Development of a Quantitative Method to Evaluate Lumbar Spinal Stenosis

INTRODUCTION
Lumbar spinal stenosis is defined as the narrowing of the spinal canal and foramina, which results in compression of the spinal cord and/or nerve roots. Each year more than 400,000 Americans suffer from lower back or leg pain caused by lumbar spinal stenosis. The three anatomic sites where stenosis can occur are the central canal, the lateral recess, and the neural foramen. Currently there is no standard procedure for diagnosing lumbar spinal stenosis and patients are diagnosed based on symptoms, physical examination, and/or imaging findings. Imaging techniques include plain X-ray, myelography, CT, and MRI imaging methods. MRI is often selected over CT scan due to its advantages with respect to differentiating between soft tissue and bony structures as well as no radiation exposure to the patient. However, diagnoses based on imaging findings are not specific to lumbar spinal stenosis and do not necessarily reflect clinical symptoms. Currently there are inconsistencies in the clinical evaluation of MRI and studies have shown low reliability and agreement when diagnosing mild, moderate, and severe stenosis. One of the potential reasons for the low reliability could be that the severity is based on the subjective review of 2D images. The objective of this study was to develop a quantitative evaluation technique using a volumetric approach to better assess the severity of lumbar spinal stenosis. The interested anatomical regions for analysis were the central canal, lateral recess, and the neural foramen.

METHODS
MRI exams from 30 patients were collected from an IRB approved, prospective clinical study on lumbar spinal stenosis. Each individual enrolled in the study was confirmed by clinical symptoms and by MRI evaluation to have either mild, moderate, or severe spinal stenosis at one or more lumbar levels. For development of the quantitative volumetric evaluation, all MRI exams were initially examined for image cut, quality, and quantity. Axial T2 weighted slices were used and analyzed because they provided the best visualization of the anatomical regions of interest. Model development, using Mimics software, of the images resulted in the establishment of criteria for volumetric analysis involving consistent slice thickness, slices parallel to the mid-plane of the intervertebral disc, and slices had to be contiguous from mid-pedicle to mid-pedicle. 12 out of 30 patient MRI exams met the criteria for one or more lumbar levels and consisted of 5 female and 7 male patients (average age of 65±9 years). The 12 exams produced a total of 28 intervertebral disc levels used for analysis: 2 from L1-2, 5 from L2-3, 7 from L3-4, 9 from L4-5, and 5 from L5-S1. For each level, masks were created marking the central canal, lateral recess, and the neural foramen. The central canal was defined as the area surrounded by the vertebra, disc, and medial to the medial border of the superior articular processes within the spinal canal. The lateral recess was defined as the region that is medial to the medial border of the pedicles and lateral to the medial border of the superior articular processes. Finally, the neural foramen was defined as the area below the pedicles where the nerve roots reside (medial border to lateral border of the pedicles). Volumes were determined for the three anatomical regions of interest. The radiologist report was used as part of the clinical information to determine the severity of stenosis. 8 discs were graded as normal (asymptomatic), 8 were mild, 6 were moderate and 6 were severe. An unpaired student T-test was performed to examine volumetric differences between normal and all stenotic grade levels. One-way ANOVAs were performed to examine regional volumetric differences between all grade levels.

RESULTS
The levels graded as normal increased in total anatomical volume moving distally in the lumbar spine. This was not necessarily the case for the stenotic levels (Fig. 1). The total anatomical volume of levels graded as normal were significantly greater than those graded as stenotic (p<0.05). Analysis of the volumetric differences based on the grade of stenosis and anatomic region is shown in Fig. 2. The volume of the central canal of mild and moderate grades was similar to the levels with a normal grade, but those levels graded as severe had 25% less volume compared to normal. Of the three anatomical regions, the volume of the lateral recess was consistent between the severity grades and approximately 15% less volume in comparison to the levels graded as normal. The data illustrated the neural foram as the most affected region with respect to change in volume in each of the three severity grades as compared to the normal levels (p<0.02). The percent of the neural foraminal volume in each of the severity grade (mild, moderate, severe) when compared to the normal levels was 66%, 62%, and 55%, respectively.

DISCUSSION
The quantitative volumetric measurement based on a clinical MRI exam was developed to provide a tool to objectively evaluate lumbar spinal stenosis. Established criteria have been developed as well as anatomical regional definitions to attempt to fully describe the complex 3D space. The results from this study represent a proof of concept of the technique. There was significantly less volume in stenotic compared to normal levels. In addition, the ability to provide more detail of quantitative changes to specific anatomical regions could lead better insight into clinical symptomology. In this group of patients, the neural foraminal volume was significantly less in each severity grade compared to normal. More work is necessary with respect to standardizing an MRI imaging protocol and validation of the volumetric technique. Future work will also need to establish a database of volumetric characteristics based on spinal level, age, race, and gender for the technique to have utility in correlating changes with clinical symptoms.

SIGNIFICANCE
The inconsistencies and variability in interpreting the MRI scans for lumbar spinal stenosis have been well documented in literature. This method may result in an innovative quantitative measurement technique that may be implemented as a tool in better diagnosing lumbar spinal stenosis and clinical outcomes.