INTRODUCTION: Accurate measurement of joint cartilage thickness can assist preoperative surgical planning, precise quantification of cartilage loss atlas to osteoarthritis, and provide guidelines for interpreting the results of biomechanical models. Estimates of cartilage thickness determined via MRI image data are often validated by direct comparison with CT arthrography results, which may erroneously imply that CT is the “gold standard” for assessing cartilage thickness. The objectives of this study were to quantify the accuracy and detection limits of MDCT arthrography for measurement of cartilage thickness and to determine the effect of contrast agent concentration, joint spacing, spatial resolution, and tube current on the accuracy of the measurements.

METHODS: An imaging phantom was designed and manufactured to quantify the error in reconstructing cartilage thickness. The phantom consisted of 9 chambers, each having a central nylon cylinder encased by sleeves of aluminum and polycarbonate to represent trabecular bone, cortical bone, and cartilage, respectively (Fig. 1). The aluminum rings were machined to a constant thickness of 1.0 mm. An outer polycarbonate ring with spacers was inserted around the cartilage sleeve to provide a “joint space” that could be filled with fluid. Cartilage thickness values of 0.25, 0.50, 0.75, 1.00, 2.00, and 4.00 mm were used with a constant joint space of 2.00 mm in six compartments. A varying joint space (0.25, 0.50, and 1.00 mm) with constant cartilage thickness (2.00 mm) was used in the remaining compartments.

CT scans of the phantom were performed with a Siemens SOMATOM® Sensation 64 CT Scanner. Constant parameters were: 120 kVp, 512 x 512 matrix, 300 mm FOV, and 1 mm slice thickness. Six fluid scans and four dry scans were performed. Contrast agent (Omnipaque 350 mgI/ML, GE Healthcare) was mixed with 1% lidocaine (Hospira Inc.) in concentrations of 25, 50, and 75%. A tube current of 200 mAs was used for each of the three concentrations (n = 3 scans) in the “transverse” plane (Fig. 1). Additional transverse scans were conducted at 150 and 250 mAs using the phantom filled with 50% contrast agent (n = 2 scans). One scan with tube current of 200 mAs was performed with 50% contrast agent parallel to the phantom chambers “longitudinal” axes (Fig. 1) to intentionally introduce volumetric averaged scans were also conducted without fluid to assess reconstruction accuracy for disarticulated cadaveric joints. Dry scans were performed in the transverse plane using tube currents of 150, 200, and 250 mAs (n = 3 scans) and in the longitudinal plane at 200 mAs.

Image data were re-sampled at 0.5 mm slice intervals for the longitudinal scans to assess differences in accuracy between an anisotropic spatial resolution (0.586 x 1.0 x 0.586 mm) and a near isotropic resolution (0.586 x 0.586 x 0.5 mm). Contours representing the outer surfaces of cortical bone and cartilage were extracted from the image data using automatic threshold software (Amira 4.0, Mercury Computer Systems). The contours were triangulated into surfaces using the Marching Cubes algorithm and thickness was determined using the Marching Cubes algorithm and thickness was determined using a published algorithm [1]. The root mean squared (RMS) and mean residual (MR) errors were calculated to assess the overall accuracy and directional error (over- or underestimation).

RESULTS: Wet Scans. RMS errors in the transverse direction grew as cartilage thickness was decreased and as the contrast agent concentration was increased (Fig. 2, left). An increase in contrast agent concentration resulted in a greater tendency for cartilage thickness to be underestimated (Fig. 2, right). Points where RMS error decreased (between 1.0 and 0.75 mm) aligned well with corresponding points of inflection on the MR error plot (Fig. 2, right). The anisotropic longitudinal reconstructions at 50% concentration produced RMS errors greater than the corresponding transverse and near-isotropic longitudinal dataset for cartilage thicker than 1.0 mm (Fig. 3, left). Increasing the contrast agent concentration over the range of joint spacing studied resulted in greater RMS errors (Fig. 3, right). Altering the tube current had little effect on the reconstruction accuracy for all wet scans (data not shown).

DISCUSSION: The thickness of simulated cartilage in the phantom was accurately measured (< 10% error) using MDCT when the true thickness exceeded 1.0 mm with (25% concentration) or without contrast agent. Nylon, polycarbonate and aluminum were chosen for the phantom because their x-ray attenuation values are similar to trabecular bone, cartilage and cortical bone, respectively [2-4]. However, the phantom materials were homogeneous with a well defined boundary between materials. Thus, when interpreting the results of this study in the context of clinical measurements of cartilage thickness with MDCT arthrography, the estimates of accuracy should be considered a best case. Despite this issue, phantom studies eliminate confounding factors such as geometry, tissue homogeneity, and measurement technique, which reduces the amount of unknown error and clarifies the influence of physical and imaging parameters of interest.

The following clinical recommendations can be made: 1) a low concentration of contrast agent should be used during CT arthrography, 2) joint space should be maximized prior to scanning (at least 0.5 mm), 3) CT slice thickness should be chosen to achieve isotropic or near-isotropic spatial resolutions, and 4) use of exposure modulation (altering tube current) should not affect the accuracy of cartilage reconstruction.

ACKNOWLEDGMENTS: Orthopedic Research and Education Foundation Research Grant.


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