AUTOMATED SIMULTANEOUS 3D SEGMENTATION OF MULTIPLE CARTILAGE SURFACES USING OPTIMAL GRAPH SEARCHING ON MRI IMAGES

+*Millington, S A; **Li, K; ***Hurwitz, S R; ****Trattnig, S; *****Sonka, M
+*Technical University of Graz, Austria,
steven.millington@tugraz.at

INTRODUCTION:

Osteoarthritis and articular cartilage injuries are very common – one in six people in the USA are affected by some form of osteoarthritis. Articular cartilage injuries and early degenerative changes are difficult to diagnose using conventional x-ray; however, cartilage sensitive MRI sequences offer a powerful non-invasive tool for evaluating articular cartilage.

A variety of manual and 2D semi-automated image segmentation techniques have been developed and applied to articular cartilage images. Most commonly these techniques have been applied to the knee joint which has the thickest cartilage layers and does not have large congruent areas. There have been relatively few studies of thin congruent cartilage layer more typical of other joints in the body e.g. the hip and ankle. Quantitative in vivo studies performed in the ankle joint to date have been limited to the central tibial plafond and the central talar dome region and the regions of clinical interest over the talar shoulders have been excluded.

In this study we evaluate a novel fully automated 3D graph searching cartilage segmentation algorithm on images of thin congruent talus cartilage layers and compare quantitative measurements against two independent standards.

METHODS:

Eight fresh frozen human, male cadaveric ankle specimens were acquired from five cadavers. Ethical approval was provided by the Human Usage Review Panel and the University of Virginia Human Investigations Committee.

Each ankle was imaged at 1.5T with a circularly polarized transmit and receive extremity coil using an isotropic 3D T1 weighted FLASH sequence with water excitation. The image resolution was 0.3mm^3 and the scan time was 17mins 14secs. Images were interpolated to 0.15mm^3 and segmented using the automated 3D graph searching algorithm.

The segmentation method consists of 3 steps: firstly, a level set based algorithm for automated bone surface pre-segmentation is used which acts as an initialization; secondly the implicit surface is converted to an explicit triangulated mesh and optimized. Finally the mesh from the second step is used to initialize a graph in a narrow band around the pre-segmented bone surface, a multi-surface graph search algorithm is then used to simultaneously obtain the precise cartilage and bone surfaces.

Two independent standards were used for comparison; firstly 50 slices were randomly selected from the 8 MR volumes and manually segmented by an experienced operator. Both coronal and sagittal slices were selected and segmented in order to assess the inherently 3D automated segmentation against 2D manual segmentation. Once the automated and manual segmentations had been completed positioning errors of the automated segmentation compared to the manual segmentation were calculated for each slice. Secondly, following MRI each ankle was disarticulated and imaged using a previously reported high resolution stereophotography method; mean cartilage thickness and volume were measured for comparison to MR measurements. The stereophotography method briefly involves imaging the cartilage surface relative to fixed photo-target, dissolving the cartilage to reveal the subchondral bone surface and imaging the bone surface relative to the fixed photo targets. The two triangulated mesh surfaces are then combined using the common co-ordinate system (the photo-targets) and quantitative measurements made. The stereophotography system has a measurement noise (accuracy) of ± 1µm

To assess precision (reproducibility) of the automated segmentation we performed a second set of experiments in which a further 5 independent initializations of the automated segmentation algorithm were performed on each of the 8 image sets varying the position and size of the initializing spheres for each initialization. The mean difference ± S.D. of cartilage thickness compared to the first automated segmentation in each of the eight ankles was calculated

RESULTS:

The average automated 3D computation time was 4mins 30secs. The mean talar cartilage thickness from automated segmentation was 1.16 ± 0.1mm. The mean talar cartilage thickness from stereophotography measurements was 1.21 ± 0.17mm. Mean talar cartilage volume from automated segmentation was 2.61 ± 0.34ml and the mean cartilage volume from stereophotography measurements was 2.62 ± 0.49ml. There was no statistical difference in mean thickness or cartilage volume between the automated segmentation measurements and the stereophotography measurements.

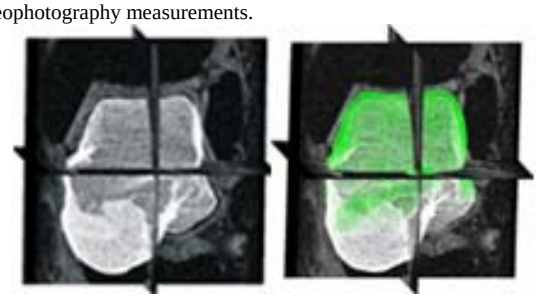

Figure 1 shows an example of the subchondral bone surface (left, white) and the cartilage surface (right, green) meshes generated by the automated 3D segmentation.

The root mean square (RMS) surface positioning errors of the automated computer segmentation compared to expert manual segmentation showed sub-voxel accuracy and were 0.03 ± 0.01mm and 0.04 ± 0.01mm for the bone and cartilage surfaces, respectively.

From the reproducibility experiments reproducibility plots of the signed differences for mean and maximal thickness between the individual measurement and the average measurement were generated, figure 2. The mean signed difference for mean thickness and maximum thickness compared to the original automated segmentation were 0.001 ± 0.06 mm and -0.017 ± 0.11 mm, respectively.

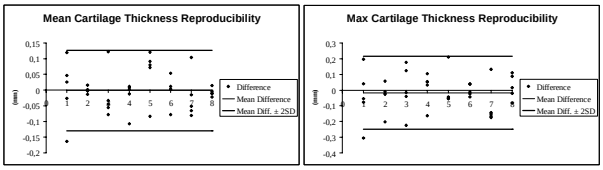

Figure 2 Reproducibility plots of cartilage thickness. The x axis shows the specimen number

DISCUSSION:

The reported automated 3D graph search segmentation algorithm has achieved highly accurate, simultaneous, rapid, automated segmentation of talar cartilage and subchondral bone surfaces in their entirety including clinically relevant regions. The results obtained using the automated algorithm compare favourably to both the stereophotographic measurements and the manual segmentation results. The reproducibility plots from the reproducibility experiments clearly show that the repeated measurements were unbiased and reproducible.

A variety of 2D manual and semi-automated techniques have been previously utilized to segment articular cartilage images; however these suffer from a number of limitations; often being labor intensive requiring an accurate initialization and being prone to subjective judgment. The novel approach reported in this study addresses a number of the existing challenges associated with traditional techniques which are not suitable for fast automated segmentation of cartilage sensitive MR images. Furthermore, we have shown that robust segmentation can be performed on thin, highly curved, congruent cartilage layers, which other had previously felt lack sufficient definition for segmentation.

Preliminary results are very encouraging and with further development the new technique has considerable potential for future use in a clinical setting and large clinical trials and can be easily applied to other joints of interest e.g. the knee.

AFFILIATED INSTITUTIONS OF CO-AUTHORS:

** Carnegie Mellon University, PA, USA, *** University of Virginia, VA, USA, **** Medical University of Vienna, Austria, ***** The University of Iowa, IA, USA