SEMI-AUTOMATION OF KNEE CARTILAGE THICKNESS ESTIMATION IN MAGNETIC RESONANCE IMAGES WITH METAL ARTEFACT

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Background

- Accurately quantitating articular cartilage change over time is desirable in 'at risk' cohorts for osteoarthritis, such as those with destabilising knee joint injury.
- Previous published works on automated methods for cartilage thickness estimation have described validation studies using images of near-perfect quality.
- The presence of MR artefact from metal implants in the bone can greatly complicate reliable segmentation of cartilage from the images and is therefore not generally accepted by conventional cartilage quantitation techniques.
- As part of the Knee Injury Cohort at the Kennedy (KICK) study, consenting individuals with recent knee injury undergo prospective 3T MR imaging of both knees at baseline (within 3 months of injury), 2 years and 5 years.
- Around 60% of these individuals have metalware in the index knee from Anterior Cruciate Ligament (ACL) reconstruction at baseline. It is therefore essential that the cartilage quantitation methods to be used in this cohort are valid in the presence of such metal artefact.
- We present preliminary data ascertaining the reliability and accuracy of our in-house software KneeSeg2[1] (an updated version of that previously published by Cashman et al.) in measuring cartilage thickness from images affected by severe metal artefact.

Method

A. Metal-containing phantom

- A phantom imitating knee geometry was designed as two Perspex cylinders filled with bone and cartilage mimicking gels and perspex rods positioned on the outer cylinder surface, providing angular landmarks every 30° for measuring cartilage thickness (Figure 1A).
- A titanium surgical screw was added to generate metal artefact in the images (Figure 1B).
- Images of the phantom and 6 volunteers were acquired on a Siemens 3T Magnetom Verio MR scanner with an 8 channel knee coil using a Double Echo Steady State (DESS) sequence[2].
- Semi- automated and manual cartilage thickness measurements were carried out offline using KneeSeg2 and Siemens Magnetom Verio Syngo MR B17 software respectively.

B. Metal-containing human knees

- The KICK study 3T MRI protocol, which is an Osteoarthritis Initiative like protocol including a DESS sequence used for cartilage quantitation, was carried out in KICK participants.
- 6 KICK participants' baseline MRI data sets were selected for further analysis which contained metal artefact in the index knees in all cases (2 titanium screws).
- Semi-automated measurements on femoral cartilage of these index knees were carried out using KneeSeg2 and re-analysed after 2 weeks by the same operator to test for intra-operator reproducibility.

Segmentation Steps

- Median filtering is applied to remove noise.
- Convolving with a Sobel kernel produces a gradient magnitude image which is then thresholded to produce a binary image of the bone, cartilage and artefact edges.
- Metal artefact within the bone is removed using the bone artefact mask (BAM), an adaptive contour manually preset by the user, which surrounds and nulls the metal artefact but does not impinge on the bone-cartilage boundary (Figure 1D).
- Conventional closing and dilation of the binary bone region produces a shell which is used as a mask to pre-segment the cartilage from the original image (Figures 1C and E).
- The final segmented cartilage thickness is computed by searching outwards from a search origin positioned in the centre of the bone until the inner cartilage boundary is reached, and then proceeding in a direction normal to the bone-cartilage interface until the outer cartilage boundary is reached.
- This procedure is repeated automatically for all slices in the volume and a cartilage thickness map is generated using cylindrical projection. The BAM shape adapts itself from each slice to the next.

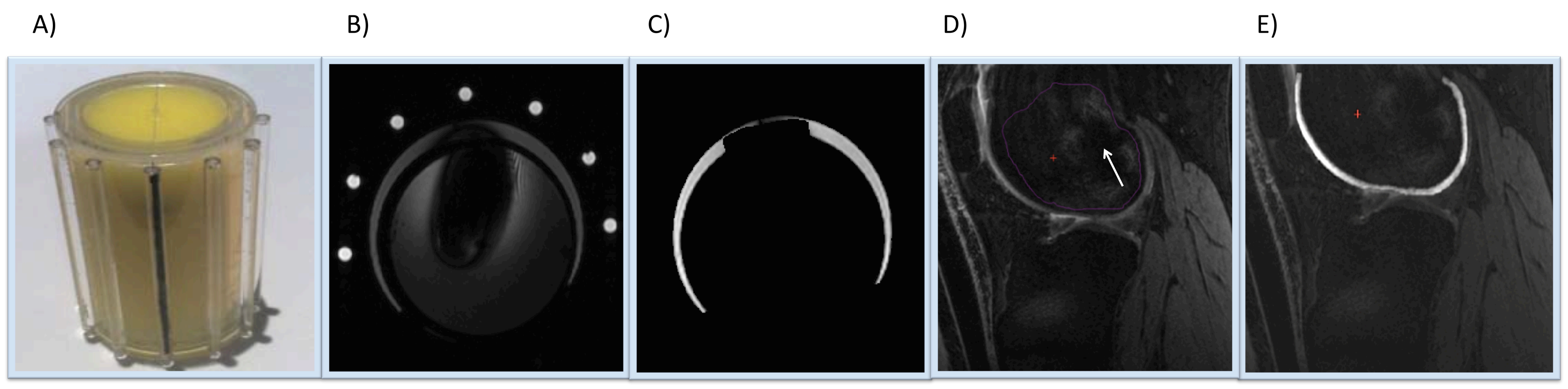

Figure 1: A) Cylindrical phantom simulating knee geometry. Inner cylinder is eccentric to provide a smooth variation of cartilage thickness with angle. B) Image of the phantom showing metal artefact within the bone and impinging on the cartilage; also the seven angular markers provided for precise location of the cartilage measurements. C) Segmented phantom cartilage obtained using the KneeSeg2 software. D) Sagittal image from one of the baseline subjects, with severe metal artefact (white arrow) within the trabecular femoral bone. The bone artefact mask is the purple contour surrounding the artefact. E) Segmented femoral cartilage produced from our semi-automated software, overlaid onto the original sagittal image. The radial angles for thickness measurements are relative to the search origin (red crosshair) placed at the centre of the bone.

Results

- Bland-Altman analysis[3] was used to quantify the agreement between automated and manual measurements at the same locations, for both phantom and clinical data sets.
- Clinically acceptable thresholds for the bias and limits of agreement (LOA) with such measurements were defined as 0.2mm and 1mm respectively.
- For the phantom, there was an acceptable level of agreement between the manual and automated measurements, except for those slices in the phantom images where the metal artefact substantially impinged on the cartilage (Figures 1B and C). These are represented by the yellow points in Figure 2A.
- For the clinical data sets, 120 measurement points were chosen in representative slices across the volume, which included slices affected by metal artefact. Figure 2B shows a negligible bias (0.05mm) but a LOA (±1.6mm) which exceeds the clinically acceptable threshold.
- 87% of the measurement points were found to lie within the clinically acceptable bias and LOA thresholds. The outliers (n= 15) were examined and all found to be due to measurement points lying in regions where either the cartilage boundaries were not clearly defined or the cartilage was severely obscured by metal artefact or effusion. If these 15 points were pre-selected and not included in the analysis, the revised LOA (±0.95mm) was within threshold.

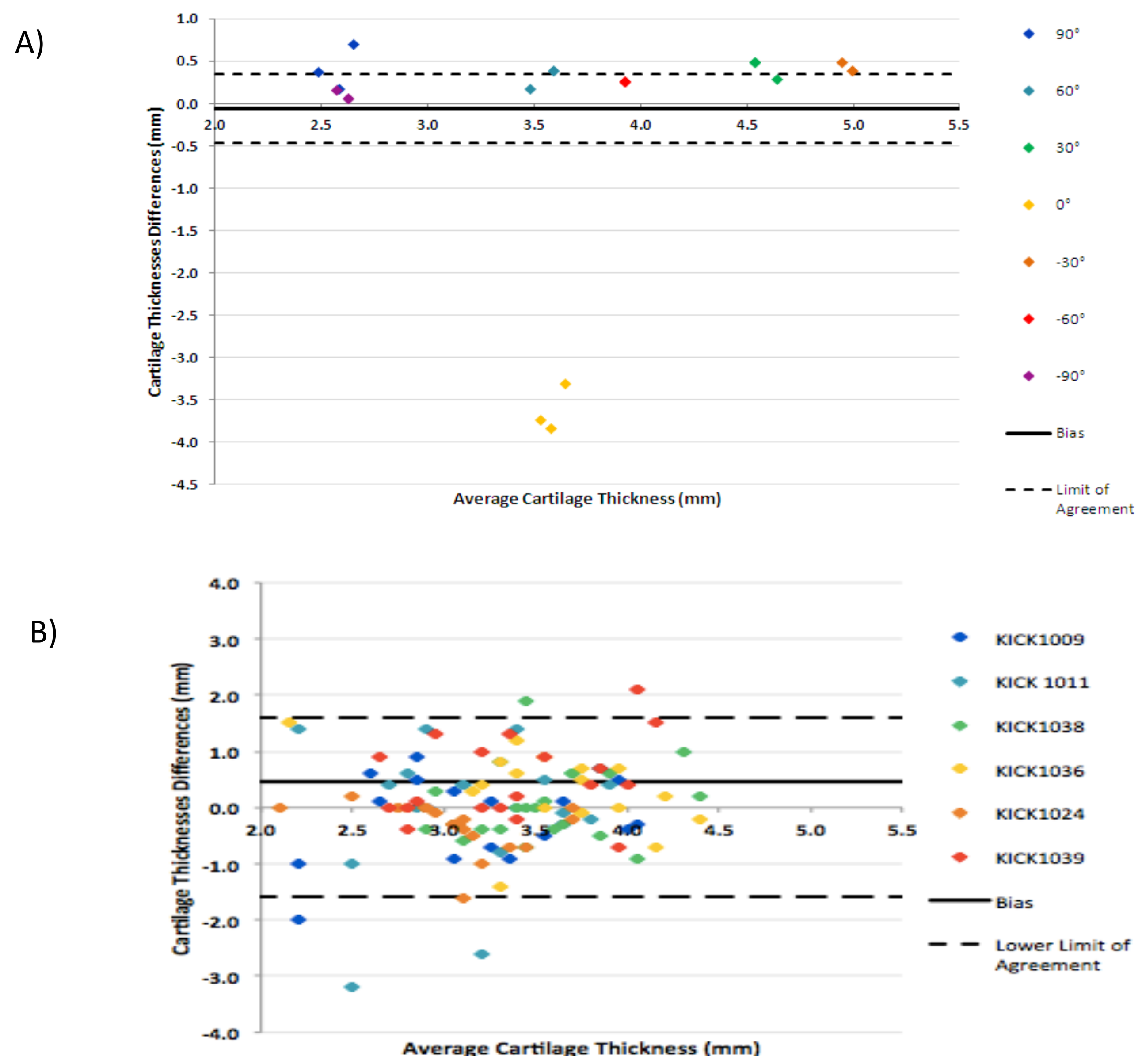

Figure 2: A) Bland-Altman comparison of manual versus semi-automated cartilage thickness measurements for the phantom. Each set of coloured points corresponds to the same angular measurement on three different non-adjacent slices. The yellow points correspond to the location where the intrusive artefact is dominant. B) Bland-Altman comparison of intra-operator semi-automated re-analysis of cartilage thickness for the 120 measurement points for the 6 clinical data sets (bias 0.05mm, LOA ±1.6mm). Each set of coloured points corresponds to a different anonymised data set.

Conclusions

- The KneeSeg2 program successfully segmented the cartilage boundaries on both phantom and clinical images containing metallic artefact, provided the artefact was mostly contained within the bone and could be masked.
- When compared with manual measurements, KneeSeg2 offered a similar level of accuracy and precision, with good intra-observer agreement. For the clinical data set, there was a 50 minute reduction in time with KneeSeg2.
- We now plan to extend this work to test inter-observer agreement of KneeSeg2 on the same clinical images, test its performance when compared with a 'gold standard' commercially available quantitation software, and examine its performance on tibial and patellar articular cartilage quantitation.

References

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