INTRODUCTION:
Blunt trauma to the ankle may produce unrecognised cartilage injury that progresses to post traumatic osteoarthritis. Unrecognised cartilage injury may also cause initiation of osteochondritis dissecans (OCD) lesions, particularly on the anterior-lateral and posterior-medial aspects of the talus.

Based on changes in articular cartilage seen in medical imagery e.g. MRI clinicians can draw conclusions on the stage and aetiology of cartilage lesions and disease. In this respect in vivo quantitative evaluation of articular cartilage is very important. Unfortunately, x-ray does not allow direct visualisation of articular cartilage and is therefore an insensitive technique, whilst arthroscopy is invasive and only allows a subjective examination of the cartilage deep to the surface layer.

Quantitative MRI of thin congruent cartilage layers has, to date, been challenging because of the trade of between maintaining an acceptable scan and signal to noise ratio whilst obtaining a sufficient resolution required for accurate quantitative measurements. As a result, only a limited number of studies have attempted to quantify ankle articular cartilage in vivo; unfortunately, none of these studies have included the highly curved, clinically relevant areas over the shoulders of the talus.

The specific aims of this study were 1) to quantitatively evaluate the articular cartilage of the entire talus including the malleolar facets and the highly curved regions over the talar shoulders by using MRI combined with an image denoising algorithm and a directional gradient vector flow (dGVF) snake segmentation algorithm. 2) To assess the precision (reproducibility) of this approach.

METHODS:
Eight fresh frozen human, male cadaveric lower leg and foot complex specimens were acquired from five cadavers. One male volunteer was also studied. Ethical approval was provided by the Human Usage Review Panel and the University of Virginia Human Investigations Committee.

A 1.5 T MRI scanner (Magneton Sonata, Siemens) was used with a circularly polarized transmit receive extremity coil. Images were acquired using an isotropic sagittal spoiled 3D gradient-echo sequence, fast low angle shot (FLASH), with selective water excitation. The resolution was 0.3 mm x 0.3 mm x 0.3 mm; the field of view was set at 160 mm (matrix 512 x 512 x 52 pixels). The image acquisition time was 17 mins 14 secs.

In a subset of 5 ankles 6 repeated data sets were acquired, with re-shimming of the magnet and repositioning of the specimen between image acquisitions.

All image data were then transferred and stored on a desktop workstation for post processing and segmentation. To make the post-processing more efficient the image volume is cropped to a smaller plane resolution of 0.15 mm x 0.15 mm. The final step, prior to segmentation, was to run a ‘denoising’ anisotropic diffusion algorithm and multi scale directional gradient vector flow (dGVF) snake segmentation algorithm.

RESULTS:
From the single measurements in eight cadaveric specimens and one volunteer the mean values ± S.D. were calculated. The mean talar cartilage thickness was 1.23 mm ± 0.11 mm; the mean maximum talar cartilage thickness was 2.48 ± 0.22 mm. When surface area was calculated the mean cartilage surface area was 21.56 ± 2.31 cm², by comparison the mean bone cartilage interface area was smaller 18.53 ± 2.02 cm² (p < 0.05). The mean cartilage volume was 2.23 ± 0.37 ml.

The precision of the technique was evaluated by calculating the coefficient of variation, CV% (min – max) from 6 repeated measurements in the subset of 5 ankles. Our approach showed good precision as the mean CV% for mean cartilage thickness was 3.44% (2.77 – 4.47%) for maximum thickness the CV% was slightly higher, 5.35% (4.12 – 7.14%). Cartilage surface area, bone cartilage interface area and volume also showed good precision with values of 3.577% (2.32 – 5.01%), 3.24% (1.48 – 4.90%) and 4.98% (2.57 – 7.54%), respectively.

Thickness distribution maps show a characteristic pattern in all of the tali evaluated; two distinct areas, anterior-laterally and posterior-medially, over the talar shoulders where the thickest cartilage was located. (Figure 1)

DISCUSSION:
In the few quantitative studies of ankle articular cartilage that have been reported the clinically relevant regions over the shoulders of the talus have been excluded. By using a high resolution isotropic cartilage sensitive MRI sequence combined with a denoising algorithm and a dGVF snake segmentation algorithm we have been able to calculate quantitative cartilage parameters for the entire talus including the highly curved regions.

The application of the anisotropic diffusion algorithm enhanced (denoised) the cartilage images without lose of detail and made the segmentation process easier and more efficient. Following denoising the dGVF snake algorithm produced robust semi-automated segmentation which was highly reproducible as confirmed by the low CV%’s seen in the repeated data sets. The reported CV% values are an improvement of previously reported values in the ankle and are in keeping with those reported for the knee joint which exhibits thicker and less congruent cartilage layers and therefore allows the most reproducible segmentation.

By examining the entire talus we have shown that the mean and maximum thicknesses, cartilage surface area, bone cartilage interface and volume for talar cartilage are greater than previously reported.

Most notably the 3D thickness distribution maps clearly demonstrate that the greatest cartilage thickness occurs over the highly curved regions of the talar shoulders and correspond to the clinically relevant area where talar cartilage lesions most commonly occur.

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Figure 1 shows a typical talar cartilage thickness distribution map, showing the thicker cartilage anterior-laterally and posterior-medically.