ABSTRACT INTRODUCTION:
Bulging of the intervertebral discs during normal motion of the spine has been proposed as a potential cause of pain through either compression of the spinal cord or impingement of exiting neural elements. Although past studies have characterized both normal and stenotic dimensions of the spinal canal and intervertebral foramen, no previous study has described the amount of disc occlusion of the spinal canal and intervertebral foramen that occurs under various dynamic loading conditions. The purpose of the current study was to quantitatively assess the percent occlusion of the spinal canal and intervertebral foramen by the intervertebral disc under different loading conditions. Previously obtained disc bulge measurements at the posterior and posterolateral points on the intervertebral disc were used to quantitatively evaluate occlusion of the spinal canal and intervertebral foramen by disc protrusion under various dynamic loading conditions.

METHODS:
Seven human lumbar spine specimens were CT scanned and imported into a DICOM image viewing software (eFilm Workstation, Merge Healthcare, Milwaukee, WI). Measurements of the diameters of the spinal canal and intervertebral foramen were taken using a re-oriented gantry angle parallel to the intervertebral disc. The sagittal canal diameter was defined as the distance between the posterior border of the mid-disc body and the junction of the margins of the laminae of the midline of the spinous process (Figure 1). The sagittal foraminal diameter was defined as the distance between the posterolateral intervertebral disc border (at the mid-disc level) and the border of the superior facet of the inferior vertebral body (Figure 2). In vitro intervertebral disc protrusion measurements were completed using a previously described method in which single FSUs were subjected to three separate load protocols in a spine test machine and disc bulge was recorded with an Optotrak Motion System (Optotrak Certus, Northern Digital Instruments, Waterloo, ON, Canada) that tracked active LEDs placed on the posterior and posterolateral aspects of the intervertebral disc. Occlusion of the spinal canal was defined as the percentage of encroachment into the spinal canal (sagittal canal diameter) by maximum measured disc bulge at the posterolateral point of the disc. Occlusion of the intervertebral foramen was defined as the percentage of encroachment into the intervertebral foramen (sagittal foraminal diameter) by maximum measured disc bulge at the posterolateral point of the disc. A repeated measures ANOVA test was used to compare the percent occlusion means among the different modes of loading for a particular region of the intervertebral disc. A least significant difference post-hoc test was used to determine which modes of load were statistically significant if a significance level was reached.

RESULTS:
The average sagittal canal diameter was 19mm ± 4. The average sagittal foraminal diameter was 5mm ± 2. Average spinal canal occlusion under 250 N axial load, ± 2.5 Nm flexion/extension, and ± 2.5 Nm lateral bend was 2.46% ± 1.86, 2.51% ± 1.02, and 1.49% ± 0.79 respectively. Maximal spinal canal occlusion was 6.75% (occurring under 250 N axial compression) and minimal spinal canal occlusion was 0.47% (occurring under ± 2.5 Nm flexion/extension). Average intervertebral foramen occlusion under 250 N axial load, ± 2.5 Nm flexion/extension, and ± 2.5 Nm lateral bend was 7.82% ± 4.72, 9.46% ± 5.68, and 11.28% ± 6.20 respectively. Maximal intervertebral foramen occlusion was 24.43% (occurring under ± 2.5 Nm lateral bend) and minimal intervertebral foramen occlusion was 2.06% (occurring under ± 2.5 Nm flexion/extension). At the posterior point of the disc, significant differences were detected only between ±2.5 Nm flexion/extension and ± 2.5 Nm lateral bend (p = 0.030). No significant differences were seen among other modes of loading at the posterior point of the disc. At the posterolateral site of the disc, significant differences were detected between 250 N axial compression and ± 2.5 Nm flexion/extension (p = 0.014). Significant differences were also detected between 250 N axial compression and ± 2.5 Nm lateral bend (p = 0.026). No significant differences were found between ± 2.5 Nm flexion/extension and ± 2.5 Nm lateral bend.

DISCUSSION:
The aim of the current study was to measure percent occlusion of the spinal canal and intervertebral foramen by disc bulge under different loading conditions. The spinal canal and intervertebral foramen diameters measured in this study correspond well to measurements from past studies. Maximal and overall occlusion percentage was greatest at the intervertebral foramen. These results support the conclusion from our previous study that disc bulge (and thus disc occlusion) for a given site on the intervertebral disc is dependent on magnitude of load, direction of applied load, and location on the intervertebral disc. Furthermore, the results of the current study support the proposal that exiting neural elements at the location of the intervertebral foramen are the most vulnerable to impingement and generation of pain.