Accuracy of Building a Three-Dimensional Model of a Complex Articular Cartilage Defect from 1.5T MRI

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Introduction

Tissue engineered tissue transplantation is a promising method to treat focal cartilage defects. With the development of tissue engineering techniques, the artificial tissues can be manufactured into arbitrary shapes to match the complex shape of the defect [1]. MRI provides a non-invasive high-resolution method to find detects and create three-dimensional models. Previously the detectible sizes of drill holes on articular cartilage [2] and the accuracy of measuring cartilage thicknesses [3] in MRI have been investigated but the accuracy of measuring arbitrary tissue shapes using MRI has not been evaluated. In our previous study, we utilized a novel three-dimensional laser scanning technique to evaluate the accuracy of articular cartilage thickness measurement in MRI [3]. The purpose of this study was to evaluate the accuracy of MRI for measuring a defect with complex shape involving the articular cartilage and underlying bone by comparing with the laser scanning technique.

Methods

A cadaveric human knee was prepared and artificial defects were surgically created on the distal femoral surface. MR images were obtained with a fat suppressed Spoiled Gradient Echo sequence (TR=19.40 ms, TE=4.60 ms, Flip Angle=20 degree) in a 1.5T GE Signa scanner using an 8-channel knee coil. The slice thickness was 0.7 mm and the in-plane resolution was 0.625x0.625 mm. The distal femur was manually segmented and made into a three-dimensional model using custom software [3]. A defect on the femur similar to an osteochondritis dissecan was made into a separate model from the femur model by assuming a smooth articular surface in the femur model. The cadaveric knee was dissected and the distal femur was laser scanned to obtain the standard shape of the distal femur including defects. The accuracy of the laser scan was between 50-100 μm depending on the surface condition of a scan object. The target defect was made into a three-dimensional model again assuming a smooth surface in the laser scan based femur model. The three-dimensional models of the distal femur from MRI and laser scanner were registered using the surface geometries. The models of the target defect were also registered along with the distal femur models. The volumes of the two models of the defect were calculated and the deviation of the shape of the model from MRI relative to the model from laser scanner was determined.

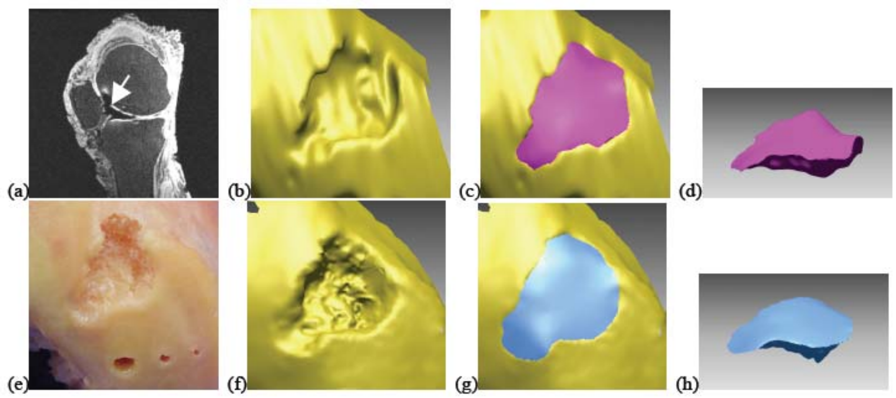

Figure 1. The top and bottom rows show the processes of creating the three-dimensional of the defect from MR images and laser scanner. The first column shows the target defect. The second column, the distal femur models with the defect. The third and fourth columns, creation of the defect models by assuming smooth femur surfaces.

Results

The volumes of the defect were 537 mm^3 from MRI and 405 mm^3 from laser scanning implying that the MRI model was 33% larger than the laser scan model. The surface areas were 479 mm^2 and 431 mm^2 for the MRI model and the laser scan model, respectively. Average deviation of the surface of the MRI model from the surface of the laser scan model was 0.4±0.4 (SD) mm.

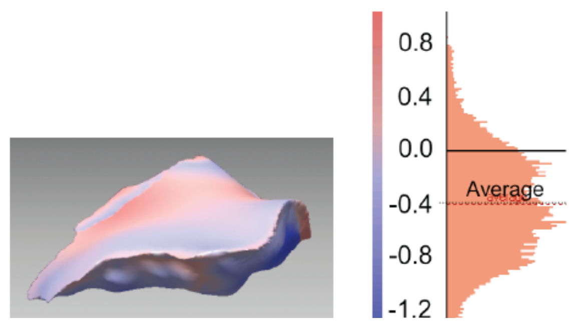

Figure 2. Deviation map and the distribution of the deviations on the surface of the MRI model were calculated. The blue and red colors indicate that the MRI model was larger and smaller than the laser scan model, respectively.

Discussion

The distal femur models (Figure 1 (b) and (f)) and the defect models (Figure 1 (d) and (h)) from MRI and the laser scanner were qualitatively very similar. Though the percentage of the volume difference between the defect models was relatively large (33%, 132 mm^2), the deviation of the surface geometry was relatively small (0.4 mm) which was within MRI resolution. In other words, 0.4 mm offset at each point on the surface of the laser scan model could cause maximum 172 mm^3 (431 mm^2 x 0.4 mm) volume difference. With the current resolution of MRI (0.625x0.625x0.7) and using the 1.5T magnet, the general shape of the defect could be detected with average 0.4 mm accuracy but the details of the complex geometry on the defect area were overestimated. In a fat-suppressed scan, the low signal of the porous cancellous bone around the defect boundary could cause overestimation of the defect. The accuracy can be further improved by using a higher field magnet and using a MR sequence sensitive to bone signals.

References

[1] Tsuchiya K. et al, Cell and Tissue Research, 316(2), 141-53, 2004, [2] Gylys-Morin V.M. et al, American Journal of Roentgenology, 148(6), 1153-1157, 1987, [3] Koo S. et al, Osteoarthritis Cartilage, 13(9), 782-9, 2005