Three-dimensional analysis of the intervertebral foramen in asymptomatic and symptomatic back pain patients

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Introduction: Low back pain (LBP) is prevalent in the population affecting 70-85% of patients in their lifetime(1). However, the exact pathophysiology of this entity is not completely understood(2). One hypothesis is that alterations in the intervertebral foramen (IVF) may contribute to the pathogenesis of LBP. Although there are various definitions of the IVF, in this study, the IVF is defined as an oval or inverted teardrop-shaped window in the interpedicular zone(3). The dorsal root ganglia, which has been implicated in LBP, is located within the IVF(4). Because the IVF’s boundaries consist of two movable joints, dynamic changes occur to the IVF dimensions(5). These dynamic changes and the presence of the dorsal root ganglia as a possible LBP generator present the possibility of the IVF contributing to the complex etiology of LBP. IVF kinematics has been studied in an in vitro mathematical model(6); however, an accurate in vivo and computerized tomography (CT) three-dimensional (3D) model has not been demonstrated in the literature. One study by Smith et al. stated the IVF could not be accurately measured using 3D CT(7); however, there are no newer publications utilizing a 3D CT model as CT technology has progressed. Therefore, using an innovative 3D CT model, we will analyze foraminal changes in asymptomatic and LBP symptomatic patients.

Materials and Methods: Twenty-one male subjects in their thirties were recruited to participate in this study (11 asymptomatic and 10 symptomatic, IRB approved). CT images of the lumbar spine were taken in a supine position and reconstructed into 3D models. A solid model of each vertebral body was converted to a surface point cloud model and post-processed using a VC++ custom program. The foramen boundaries consisted of the superior and inferior pedicles, the posterosuperior margin of the superior vertebral body, the posterosuperior margin of the inferior vertebral body, and the superior and inferior articular facets. A point was defined in an arbitrary central position within the foramen as a temporary center of gravity (COG). This arbitrary COG was used as the origin of a spherical coordinate system, where relative least distances between its temporary origin and points along the foraminal physical boundaries were calculated. A search for the least distances was conducted within a 10-degree circular sector contained in the sagittal plane and centered at the temporary COG. These least distances determined a boundary of 36 points after a complete revolution around the temporary COG. Once the initial boundary points were determined, the COG of the resulting 3D surface was updated. This enabled the formation of a concave 3D surface comprised of triangles defined by the radial distance from two outward boundary points to the COG and the distance between said boundary points as edges (Fig 1).

The resulting plane triangular surface areas were summed to obtain an area approximation of the 3D surface.

In order to compare these results with previous studies, a projection of this 3D surface onto the sagittal plane was used to compute a plane area and to define the parameters to characterize the foraminal shape. The foraminal height was defined as the largest distance in the cranial-caudal direction; and the foraminal width was defined as the smallest distance in the antero-posterior direction.

An unpaired t-test was used for comparison between the symptomatic and asymptomatic groups. A level effect was analyzed by ANOVA with a Fischer’s post hoc test.

Results: Comparing symptomatic to asymptomatic patients, there was a trend to a narrower minimum distance with the symptomatic patients having a smaller distance (6.58 +/- 1.88 mm versus 5.85 +/- 0.82 mm, p=0.983). The maximum distance, however, demonstrated no difference in length (16.10 +/- 3.15 mm in normal versus 16.90 +/- 8.80 mm, p=0.688). The area of the foramen also did not show any significant difference as the symptomatic patients had an area of 95.00 +/- 27.83 mm2 compared to asymptomatic 103.07 +/- 37.87 mm2, p=0.420. When comparing different levels, the L4-5 foraminal area difference was statistically smaller than the L1-2, L2-3, and L3-4 levels. The L3-4 level was statistically smaller in area than L2-3 and had a trend to be smaller versus the L1-2. L2-3 was smaller than L1-2 but there were no significant difference (Table 1). Table 1: Summary of measured foraminal geometric parameters. Mean (std).

Discussion: This study is the first known study to examine the foraminal dimension in vivo using CT. This novel technique compares well with previous cadaveric studies that have shown foraminal areas ranging from 80.4 mm2 to 103.6 mm2 (this study 71.84 mm2 to 119.05 mm2)(8). Our study challenges the Smith et al. study which states CT is unable to accurately measure the foramen(7). This difference may be attributed to better current CT technique and technology. This study, more importantly, suggests that foraminal narrowing may play a role in the pathogenesis of axial back pain as the foraminal width narrows in asymptomatic compared to symptomatic patients. When the foraminal width is analyzed at different segmental levels however, there is not a significant difference between the two groups. We believe this is because of the small sample size; therefore, we are planning on analyzing other age groups and females. In addition, we have analyzed only the IVF in neutral position. We have developed a technique to extrapolate neutral CT imaging to plane radiograph flexion and extension and simulate CT flexion and extension. We plan on analyzing the IVF dimensions in these positions as well. Overall, this study demonstrates the feasibility of using CT imaging to analyze IVF differences in patients with symptomatic axial back pain.


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