AN EVALUATION OF MRI SEGMENTATION FOR KNEE ARTICULAR CARTILAGE

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INTRODUCTION
Osteoarthritis (OA) is a progressive degenerative disease resulting from a disruption in equilibrium between the repair and damage of joint tissues. Typically characterized by cartilage breakdown, bone remodeling, reduction in joint space, and inflammation, approximately 10-12% of the adult population displays symptoms of OA. This number is expected to double by 2020 [1]. As the knee is one of the most frequently injured or damaged components of the human motion system, it is the joint most commonly affected by OA [2].

New medications and treatments for OA benefit from methods of diagnosis that reflect the disease’s progression. Examination via radiography only provides an indirect measurement of cartilage loss and does not include damage to other soft tissues such as the menisci [3]. Hence, the ability to examine the articular cartilage of the knee directly provides a much more accurate platform for evaluation.

One potential method is the generation of a cartilage computer model via segmentation of images from magnetic resonance imaging (MRI). Segmentation is defined as the outlining of a desired structure in space in order to identify which pixels or voxels belong to the object [4]. This assignment will allow for the calculation of cartilage volume, thickness, and surface area – all relevant statistics when determining the extent and rate of progression of OA within a patient [3].

There is currently a large amount of ongoing research into MRI segmentation. Brem et al demonstrated that using segmentation to create computer models of articular cartilage was reproducible and accurate. However, this was an inter-user test-retest evaluation of MRI segmentation. Currently, limited information is available concerning the accuracy of MRI segmentation when compared to actual articular cartilage [3].

OBJECTIVE
The objective of this project is to evaluate the accuracy of a semi-automated, voxel intensity-based method of MRI segmentation by comparing the cartilage thickness of laser scanned models of cadaveric articular cartilage to that of models generated by MRI.

SUCCESS CRITERIA
A high level of accuracy for the semi-automated, voxel intensity-based method of MRI segmentation will be achieved if there is a less than 10% thickness difference between the cadaveric articular cartilage and the segmented cartilage models over the examined regions.

MATERIALS AND METHODS
Three cadaveric knees were evaluated over the course of this study. Each knee was allowed to completely defrost before three reference spheres filled with fiducial fluid were placed in each bone. A sagittal 3T MRI DESS scan with a voxel size of 0.44 mm was performed. The knees were then dissected by an orthopaedic surgeon such that only the bone, articular cartilage, and reference spheres remained. These were laser scanned using a FaroArm scanner (50 μm resolution). After a chemical bath removed the cartilage, the subchondral bone and spheres were scanned again.

The MRI scans were imported into the medical image processing software Mimics and segmented using a semi-automated, voxel based method known as LiveWire. A triangular mesh 3D model of each bone, piece of cartilage and set of reference spheres was generated. Anatomical landmarks were placed on each bone according to laboratory standards. These markers were then copied onto the MRI cartilage models.

The laser scanned models of cartilage, and the subchondral bone were refined using the 3D image processing software Geomagic. The two models were combined into one triangular mesh to represent each bone’s articular cartilage. To allow for accurate analysis of the same regions of cartilage, the MRI model coordinate system was applied to the laser scan data by aligning the reference spheres visible in each data collection method. There was an RMS error of 0.39 mm during the alignment of the MRI and laser scanned reference spheres.

Thickness of the cartilage models was evaluated by projecting distance vectors from each triangle on the cartilage-bone boundary of the mesh to the other side of the model. These vectors were sent vertically in the tibia, and radially in the femur as the cartilage models were approximated as a plane and cylinder respectively. Due to the propensity toward higher levels of error while determining cartilage thickness due to the curvature of the femur, only the tibial articular cartilage underwent initial analysis [5]. The average thickness was evaluated in both the medial and lateral compartments of the tibia over the subcompartments defined in Figure 1.

Average percent difference in cartilage thickness over each subcompartment was calculated with respect to the thickness of the laser scanned cartilage. The average difference in cartilage thickness over subcompartments 1–3 was also calculated as these subcompartments encompass the complete area of the tibial plateau examined in each compartment.
RESULTS

The average percent difference in cartilage thickness over the five regions defined was calculated in both the lateral and medial compartments of the three tibias. In both compartments, the MRI cartilage model was consistently thinner than that of the laser scanned data, hence resulting in negative percent difference values. This is observable in Figure 2 where the subcompartments are as follows - 1: Medial, 2: Central, 3: Lateral, 4: Anterior, 5: Posterior.

A large amount of error is visible in Figure 2. In particular, the medial subcompartment of the lateral compartment experienced a 95% range in average percent difference over the samples calculated. The average difference in cartilage thickness between the laser scanned model and the MRI model in subcompartments 1-3 is -0.36±.03 mm medially and -0.29±.07 mm laterally.

DISCUSSION

Accurate MRI cartilage segmentation was defined to differ from laser scanned cartilage thickness by no more than 10%. This criterion was achieved in the lateral compartment of the tibia. However, all subcompartments of the medial compartment had a greater than 10% average percent difference between the models. In both compartments, the MRI cartilage thicknesses were less than those of the laser scan. This discrepancy points toward an under-segmentation trend when generating the MRI models.

It is important to note the large error present in both compartments of the tibia. While the average percent difference was reasonably close to the desired threshold, the individual values varied greatly as evidenced by the 95% spread present in the medial subcompartment of the lateral compartment. Ultimately, a larger sample size will be necessary to conclude whether MRI segmentation was accurate within the success criteria given.

In subcompartments 1-3, the average difference in cartilage thickness was under 0.40 mm in both the medial and lateral compartments. As the voxel size of the 3T MRI scan utilized was 0.44 mm, this average difference was less than one voxel in both compartments. However, due to the high amount of variance in the cartilage thickness measurements, the average difference calculated here may not be representative of the true discrepancy in thickness from MRI segmentation.

There were multiple sources of error for this research study. The alignment of the reference spheres had a RMS error of 0.39 mm across all bones. This change in alignment could directly impact the cartilage thickness measured. In addition, the masks were smoothed in order to reduce time necessary for calculations. Ultimately, an evaluation of this smoothing error and a larger sample size will be necessary to determine the whether this method of MRI segmentation will be accurate enough to provide useful information about the presence of OA.

CONCLUSION

While the average percent difference in cartilage thickness for the medial and lateral compartments were in the proximity of, or below the defined threshold for success, the high amount of variance present makes this evaluation inconclusive. An expanded sample size and refinement of the MRI segmentation process would be necessary to increase accuracy of articular cartilage computer modeling. With enough improvement, the creation of 3D models form MRI could prove highly useful for the diagnosis and tracking of OA disease progression.

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REFERENCES