INTRODUCTION:
The intervertebral disc undergoes more extensive structural and compositional changes with age and degeneration than any other musculoskeletal tissue. The disc’s cartilaginous endplate (CEP), a thin layer of hyaline cartilage, provides a mechanical barrier and a nutritional conduit between the vertebral bone and the disc. With age and degeneration, the CEP becomes thinner, calcifies, and may have reduced porosity. It has thus been implied as a contributor to the degenerative cascade by limiting diffusion of nutrients into the disc [1-3].

Magnetic resonance imaging (MRI) is a non-invasive medical imaging technique that uses no ionizing radiation. MRI is known for its superior soft tissue contrast, which makes it advantageous for disc applications. MRI has been used to determine disc composition [4] and volume [5] and to classify the stage of degeneration through a number of grading systems [6, 7]. However, three-dimensional (3D) disc and CEP geometry have not been quantified using MRI. Limitations in spatial resolution, field strength, signal to noise ratio, and its dependence on tissue water (which makes distinguishing between soft tissue substructures difficult) have prevented these critical quantitative morphological measurements. Recently, we have utilized novel MRI methods with a 7T scanner for disc imaging [8]. The objective of this study was to quantify volumes and geometry of the disc and the CEP using high-resolution 3D MRI. In addition, we report novel observations of the MRI-appearance of the CEP microstructure, including its porosity.

METHODS:
Fresh frozen lumbar motion segments from human cadavers (age 42-78 yrs, n=5), were imaged on a 7T Siemens whole-body MRI scanner using a custom-made transmit/receive RF coil. Each sample was thawed, sealed in an air-tight storage bag, and then embedded in 2% agarose. Imaging: Two separate 3D FLASH sequences with short and long echo times (TE=3.7 and 20 ms) were used to achieve full volume coverage of the disc and visualization of the CEP. Each scan produced 200 μm isotropic voxel resolution with a total imaging time of ~24 min (6min for short TE, and 18min for long TE). The short TE sequence provided anatomical images for structural quantification of the disc and CEP based on a newly observed intensity difference between the CEP and disc (Fig.1A), while the long TE sequence (T2-weighted) provided visualization of structural features such as lamellae in the annulus (Fig.1B). The latter structures were confirmed by a much longer 3D turbo spin echo (TSE) image sequence. In addition, we report T1rho values for degenerate discs using a previously developed method [4].

Analysis: Disc and CEP were segmented manually; area and volume were calculated using OsiriX software. The volume of the entire disc included annulus, nucleus, and the CEP, and the volume of the CEP included both superior and inferior endplates. Disc and CEP cross-sectional areas were calculated from axial slices through the disc and through the superior and inferior CEP, the latter two averaged. Similarly, disc and CEP heights were calculated from a mid-sagittal section and superior and inferior CEP were averaged. Average geometry from the four moderately degenerate L4-L5 discs was calculated.

RESULTS:
Use of two flash sequences enabled quantification of several key disc features. The short TE image (Fig.1A) showed clear contrast between CEP (bright) and disc (see insert), while the long TE image (Fig.1B) provided structural features, such as annular lamellae. From the short TE 3D isotropic dataset, a segmented and volume rendered image (Fig.2) showed the boundaries between disc and CEP, from which volumes were calculated (Table 1). In a healthy disc, the CEP volume was 8.3% of the entire disc, while in the degenerate L4-L5 discs the average CEP volume was only 3.7% of the entire disc. The axial section of the average area of the degenerate L4-L5 CEP was 5.33 cm², which was 27.2% of the disc area (Table 1). Finally, from a mid-sagittal image, the L4-L5 CEP height was 0.11 cm, 9.9% of the disc height. In addition to quantifying CEP geometry, these images demonstrated CEP porosity (Fig.3). Furthermore, AF lamellar structures were confirmed by TSE images (Fig. 4).

DISCUSSION:
To the best of our knowledge, this study is the first to distinguish CEP from the disc by 3D MRI, showing detailed features of the CEP geometry, porosity, and AF lamellar structure. This will likely contribute to understanding of disc degeneration. While preliminary, and of small sample size, the results suggest CEP volume decreases with degeneration. This study also demonstrated the visualization of CEP pores with MRI. The pores of the avascular CEP (Fig.3) may indicate the proximity of capillaries. Future work will quantify the porosity of the CEP, and relate it to CEP mechanics. Furthermore, with the relatively short scan time of this method, in vivo application is feasible.

ACKNOWLEDGEMENT:
Funded by NIH grant R1C AR058450.