Assessment of Mechanical Properties of Trapeziometacarpal Joint Cartilage using Contrast-Enhanced Computed Tomography

Reza Nickmanesh[1,2], Benjamin Dourthe[3], Mark Grinstaff [4,5],Rachel Stewart[4,5], Priscilla D'Agostino[3], Faes Kerkhof[3], G. Harry van Lenthe[6], Evie Vereecke[3], David Wilson[1,2]

[1] Center for Hip Health and Mobility (CHHM), Vancouver, BC, Canada [2] Department of Orthopaedics, University of British Columbia, Vancouver, BC, Canada [3] Department of Development & Regeneration, University of Leuven Campus Kulak, Kortrijk, Belgium [4] Departments of Chemistry and Biomedical Engineering, Boston University, Boston, MA, USA [5] Center for Advanced Orthopaedic Studies, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, USA [6] Biomechanics Section, University of Leuven, Leuven, Belgium

Target audience: orthopaedic surgeons, biomechanics researchers, radiologists, cartilage researchers

Purpose: The trapeziometacarpal (TMC) joint is a common site of osteoarthritis (OA) in the hand [1]. TMC OA results in significant functional disabilities due to the broad range of activities performed by this joint [2]. In addition, the human TMC joint's specific morphology represents an ideal model for OA research and for the development of novel diagnostic and therapeutic methods. However, our understanding of OA initiation and progression at this joint is limited because of the inherent challenges associated with imaging and mechanical testing of TMC cartilage. Contrast-enhanced computed tomography (CECT) is an imaging technique for quantification of glycosaminoglycan (GAG) content in cartilage. CECT with a cationic contrast agent (CA4+) correlates with cartilage GAG content and compressive stiffness in animal models [3-5] and in the human metacarpal joint [6]. However, the CECT attenuation-compressive stiffness relationship has not been studied in the TMC joint, and this relationship varies substantially between joints. Therefore, our research question was: Is CECT attenuation using CA4+ contrast agent associated with compressive stiffness in intact TMC cartilage surfaces?

Methods: The TMC joint of 16 fresh-frozen cadaver hands (10 female, 6 males, age: 66-101 yrs) was excised by an orthopaedic hand surgeon. Intact, whole first metacarpal (MC1) and trapezium (TP) cartilage surfaces were extracted for testing. For each specimen, load-displacement behaviour was measured at 9 testing sites using a standardized indentation testing device (Mach1, Biomomentum, Canada) with a spherical indenter (D=1mm). Young's modulus was calculated at each testing site using the load-displacement curves and measurements of cartilage thickness from CT images. The average of the 9 moduli was reported as a measure of cartilage compressive stiffness. The samples were then immersed in CA4+ contrast agent solution for 48 hours and subsequently scanned with a resolution of 41µm in a HR-pQCT scanner (Xtreme CT, Scanco, Zurich). The averages of CECT attenuations for each sample were computed for both superficial cartilage (200 µm depth from the surface) and for the full cartilage thickness. Correlations between compressive stiffness and CECT attenuation were assessed with scatter plots and Pearson's correlation coefficient.

Results: A significant positive correlation was observed between stiffness and mean CECT attenuations in superficial and full-depth cartilage in both first metacarpal and trapezium cartilage (Fig.1). Correlation coefficients were r=0.82 and 0.78 ($p<0.01$) in metacarpal specimens and r=0.8 and 0.76 ($p<0.01$) in trapezium specimens for superficial and full-depth CECT attenuation, respectively. We found similar patterns of stiffness and CECT attenuation across cartilage surfaces (normalized data is presented for easier comparison) (Fig.2).

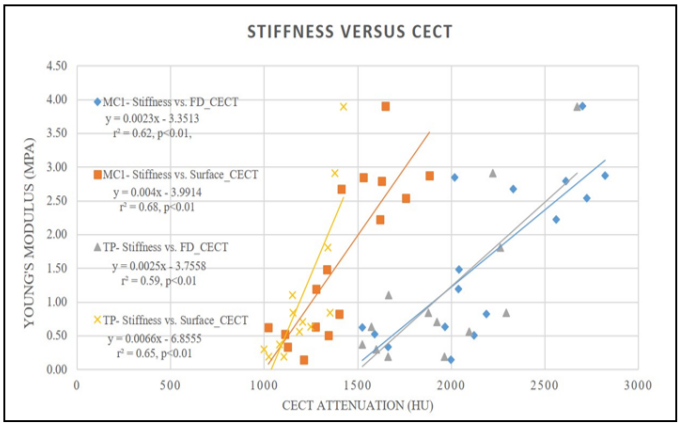

Fig. 1. Scatter plots of stiffness vs. mean CECT attenuation

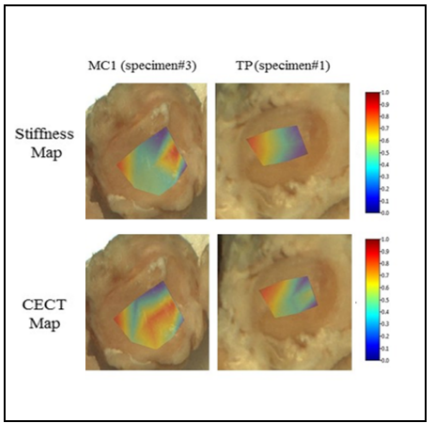

Fig.2. Stiffness vs. CECT attenuation maps

Discussion: We found a significant correlation between compressive stiffness and CECT attenuation in TMC cartilage specimens. This is the first study to investigate the applicability of CECT for non-invasive assessment of TMC cartilage stiffness. Our finding of correlation between CECT attenuation and mechanical stiffness is consistent with studies from other joints [5-7]. A key strength of the study is that both imaging and mechanical testing were performed on intact articular surfaces, which better represents physiological behaviour of the joint than the more widely-used testing of excised cartilage plugs. The main limitation of this study is that we were unable to perform the histological assessments to determine the exact relationship between CECT attenuation and GAG content. Overall, the results support the use of CECT to assess mean stiffness changes in the cartilage region as well as in the distribution of stiffness across the cartilage surface.

Conclusion: Compressive stiffness correlates with CECT attenuation in intact first metacarpal and trapezium cartilage. This imaging approach may be useful for assessing functional changes in cartilage associated with disease and injury, and for monitoring the effect of disease-modifying drugs and other treatments in OA studies.

References: [1] A.L. Armstrong et al. J. Hand Surg. 1994. [2] Carrie R. Swigart et al. Curr Rev Musculoskelet Med .2008 [3] B. A. Lakin, et al. Osteoarthr. Cartil. 2013. [4] P. N. Bansal et al. Osteoarthr. Cartil. 2011. [5] B. a. Lakin et al. Osteoarthr. Cartil. 2014. [6] B. A. Lakin et al. Osteoarthr. Cartil. 2015. [7] B. A. Lakin, et al. Osteoarthr. Cartil, 2013.

Sponsor: Research Foundation Flanders (FWO) and Natural Sciences and Engineering Research Council of Canada (NSERC)