BIOMECHANICAL MODELING TO IDENTIFY RISK FACTORS IN KNEE OA: MODEL DEPENDENCE UPON SOURCE MRI FIELD STRENGTH

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INTRODUCTION

The MOST study is an investigation of the incidence and progression of knee osteoarthritis (OA) in a cohort of 3026 men and women, 50–79 years old. It aims to determine the effects of physical activity, weight, diet and other factors on knee pain and OA. In addition to routine physical check-ups, 1.0T (T = Tesla – magnetic field strength) MRI scans were obtained of subjects' knees at baseline and at regular intervals over a 30-month period, providing a unique opportunity to identify mechanical risk factors for knee OA.

Discrete element analysis (DEA – Li et al. 1997) is a means of estimating articular joint contact stress, using surface geometries derived from CT or MRI. DEA treats apposed bones at an articular joint as rigid bodies, while the intervening cartilage is modeled as a continuous system of springs. Bone displacements or loads provide input to the model. Using DEA, contact stress solutions can be obtained orders of magnitude more quickly than for finite element analysis, making it especially well suited for studying a large cohort.

In addition to 2522 MOST subjects who underwent 1.0T MRI scans, 350 MOST subjects also had knees scanned in a 1.5T scanner. Given the desire to study as large a cohort as possible, using 1.0T scans for study would be preferable. The current study investigates the influence of source MRI field strength upon DEA estimates of joint contact stress in a series of MOST subjects.

METHODS

Standardized MRI scans (both 1.0T and 1.5T field strength) were obtained for seven subjects' knees at study commencement. The MRI images were segmented using OsiriX software (homepage.mac.com/rossetantoine/osirix), yielding a 3D cloud of points defining the subchondral bone surfaces of both the femur and the tibia.

Smoothed surfaces were then fit to the points using Geomagic Studio software (Geomagic; Research Triangle Park, NC). The smoothed surfaces were imported into MATLAB (The Mathworks, Inc.; Natick, MA), where DEA solutions were computed (Figure 1). The cartilage was assumed to be 6 mm thick, with an elastic modulus of 12 MPa, and a Poisson's ratio of 0.45. A 1000 N axial load and moments as necessary to resist tibial rotation (determined iteratively) were applied to the tibia, with the femur fixed against both translations and rotations.

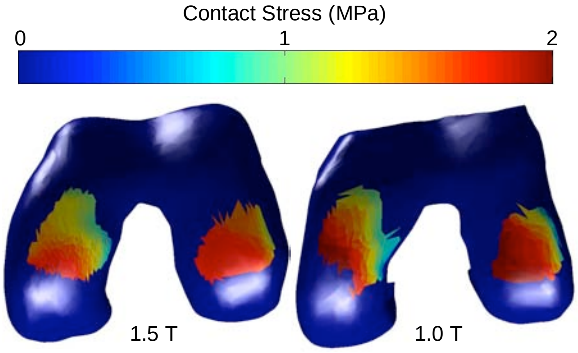

Figure 1: DEA-computed contact stress distributions for the left knee of a subject, derived from 1.5T scan (left) and 1.0T scan (right). Computed peak stress values were 2.17 MPa, and 2.02 MPa, and contact areas were 666.4 and 686.7 mm^2, respectively.

RESULTS AND DISCUSSION

DEA solutions took less than a minute to solve for each case. Estimates of peak contact stress (MPa), as well as the contact stress distributions, were highly consistent, independent of MRI field strength (Figure 1 and Table 2).

Table 2: Comparison of DEA results obtained working from 1.0T and 1.5T MRI scans.

Peak Contact Stress (MPa)				
Case	1.5 T	1.0 T	Diff	%Diff
1	1.51	1.36	0.15	10%
2	1.70	1.79	-0.09	-5%
3	2.16	1.98	0.17	8%
4	2.30	2.43	-0.14	-6%
5	2.49	2.47	0.01	1%
6	3.17	3.47	-0.30	-10%
7	3.63	3.39	0.25	7%
Mean	2.4	2.4	0.0	0.0
StDev	0.8	0.8	0.2	0.1

SUMMARY/CONCLUSIONS

This study incorporates biomechanical modeling of knee joint stress (using discrete element analysis), working only from baseline MRI images. It bridges the gap between associative and physical models of knee OA, enabling an epidemiological model to test whether risk factors identified at baseline may act through increased articular surface loading.

The close agreement between contact stress estimates derived from source MRI data of 1.0T and 1.5T field strength indicates that the 1.0T scans are equally acceptable for estimating contact stress. As a result, a much larger cohort of patients may be included in these epidemiologic investigations.

The versatility of this method for estimating knee joint contact stresses makes its application to subject-specific modeling highly attractive. This type of study has not previously been possible with more complex conventional (i.e., FEA) techniques. By identifying thresholds of contact stress that predict development of painful knee OA, this type of study has the potential to improve patient care, and to guide the utilization of expensive interventions as they become available.

REFERENCES

Kawai T and Takeuchi N. *ASCE Int. Conf. Comput. Civ. Engng*, New York, 1981.
Li G, Sakamoto M, Chao EY. *J Biomech* **30**:635-8, 1997.

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