A New Volumetric Radiologic Method to Assess Indirect Decompression After Extreme Lateral Interbody Fusion Using High-Resolution Intraoperative Computed Tomography

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■ BACKGROUND: **Two-dimensional radiographic methods have been proposed to evaluate the radiographic outcome after indirect decompression through extreme lateral interbody fusion (XLIF). However, the assessment of neural decompression in a single plane may underestimate the effect of indirect decompression on central canal and foraminal volumes. The present study aimed to assess the reliability and consistency of a novel 3-dimensional radiographic method that assesses neural decompression by volumetric analysis using a new generation of intraoperative fan-beam computed tomography scanner in patients undergoing XLIF.**

■ METHODS: **Prospectively collected data from 7 patients (9 levels) undergoing XLIF was retrospectively analyzed. Three independent, blind raters using imaging analysis software performed volumetric measurements pre- and postoperatively to determine central canal and foraminal volumes. Intrarater and Interrater reliability tests were performed to assess the reliability of this novel volumetric method.**

■ RESULTS: **The interrater reliability between the three raters ranged from 0.800 to 0.952, $P < 0.0001$. The test-retest analysis on a randomly selected subset of three patients showed good to excellent internal reliability (range of 0.78—1.00) for all 3 raters. There was a significant increase in mean volume ≈20% for right foramen, left foramen, and central canal volumes postoperatively ($P = 0.0472$; $P = 0.0066$; $P = 0.0003$, respectively).**

■ CONCLUSIONS: **Here we demonstrate a new volumetric analysis technique that is feasible, reliable, and reproducible amongst independent raters for central canal and foraminal volumes in the lumbar spine using an intraoperative computed tomography scanner.**

INTRODUCTION

Magnetic resonance imaging (MRI) is considered the gold standard for assessing degenerative lumbar spinal stenosis (DLSS); however, there is little consensus regarding which radiologic factors are predictive of positive clinical outcomes in patients who have undergone indirect decompression. This in part is attributed to the lack of well-defined radiologic criteria for evaluating DLSS.[1-3] Although there have been studies that focus on qualitative/descriptive factors and the development of clinical algorithms for selecting appropriate candidates for extreme lateral interbody fusion (XLIF),[4-6] the current radiologic methods used to assess indirect decompression only include 2-dimensional (2D)

Key words
- XLIF
- Transpsoas surgery
- CT
- Minimally Invasive Surgical Procedures
- Neuronavigation
- Spine

Abbreviations and Acronyms
2D: 2-dimensional
3D: 3-dimensional
CT: Computed tomography
DLSS: Degenerative lumbar spinal stenosis
iCBCT: Cone-beam intraoperative computed tomography
iCT: Intraoperative computed tomography
MRI: Magnetic resonance imaging
ROI: Region of interest
XLIF: Extreme lateral interbody fusion

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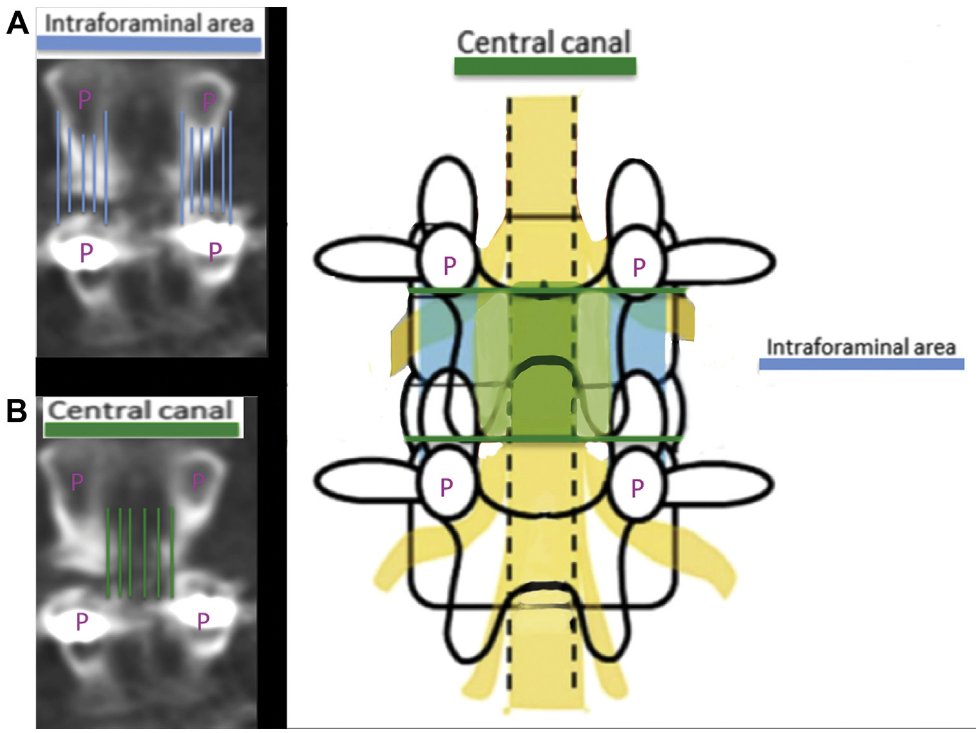

Figure 1. Illustration portraying the relevant regions in calculating pre- and postoperative volumes. The intraforaminal area is noted in relation to the superior and inferior pedicles, indicated in *blue* (**A**) and the central canal region indicated in *green* (**B**). Modified from Alimi et al.,[14] by permission of Oxford University Press.

parameters, such as disc height, foramen height/diameter, foramen cross-sectional area, central canal diameter, central canal cross-sectional area, or segmental coronal Cobb angle. None of these parameters adequately account for the role of soft tissue in indirect decompression surgeries.[7-11] In addition, there is no clear, determinable correlation or algorithm involving a 2D radiographical parameter that can aid in predicting surgical and clinical outcomes. For example, a systematic review completed by our group examined 1080 patients who underwent indirect decompression and demonstrated a ∼30% increase in foraminal height and ∼25% increase in canal area; however, no clear correlation was found between any of the radiographical parameters included in the study and XLIF clinical outcomes.[12]

Based on the data that an increase in virtually any 2D parameter correlates with successful XLIF outcomes, we have reason to believe that 2D parameters do not give a holistic representation of the anatomical changes occurring during XLIF and may in fact underestimate the real 3-dimensional (3D) anatomical changes that have occurred. Thus, it is logical to assume that a 3D volumetric analysis would provide a more accurate anatomical representation and has the potential to provide more accurate predictive criteria for patients undergoing XLIF. Volumetric analysis also may better elucidate correlations between radiographical findings and clinical outcomes in DLSS. More importantly, 2D measurements may hide the true effects of "ligamentotaxis" and decompression of neural elements inside of the central canal and foramen. In such cases where the effects of ligamentotaxis would require surgical correction, postoperative and follow-up measures would already be too late, and the patient already would have suffered the effects. This is why intraoperative radiographical analysis is important for indirect decompressive spine surgery.

Analysis tools for intraoperative computed tomography (iCT) scan images would aid the surgeon in analyzing the effectiveness of the operation pre- and postinstrumentation, during the operation, and allow the surgeon to take corrective measures in real time. Gates et al.[13] attempted to address this issue by analyzing pre- and postoperative T2-weighted MRIs of patients undergoing XLIF.[13] Although MRI offers better resolution for soft-tissue impact on lumbar stenosis, intraoperative MRI is impractical and not cost-effective for XLIF. Currently, no study has been able to use a fan-beam iCT scanner with high soft tissue resolution capacity to determine the intraoperative or postoperative 3D effects of XLIF on central canal or foraminal volumes.

The purpose of this study was to explore the capacity of a fan-beam iCT scanner to accurately and precisely measure central canal and foraminal volumes intraoperatively while accounting for the effects of surrounding soft tissue. Thus, the present study was not intended to compare iCT versus MRI soft-tissue capabilities. We conducted our study by addressing the following hypothesis: the measurement of 3D spine radiographic parameters by independent raters is possible, reliable, and repeatable in