MEASUREMENT OF ACETABULAR CARTILAGE THICKNESS WITH CT ARTHROGRAPHY: ACCURACY OF THREE-DIMENSIONAL RECONSTRUCTIONS

INTRODUCTION: Noninvasive or minimally-invasive techniques that allow accurate reproduction of acellular cartilage thickness in vivo could assist with surgical planning for osteoarthritis or allow precise quantification of cartilage loss for longitudinal studies, and provide guidelines for interpreting biomechanical models. Current techniques to estimate cartilage thickness in vivo use 3D reconstructions from CT or MR images. CT arthrography has been shown to have superior accuracy for measuring cartilage thickness in the ankle [1], but its accuracy for imaging hip cartilage has not been evaluated. Due to its high resolution geometry, imaging of cartilage with CT may be prone to error due to volumetric averaging (i.e. staircase artifact). Computational methods employed to date use custom algorithms and software to estimate thickness, which are not readily available for direct clinical application. The purpose of this study was to assess the accuracy of hip joint cartilage thickness estimated from reconstructions made by segmentation of CT arthrography data using commercial software.

METHODS: Four fresh-frozen cadaver articulated hips were dissected free of musculoskeletal tissues, leaving the cartilage, labrum and hip joint capsule intact. The hips were disarticulated and four 1.5 mm holes were drilled [1] into four quadrants of the acetabulum (Fig. 1). The arthroscopy was repaired and the articular hip specimens were injected with 20ml of Omnipaque™ solution using a 21-gauge needle. Specimens were CT scanned in neutral anatomical position (anterior superior iliac spine in line with pubis symphysis joint) using a Siemens SOMATOM® Emotion CT Scanner. Parameters for CT scans were: 130 kVp, 160 mm FOV, 512 x 512 acquisition matrix, 1.5 second gantry rotation, pitch 1.5, slice thickness 0.75 mm. Osteochondral plugs were harvested around each drill hole as described previously [1]. Cores were bisected longitudinally and placed on a microscopic stage with an optical measuring grid overlaying the bisected edge of the cartilage sample. A digital microscopic image was acquired at a magnification of 40X. Following calibration, thickness measurements from each side of the drill hole were taken and the average of these values was determined for each hole.

CT data were transferred to a PC for segmentation using Mimics 10.1. A baseline threshold mask was defined using pixel intensities previously shown to result in accurate reconstructions of bone and cartilage [2]. Next, separate splines were created for acellular articular cartilage and subchondral bone by manually segmenting bone and cartilage from the baseline mask. Segmentation was repeated by the first author (time lapse of 6 months) to determine intraobserver reliability and was also performed by the senior author to assess interobserver reliability.

Polyhedral surfaces of the outer layers of the articular cartilage and subchondral bone were created using Mimics 10.1 and analyzed for cartilage thickness using a validated algorithm [2]. Values of cartilage thickness for ~20 nodes along the circumference of each hole on the reconstructed surface were averaged to determine CT estimated cartilage thickness. A Bland Altman plot [4], including 95% confidence intervals [5], was generated to quantify agreement between CT based estimates of cartilage thickness and physical measurements and included both segmentation trials made by the first author. Linear regression was also performed to establish a relationship between experimental and CT measures of cartilage thickness. Inter and intraobserver repeatability was assessed using the coefficient of variation, intraclass correlation coefficient, repeatability coefficient, and percent variability using SPSS.

RESULTS: Cartilage thickness for the four acetabuli ranged from 1.13-3.49 mm as measured experimentally and 1.06-4.03 mm as measured by CT (both observers). A fringe plot of reconstructed cartilage (Fig. 1) demonstrated thickness values ranging from 0.5-4.2 mm, where thicker cartilage was predominately located at the proximal roof with thinner cartilage at the posterior lunar surface.

Analysis of the Bland Altman plot (Fig. 2) demonstrated that cartilage was reconstructed to a bias = -0.125 mm and repeatability coefficient (1.96 X the standard deviation of the differences between experimental and CT) of ±0.46 mm. Regression of the difference (Experimental – CT) to the average ((Experimental + CT)/2) yielded a significant (p<0.001) negative relationship (Difference = -0.26 – 0.21 x Mean, R²=0.22), indicating that there was tendency for CT to overestimate thick cartilage and underestimate thin cartilage. Only four datapoints were outside the 95% confidence interval, which was approximately 0.8 mm wide (Fig. 2). Regression of experimental measurements vs. CT (both trials for first author) yielded a significant (p<0.001) relationship (Experimental = 0.35 + 0.76 x CT, R²=0.85).

The intra and interobserver repeatabilities of cartilage thickness as estimated from surfaces reconstructed from CT data were excellent. For intraobserver correlation the coefficient of variation was 14.8%, the intraclass correlation coefficient was 0.88, the repeatability coefficient was 0.55 mm, and the percent variability was 11.77%. For interobserver correlation the coefficient of variation was 13.47%, the intraclass correlation coefficient was 0.90, the repeatability coefficient was 0.52 mm, and the percent variability was 11.63%.

DISCUSSION: The results of this study demonstrate that cartilage thickness can be estimated to ±0.5 mm of the true value with 95% confidence when CT arthrography image data are reconstructed using commercial segmentation software. Excellent intra and interobserver agreement suggest hip joint cartilage thickness can be estimated by a clinician or basic science researcher with equal results.

Although manual segmentation could compromise the accuracy of the 3D reconstruction, the pixel resolution used in this study (0.3125 mm) was similar to the error (±0.46 mm); therefore, it is unlikely that a purely automatic segmentation technique would substantially improve the accuracy. Furthermore, the R² value in the present study (0.85), based on manual segmentation, was in excellent agreement with a similar study (R²=0.81) [1] that used an arguably more controlled technique and custom visualization software to measure ankle cartilage thickness based on CT arthrography images. Assuming that an accuracy of ±0.5 mm is sufficient, it can be concluded that reconstruction of cartilage geometry from CT arthrography data could be used as a pre-operative surgical planning tool for osteochondroplasty candidates. Although invasive with regards to injection of dye and ionizing radiation, CT arthrography may be superior to MRI in instances where accurate reconstructions of both bone and cartilage are required (i.e. biomechanical models [3]). A thorough understanding of the complex morphology of the normal hip and the variation present in pathologic states is critical for the development of improved techniques for joint-preserving surgeries. The ability to assess acellular cartilage thickness and distribution with CT arthrography may facilitate the development of new and patient-specific interventions for conditions such as femoroacetabular impingement, hip dysplasia, and traumatic lesions of the acetabulum.

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