index averaging 17.81%. The posterior disc height yielded a median of 5.1 mm.

Table 2 illustrates the bivariate analysis results between the FW/LE index < 10% for predicting foraminal reduction, encompassing lateral, flexion, and extension radiographs, as well as magnetic resonance imaging. In lateral radiographs, an odds ratio (OR) of 3.07 was obtained for foraminal compression, with a p-value of 0.004. In flexion radiographs, the OR was 3.59, with a p-value of 0.013. In extension radiographs, the OR was 4.01, with a p-value < 0.0001. For left foramina measured by magnetic resonance imaging, the OR was 0.195, with a p-value of 0.002. For right foramina, the OR was 3.07, with a p-value of 0.004.

Table 1: Description of the patients' characteristics and foraminal measurements.

Gender, n (%)			
Female	23 (46.9)		
Male	26 (53.1)		
Age	55 [21-83]*		
Oswestry	49 (10)‡		
BMI	24.5 (22.49-26.6)§		
Radiograph	**Lateral**	**Flexion**	**Extension**
Foraminal			
Height	19 (16.2-21.9)§	20.4 (4.5)‡	19.6 (16.8-21.5)§
Width	7.1 (2.8)‡	8.1 (3)‡	7.1 (2.8)‡
Inferior Endplate	39.8 (38.1-42.4)§	41.2 (21.8)‡	40.5 (37.7-43.4)§
FW/LE index	17.81 (7.21)‡	20.87 (10.61)‡	17.53 (7.11)‡
Posterior disc height	5.1 (4.1-6.3)§	6.2 (3.5)§	5.5 (4.4-6.7)§
Magnetic resonance	**Left**	**Right**	
Foraminal			
Height	19.8 (17.3-22.3)§	19.6 (16.2-21.9)§	
Width	7.5 (6.2-8.7)§	7.1 (2.8)‡	
Inferior endplate	31.94 (3.07)‡	39.8 (38.1-42.4)§	
FW/LE index	23.30 (19.51-27.48)§	17.81 (7.21)‡	
Posterior disc height	6.3 (1.9)‡	5.1 (4.1-6.3)§	

BMI = body mass index. FW/LE = foraminal width/lower endplate.
* Mean [range of age]. ‡ Mean ± standard deviation. § p50 (p25-p75).

Table 2: Bivariate analysis of the FW/LE index < 10% to predict foraminal decrease.

FW/LE index < 10%	OR (CI 95%)	p
Radiograph		
Lateral	3.07 (1.43-6.58)	0.004
Flexion	3.59 (1.32-9.81)	0.013
Extension radiograph	4.01 (1.86-8.64)	< 0.0001
Magnetic resonance imaging		
Left	0.195 (0.07-0.56)	0.002
Right	3.07 (1.43-6.58)	0.004

FW/LE = foraminal width/lower endplate. CI95% = 95% confidence interval.

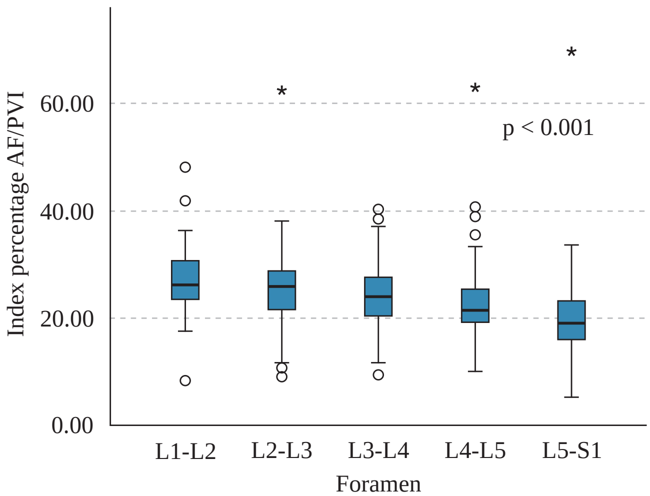

Figure 3: Analysis of heterogeneity of the FW/LE index among the different foramina analyzed.

Additionally, *Figure 3* illustrates a Kruskal-Wallis's test comparing the foraminal width index and the lower endplate in radiographs and magnetic resonance imaging, indicating that at levels L4-L5 and L5-S1, there is a lower FW/LE index ($p < 0.001$).

Discussion

The debate surrounding the optimal decompression approach for patients with lumbar and foraminal spinal stenosis remains contentious.[14] Dr. Gagliardi and colleagues conducted a systematic review comparing the outcomes of direct and indirect lumbar decompression at a one-year follow-up. Interestingly, their findings revealed that the choice of decompression method did not correlate with the severity of foraminal or spinal stenosis. Clinical outcomes demonstrated no significant discrepancy across the various decompression approaches.[14]

This study succeeded in developing the FW/LE index, representing a pioneering objective metric suggesting the appropriate approach based on foraminal constriction, thereby mitigating the risk of surgical failure attributable to this factor.

During the index's development, it was observed that the study cohort's mean age of 55 years aligned with prior literature,[3] suggesting the index's applicability in patients anticipated to experience intervertebral disc height loss due to degenerative processes.

When traversing the foraminal space, the nerve root measures approximately 5.5 mm on the right side at L4 and 5.8 mm on the left. At L5, these dimensions are approximately 6.1 mm on the right and 5.7 mm on the left 13. Notably, the nerve root occupies roughly 23.89 to 32.18% of the foraminal area depending on the lumbar level.[13] Consequently, a foraminal width of less than 4 mm suggests nerve compression at L4-L5 and L5-S1, even post soft tissue removal such as the intervertebral disc or ligamentum flavum, corresponding to an index below 10%.

Measurement of the FW/LE index was confined to unaffected foramina L1-L2, L2-L3, and L3-L4 to establish a comparative benchmark against affected foramina. The index's utilization between two structures served to counterbalance radiographic technique variations, as these structures are influenced by identical magnification factors.[15]

Emphasizing the need for comprehensive foraminal constriction assessment, dynamic radiographs, and magnetic resonance imaging were incorporated, given the lumbar spine positional impact on foraminal dimensions, even though our findings from the bivariate analysis demonstrate statistical significance across all studies included.[16,17,18,19,20]

In our magnetic resonance imaging measurements, a statistically significant difference was noted in left foramina, likely influenced by the inclusion of 8 patients with adult degenerative scoliosis, representing 40 foramina.

This study bears significance as, in the event of significant clinical findings, it could aid surgical decision-making. The previous classifications for spinal stenosis, lateral recess stenosis and foraminal stenosis do not suggest a therapeutic conduct. The FW/LE index given its reliance on bone references, underscores persisting nerve compression post soft tissue resection. Notably, in cases of indirect decompression, such as lateral or anterior approaches, a FW/LE index below 10% could heighten the risk of surgical failure due to inadequate foraminal decompression. Future studies are warranted to ensure measurement consistency across observers and correlation with clinical outcomes in patients with an index below 10%.

To extrapolate the study's findings, comparative analyses of preoperative and postoperative clinical outcomes, alongside validated functional scores such as the Oswestry Disability Index in the Mexican population,[21] are recommended.

Conclusions

The FW/LE index has emerged as a valuable tool for evaluating foraminal stenosis, offering a novel measurement approach. Assessing the degree of obstruction allows for the assessment of whether direct or indirect decompression would be more beneficial. This study paves the way for further exploration of preoperative and postoperative clinical outcomes across various surgical decompression methods guided by the FW/LE index. To enhance decision-making, it is recommended to conduct research comparing pre- and postoperative clinical findings in individual patients, considering their FW/LE index measurements.

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