Dynamic and Static Ultrasound Imaging of the Intervertebral Disc

Buckland, D.M.; Perez-Rossello J.M.; Lin, J.; Jamison IV, D.; Snyder, B.D.

Introduction:
Neck pain is one of the most pervasive problems in occupational health and is a common presenting complaint in physician offices, outpatient clinics and emergency rooms. Cervical spine disease, as a result of injury and/or degeneration results in pain, morbidity, disability and is associated with increased medical expenditures. Currently there are no protocols to assess the cervical spine of personnel operating in extreme work environments. Large equipment size and power requirements of computed tomography (CT) and Magnetic Resonance Imaging (MRI) limit the ability to evaluate the anatomy and dynamic motion of cervical spine intervertebral discs (IVD) in individuals working in extreme environments. The purpose of this study is to demonstrate that clinical ultrasound (US) can provide a portable imaging modality capable of quantifying IVD motion and be used to estimate the mechanical compliance of functional spinal units in response to applied loads.

Methods:
IVD height was measured ex-vivo both statically and dynamically.

Static Analysis: Twelve, fresh frozen, cadaveric, adult, ovine cervical spines (34 IVD) were thawed and held in the neutral anatomic position. The paracervical muscles and adipose tissue were retained, but trachea, esophagus, skin, and wool were removed. Each spine was imaged by CT (multi-detector helical), MRI (3T Magnet, T2 weighted images), and US using a 15 MHz linear transducer. The US transducer was positioned in the interval between the sternocleidomastoid muscle and the tracheal bed while sonically coupled to the spine using a hydrogel; the trajectory of the US pulse oriented toward the midline of the anterior cervical spine similar anatomically to the surgical approach to the anterior cervical spine. Two board certified radiologists measured the anterior IVD between consecutive vertebral bodies for each of the three imaging modalities. The measured IVD space heights were analyzed by a Generalized Linear Model (GLM) and post-hoc Tukey test to determine the affect of radiologist and imaging modality on the measured IVD height.

Dynamic Analysis: Five, fresh frozen, cadaveric, adult, human lumbar functional spinal units (FSU) were thawed, the posterior elements removed, the upper and lower vertebral bodies of each FSU potted in plastic and mounted in a mechanical testing machine (Instron, Norwood, MA). A 15 MHz linear transducer US probe was held 3-4 cm away from the lumbar FSU, sonically coupled to it using a hydrogel (standard clinical protocol). A series of 0.5 and 1.0mm compressive impulse displacements were sequentially applied over durations of 250, 600, and 1000 ms (4, 1.6, and 1Hz). Force-displacement data were collected from the the impact load cell in LVDT mounted along the load frame. The corresponding displacement of the IVD was measured from real-time US images by two independent readers. Displacement data measured by US and the LVDT were compared using a general linear model to determine the affect of impulse displacement magnitude and frequency.

Results:
Static Analysis: The measured IVD displacement was unaffected by observer or whether the probe was positioned from the left or right side of the neck. However the imaging modality did affect the measured IVD displacement (p<0.01); post-hoc analysis (Fig. 1) indicated that IVD heights measured by CT were on average 1.1 mm greater than those measured by MRI (p=0.09), and 0.9 mm less than those measured by US (p=0.04); IVD heights measured by MRI were 2.0 mm less than those measured by US (p<0.01).

Dynamic Analysis: There was no significant difference between IVD displacements measured by the LVDT and ultrasound probe (observed mean error of 0.3mm (range -0.5 - 1.1 mm)). The measured IVD displacement was unaffected by impulse magnitude or frequency.

Discussion:
This is the first study to demonstrate the ability of US to measure IVD height statically and dynamically. A perceived limitation of US is lack of repeatability, but our model did not show a significant difference between US measurements taken from the left or right side of the same IVD. Another limitation of US is the perceived dependence of the operator performing or interpreting the study. However we did not see any significant differences between radiologists or trained operators interpreting the US images. This study did not look at the dependence of the operator on the quality of the image acquisition. The statistical analysis revealed that the measured IVD height was dependent on the imaging modality used to make the measurement. Differences between IVD heights measured by each modality are most likely due to differences in the way that the disc space is imaged (e.g. the IVD height on CT is calculated as the distance between the superior and inferior bony endplate, whereas MRI and US measure the soft tissue of the disc directly). If CT is taken as the gold standard for IVD height, the difference of 0.9 mm for IVD height measured by US compared to CT while statistically significant may be clinically insignificant.

The dynamic study demonstrated that changes in IVD heights in response to applied impact loads typically applied during work place conditions could be measured accurately by US. While load frequency or displacement magnitude did not affect the measured change in IVD height, it can be assumed that as conditions approach the signal acquisition speed of 15 Hz or the resolution of the US system (~0.25mm), accuracy would be impaired. If the applied load is known, the dynamic change in IVD height measured by US can be used to calculate the global compliance of the FSU.

Discussion:
Based on the results of this study, we have conducted a small pilot study to establish the feasibility of using this technique in-vivo in humans. Real-time co-registration analysis revealed that many anatomic features visible on CT and MRI, such as disc bulges and separated vertebral endplates were visible on US. Our preliminary results reveal correlations between narrowed IVD spaces for cervical spines evaluated by both MRI and US. In-vivo measurement of the mechanical compliance of the C4–5 FSU determined by measuring changes in IVD height using real time US images in response to a 20lb uni-axial load applied to the head in compression and distraction demonstrated that the compliance of the FSU was decreased in older subjects compared to younger subjects. These results suggest that clinical US systems may provide a low cost, portable, and convenient method to assess the cervical IVD space anatomy in patients without the use of ionizing radiation and as a tool to evaluate the dynamic motion of the cervical spine during extreme work place conditions.