SPINAL STRUCTURAL CANAL
MEASUREMENTS AND THEIR RELATIONSHIPS TO
PAIN, DISABILITY, AND PHYSICAL FUNCTION AMONG OLDER
ADULTS WITH AND WITHOUT CHRONIC LOW BACK PAIN

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Bachelors of Science in Exercise Science with Distinction

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ABSTRACT

In the United States, approximately 6 million older adults experience frequent low back pain (LBP) and 23% report suffering from LBP of moderate intensity. Among older adults, chronic LBP is associated with impaired physical function and is one of the most disabling chronic conditions. LBP may be accompanied by radicular symptoms, i.e. pain, numbness, tingling, and/or weakness, that radiates into the lower extremities. Clinical symptoms and spinal canal structural measurements (i.e. anteroposterior canal diameter (APCD), canal cross-sectional area (CCSA), and dural sac cross-sectional area (DSCSA)) have been used to diagnosis adults with chronic LBP, with and without leg pain, and to justify surgical interventions. Self-report measures assess a patient’s personal perception of function, while performance-based measures objectively assess a person’s ability to perform an activity. Thus, both types of measures are important in assessing a patient’s physical function and LBP-related disability. Among older adults with and without leg pain, there may be a relationship between the size of spinal canal structures, i.e. the spinal canal and the dural sac, and pain intensity, physical function, and disability. Relationships in the presence of LBP may differ from those found among older adults without LBP, while relationships found among older adults with chronic LBP + leg pain may differ from relationships found among older adults with chronic LBP only. Also located in the spinal canal is
epidural fat, which has been proposed to be protective due to its anatomical location. What remains unknown is how this epidural fat is related to pain, physical function, and disability among older adults with chronic LBP with and without leg pain. Similarly, it is possible that relationships found among epidural fat and pain, function, and disability, among older adults with chronic LBP may differ from older adults without LBP. The specific aims of this thesis are: (1) to establish inter-examiner measurement reliability for structural spinal canal measurements among older adults with chronic LBP, (2) to assess for differences in structural spinal canal measurements among older adults with chronic LBP, chronic LBP + leg pain, and without LBP, (3) to examine relationships among structural spinal canal measurements and pain, physical function, i.e. self-report and performance-based, and disability, among older adults with LBP, LBP + leg pain, and without LBP, and (4) to examine epidural fat and its relationships to pain, physical function, and disability, among older adults with chronic LBP, chronic LBP + leg pain, and without LBP. Findings indicate that spinal canal structural measurement can be reliably determined. Measurements proposed in previous studies, i.e. APCD, CCSA, and DSCSA were not significantly different among older adults with and without chronic LBP and were not different between older adults with LBP as compared to those without LBP. Ratio spinal canal measurements emerged as a means of distinguishing between older adults with chronic LBP (with or without leg pain) and without LBP. Further, ratio measurements were associated with pain, physical function, and disability (beyond covariates) among older adults with chronic LBP but not among those without LBP. Epidural fat helps to
explain LBP intensity, self-reported and performance-based physical function among older adults with chronic LBP without leg pain; greater epidural fat in those with lower LBP intensities and better physical function, supporting the theory that epidural fat may be protective. Future work is needed to evaluate these relationships longitudinally.
Chapter 1

RELIABILITY OF STRUCTURAL SPINAL CANAL MEASUREMENTS

1.1 Introduction

Low back pain (LBP) is a prevalent problem with 70-85% of people experiencing LBP in their lifetime [1]. In the United States, approximately 6 million older adults experience frequent LBP [2] and 23% report suffering from LBP of moderate intensity [3]. Amongst older adults, LBP has been associated with impaired physical function (e.g. difficulty with performing daily activities, functional limitations), [3,4] which may lead to a loss of independence [3]. LBP among older adults is not only debilitating, but it is costly; between 1991 and 2002 there was a 131.7% increase in the number of older adults with LBP and a concurrent 387.2% increase in LBP-related, Medicare healthcare charges [5].

Treatment options for LBP among older adults range from conservative management to surgical interventions. Conservative management options include medications (i.e. analgesics, non-steroidal anti-inflammatories), injections (e.g. epidural steroid injections, selective nerve root blocks), and physical rehabilitation [6]. Among older adults, the most common surgical procedures are those that address lumbar spinal stenosis, i.e. decompression with or without spinal fusion [7]. Surgical complications include nerve damage, dural tears, spinal fluid leak, and infection [7]. Given surgical costs [8] and potential complications [7], surgical management should be based on objective data that is associated with patient symptomology.
Currently, clinical symptoms and spinal canal structural measurements are used to justify surgical interventions [9]. Lumbar spinal stenosis is one of the most common chronic LBP conditions among older adults [10]. Patients typically complain of neurogenic claudication, which is defined as pain or discomfort that extends beyond the spinal region and into the gluteals and/or lower extremities [11]. Complaints of neurogenic claudication may lead to diagnostic testing, i.e. MRI, for assessment of the spinal canal [12]. Structural spinal measurements obtained from magnetic resonance images provide information regarding what space is or is not available for neural structures. Proposed measurements have included anteroposterior (AP) canal diameter, canal cross-sectional area (CSA), and dural sac CSA (Table 1.1) [13-16]. However, as shown in Table 1.1, there is no consensus as to what spinal canal measurement should be used to determine that the patient has “Lumbar Spinal Stenosis” and there is ambiguity regarding what value constitutes “lumbar spinal stenosis”. For example, among middle-aged adults, Hamanishi and colleagues defined lumbar spinal stenosis as $<$100 mm$^2$ using dural sac cross-sectional area (DSCSA) [15], while among older adults, others have defined stenosis as anteroposterior canal diameter (APCD) measurements of $<$15 mm [13].

Further, while structural canal measurements are being used to determine the degree of structural spinal stenosis and the need for surgical intervention, there are few studies that have evaluated reliability of structural spinal canal measurements, particularly in older adults (Table 1.2) [17-19]. Age-related changes, especially at lower lumbar levels [10], may affect measurement accuracy. Thus, it is important that
reliability studies be conducted in older adults if these measurements are going to be used to make surgical decisions in this patient population. Additionally, prior spinal structural measurement reliability studies have not reported standard error of measurements (SEMs). SEMs are based on standard deviations and reliability coefficients and provide the clinician with knowledge of measurement error [20]. SEMs may be important when making surgical decisions about individuals whose measurements are close to a given cut-point for structural spinal stenosis. For example, a 65 year-old patient with an AP canal diameter of 14.75 mm, which is just under the proposed cut-point by Fukusaki et al (i.e. < 15 mm) [13], may or may not have structural spinal stenosis, if the SEM is .50 mm.

Previous studies have assessed measurement reliability by averaging across disc levels (Table 1.2) [17-19]. We believe it may be important to establish reliability at each disc space among older adults, as certain levels may have greater measurement error due to age-related changes. For example, in the lumbar spine, level L4/5 is most likely to experience age-related, degenerative changes [10]. Degeneration may result in increased challenges when delineating anatomical structures, so it is possible that measurements at this space may have greater SEMs than adjacent levels.

Clinically, decompression with or without fusion for lumbar spinal stenosis is typically performed at a single level [21], so level-specific information may be more important than information averaged across multiple levels. The primary objective of this study was to establish inter-examiner measurement reliability for structural canal assessment for each disc space, i.e. levels L2/3 through L5/S1, among older adults.
with chronic LBP. We sought to determine if a novice examiner could attain adequate reliability. We hypothesized that that measurement reliability would be excellent for structural measurements at each disc level, but that reliability and thus, SEMs, would be improved by averaging across disc levels.

1.2 Methods

Participants. This was a secondary data analysis of the baseline MRI data from twenty, community-dwelling older adults, aged 60 to 85 years, who were randomly selected from a sample of 66 individuals who participated in a clinical trial from May 2009 through April of 2011. For inclusion, individuals had to have chronic low back pain (LBP), defined as LBP of at least 3 months duration, and pain of at least moderate intensity, i.e. ≥ 3/10. Participants were excluded if they had (1) a history of low back surgery; (2) had received LBP services in the past 6 months; (3) experienced a recent traumatic event; (4) a neurological disorder; or (5) a terminal illness. The Institutional Review Board for Human Subjects Research at the University of Delaware approved this study.

Data Collection. Participants completed the informed consent process. Participants underwent body anthropometric measurements, including height and weight for calculation of body mass index, and a safety screen with a technician before undergoing MRI. Individuals were placed in a standardized position in supine with a pillow under the knees. Images were obtained on a 1.5 Tesla scanner (Siemens
MAGNETOM, Erlangen, Germany) with a flexible spine coil. T1-weighted, spin-echo images were produced in the axial plane (repetition time/echo time=879/13ms; field of view=230mmX230mm; encoding matrix=480X640; phase encoding direction=anterior-to-posterior; bandwidth=180; flip angle=150 degrees; slice thickness=5mm with 1.5mm gap; acquisition time~8 minutes).

**Data Analysis.** Two examiners took measurements of canal cross-sectional area (CCSA), dural sac cross-sectional area (DSCSA), anteroposterior canal diameter (APCD), dural sac diameter (DSD), and epidural fat diameter (EFD) [See Figures 1.1 and 1.2]. Sagittal images were utilized to determine the axial image that best represented the disc space for levels L2/3 through L5/S1, resulting in 4 axial images per participant. At higher disc levels, if more than one axial image cut through the disc space, the examiner was instructed to choose the one that cut through the disc space best. Using ImageJ software (Bethesda, MD), diameter measurements were taken by drawing a line from the posterior to the anterior portion of the spinal canal structure, while cross-sectional area measurements were taken by tracing just inside the border of the targeted structure. The two examiners, one with post-doctoral training in MRI data acquisition and analysis, and the other with no prior MRI training, met for 30 minutes prior to data analysis to discuss and practice the measurement technique. Each examiner was blinded to measurements of the other examiner.

**Statistical Analysis.** Using IBM SPSS Statistics 23 (SPSS, Inc., Armonk, NY), after checking for parametric assumptions, means and standard deviations were calculated. Two-way intraclass correlation coefficient (ICC) with 95% confidence interval (CIs)
were calculated to estimate inter-examiner measurement reliability of assessments of a single slice, i.e. a single disc level (model 3,1), and assessments of the average of the 4 slices, i.e. the average across disc levels, (model 3,4). Based on proposed ICC cut-offs by Fleiss, ICCs ≥ 0.75 were considered excellent, ICCs of 0.40-0.75 were considered fair-to-good, and those <.40 were considered poor [22]. SEMs were calculated using the formula $SEM = SD \sqrt{1-r}$ where SD is the standard deviation and r is the reliability coefficient or the ICC value [23].

### 1.3 Results

Participant demographics are provided in Table 1.3. Sixty-five percent of the sample was female and average body mass index was 27.89±4.20 kg/m$^2$. Average LBP intensity was 3.72±1.71, with 55% of the sample have symptoms distal to the low back but proximal to the gluteal fold, and 45% of the sample having symptoms distal to the gluteal fold. Table 1.4 provides means and standard deviations for structural canal measurements as obtained at each disc level, ICCs and 95% CIs for inter-examiner measurement reliability (3,1), and SEMs. Inter-examiner measurement reliability ICC point estimates were excellent for all measurements (ICCs= .76 to .96) except for L2/3 APCD and L4/5 EFD, where reliability was fair-to-good, i.e. .67 and .63 respectively. The SEM was less than 15% of the mean for all measurements except for L4/5 and L5/S1 EFD, where SEMs were approximately 30% of the mean. Table 1.5 provides means and standard deviations for structural canal measurements
averaged across disc levels. ICC point estimates (ICCs=.93 to .97) for measurements averaged across disc levels were excellent (Table 1.5). The 95% CIs were excellent for measurements averaged across disc levels. SEMs for structural canal measurements averaged across disc levels were lower, indicating decreased measurement error when averaging across levels.

1.4 Discussion

To our knowledge, this is the most comprehensive study with respect to evaluating inter-examiner reliability for structural canal measurements, in older adults with LBP. This is the first study to report reliability of structural spinal canal measurements at each disc level, i.e. L2/3 to L5/S1, as opposed to averaging across levels. Both linear and CSA measurement techniques, using a single measurement, generally had excellent reliability (ICCs=.76 to .96), with the exception of L2/3 APCD (ICC=.67) and L4/5 EFD (ICC=.63), where reliability was fair-to-good. For L2/3 APCD assessment and L4/5 and L5/S1 EFD assessment, it may be more difficult to reliably determine differences that supersede measurement error, when compared to assessment of APCD at distal levels and EFD at proximal levels. However, overall it appears that examiners may reliably take single-level spinal structural measurements when assessing the appropriateness of a level-specific intervention. When averaged across disc levels, measurement reliability was improved (ICC=.93 to .97); SEMs were reduced. If a proposed intervention is not intended to target a specific level, structural
measurements averaged across disc levels may be an appropriate and more accurate means of assessing the size of spinal structures.

Lower inter-examiner measurement reliability for L2/3 APCD, may be explained by preservation of disc space at this level when compared to lower levels. The L2/3 disc level experiences less, age-related, degenerative changes as compared to lower disc levels [10]. When selecting the image that best represented the disc level, often there was more than 1 image to choose from, unlike other disc levels. This may have resulted in the examiners selecting different slices and thus, may have affected inter-examiner measurement reliability.

The L4/5 disc level is prone to age-related, degenerative changes, such as narrowing of the spinal canal [10]. Narrowing of the spinal canal, i.e. structural spinal stenosis, is associated with decreased epidural fat [11][24]. Among our older adults with chronic LBP, epidural fat, which helps protect the dural sac and spinal cord [24], was less at lower disc levels, i.e. L4/5 and L5/S1 when compared to higher levels, i.e. L2/3 and L3/4 (mean: 5.51 mm versus 3.75 mm). Age-related degenerative changes in spinal canal structure at L4/5, combined with reduced epidural fat, may make distinguishing small amounts of epidural fat from adjacent structures more challenging than at adjacent levels with less degeneration and greater epidural fat; this may help to explain the lower reliability point estimates and greater SEM for L4/5 EFD.

Like Lurie and colleagues [17,18], we took structural spinal canal measurements on axial images using Image J software. T1-weighted images were chosen over T2-weighted images, as T1 images more clearly show the dural sac,
epidural space, and epidural fat [12,25]. Lurie and colleagues reported ICCs from .58 to .97 for structural spinal canal measurements taken by radiologists, when measurements were averaged across disc levels (Table 2) [17-19]. In comparison, our inter-examiner ICCs for average measurements, i.e. 0.93 to 0.97, were higher, despite the use of a novice examiner. Thus, we believe that spinal canal structural measurements, can be reliably done with minimal training, even by a novice examiner.

**Study Limitations.** This study was a secondary data analysis of older adults with chronic LBP, an appropriate sample, given that these individuals may be assessed for lumbar spinal stenosis [9]. However, while we have provided data regarding symptomology, we do not know whether or not each participant had a clinical diagnosis of lumbar spinal stenosis. What is known is that greater than 50% of this sample had symptoms of neurogenic claudication, the hallmark symptom of spinal stenosis [11]. Based on proposed cut-points for structural lumbar spinal stenosis (Table 1.1) [13-16] and our mean values for APCD, CCSA, and DSCSA, our sample, as a whole, would not be considered structurally stenotic. Only 5% of our sample with symptoms of neurogenic claudication fell below the proposed cut-point for AP canal diameter of 15 mm [13], and none fell below the proposed cut-point of 13 mm or 12 mm [14,15]. Thus, while spinal structural measurements are reliable, it remains to be questioned whether such measurements are correlated to patient symptomology. A single 1.5 Tesla magnet was used for data acquisition. Reliability results may have been impacted by magnet strength, parameter selection, patient positioning, patient anthropometrics, or movement artifact. From a procedural standpoint, we did not use
standard equipment for measurements, i.e. examiner 1 used a computer monitor and mouse and examiner 2 used a laptop and touch pad.

1.5 Conclusions

Structural spinal canal measurements can be reliably determined from T1-weighted lumbar spine MRIs in older adults with chronic LBP. Examiners may take measurements at a specific region of interest, i.e. single disc level, or average across disc levels. Provided SEMs may assist with the interpretation of whether or not a given individual is truly stenotic when measurement values lie close to proposed cut-points. Spinal canal measurements require minimal training and may be taught to support staff. Future studies may explore relationships among spinal canal measurements and symptomology among older adults with chronic LBP.
### 1.6 Tables & Figures

Table 1.1: Definition of Lumbar Spinal Stenosis via Spinal Canal Measurements [13-16]

<table>
<thead>
<tr>
<th>Study</th>
<th>Structural Canal Measure</th>
<th>LSS definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fukusaki et al. 1999</td>
<td>AP Canal Diameter</td>
<td>&lt;15 mm</td>
</tr>
<tr>
<td>Geisser et al. 2007</td>
<td>AP Canal Diameter</td>
<td>&lt;13 mm</td>
</tr>
<tr>
<td>Koc et al. 2009</td>
<td>AP Canal Diameter</td>
<td>&lt;12 mm</td>
</tr>
<tr>
<td>Hamanishi et al. 1994</td>
<td>Dural Sac CSA</td>
<td>&lt;100 mm²</td>
</tr>
</tbody>
</table>

Abbreviations: SD = standard deviation; LSS = Lumbar Spinal Stenosis; AP = anteroposterior; CSA = cross-sectional area; mm = millimeters