Introduction
It has become common surgical practice to insert implants or bone graft between two vertebrae to provide stability following removal of diseased or damaged vertebral and/or intervertebral discs. One failure mode of these implants is subsidence or sinking of the implant into one or both adjacent vertebrae. A critical factor affecting subsidence is the strength of the vertebral endplate and underlying cancellous bone. Presumably, the structural characteristics of the endplate vary across its surface, but this has not been previously studied. Our objective is to determine the variation in failure load and stiffness across the human lumbar vertebral endplate and underlying cancellous bone.

Methods
Twelve endplates (6 superior and 6 inferior) from the lower lumbar spine (L3, L4, L5) were tested in this study. The x-ray appearance of all specimens indicated healthy discs and only two endplates had small osteophytes around the perimeter. The endplates were cleaned using a scalpel to remove cartilage and other soft tissue. Care was taken to ensure that the bony endplate was not damaged during the cleaning process. Indentation tests at standardised locations on the endplate were conducted using a custom-built material testing machine. An adjustable mounting device and a water level were used to ensure that the endplate was horizontal. To allow comparison across specimens, the tests were performed at grid sites defined by percentages of endplate dimensions. The anterior-posterior diameter (AP) and lateral diameter (LAT) were measured using Vernier calipers and were used to define the test sites. The AP diameter was defined to be in the mid-sagittal plane and the lateral diameter was defined to be perpendicular to the AP line, across the widest portion of the endplate. A perpendicular line bisecting the AP diameter was defined as 0% LAT (Figure 1). These two lines became the axes used to define the test sites. Tests were performed at the intersections of the lines shown in Figure 1. Each indentation site was a minimum of 6mm (centre-to-centre) from neighbouring indentation sites, and no indentation was made closer than 1.5mm to the edge of the endplate. Tests were performed by pressing a 3mm-diameter hemispherical indenter into the endplate at 0.2 mm/s to a depth of 3mm. Force and displacement were recorded at 20Hz. Damage was very localised and there was no visible interaction of indentation sites. The failure load was defined as the maximum load reached prior to a decrease in the force reading of more than 5%. The stiffness was defined as the slope of the load-displacement curve in the initial penetration (linear) region. The failure load and stiffness values for each indentation site were normalized with respect to the corresponding values at the endplate centre (i.e. AP = 0%, LAT = 0%). To compare these normalized forces and stiffnesses, a two-factor ANOVA design. Therefore, specific effects of the AP direction and LAT direction were tested, followed by a complete ANOVA within the shaded region shown in Figure 1. Post-hoc Student-Newman-Keuls tests were used for pairwise comparisons and a 95% significance level was assumed.

Results
For failure load, there were statistically significant differences across both the AP (p<.00001) and LAT (p<.007) directions. Pairwise comparisons found that the central endplate (LAT = 0%) had about 50% of the strength of the most lateral test sites (i.e. +/- 45% LAT). Further, the central endplate (AP = 0%) had about 70% of the strength of the most anterior test sites (i.e. 40% AP) and 50% of the strength of both of the posterior test regions (i.e. -20%, -40% AP). There was no interaction between the AP and LAT directions, as shown in Figure 2 (p=0.91). In this Figure, note that the curves all show that the posterior test sites (i.e. -40% AP) were strongest, as were the most lateral test sites (i.e. -30%, 30% LAT). Of interest, it was found that the average strength of the postero-lateral endplate (+/- 30% LAT, -40% AP) was over 4 times stronger than the central endplate (i.e. at the intersection of 0%AP, 0%LAT).

Discussion
It has long been postulated that the periphery of the vertebral endplate is stronger than the centre, but no supportive data have been published. This study clearly establishes that there is a significant difference in bone strength across the endplate, with the bone at the periphery being two to four times stronger than the bone in the middle of the endplate. Most interbody implants are placed in the centre of the vertebral endplate and the results of this study seem to indicate that subsidence would be resisted more effectively by placing implants closer to the periphery of the endplate. This study is limited in that it does not consider differences based on endplate (superior/inferior), spinal level, bone density, or disc condition. Ongoing research will look at the effects of these variables.

Acknowledgements: This study was supported by the George W. Bagby Research Foundation and NSERC. The technical assistance of Mr. Alston Bonamis is greatly appreciated.

Figure 1. Grid Pattern Showing the Locations of Indentation Tests on Each Endplate

Figure 2. Variation in Normalized Failure Load Across the Endplate Surface

This study was supported by the George W. Bagby Research Foundation and NSERC.