A Mapping of Articular Cartilage Integrity and Biphasic Properties in Healthy and Osteoarthritic Trapeziometacarpal Joints

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INTRODUCTION: The trapeziometacarpal (TMC) joint is the most common site for osteoarthritis (OA) in the upper limb. TMC OA leads to articular cartilage (AC) degeneration and deterioration on both the metacarpal (MC) and trapezium (TR) articulating surfaces. Previous histopathology studies have reported anterior oblique ligament (AOL) degeneration and detachment at the MC ulnar insertion as OA progresses. Our prior work further demonstrated the attenuated AOL viscoelastic tensile properties in osteoarthritic TMCs. It is well known that the TMC is mainly stabilized by the surrounding ligaments due to its limited bony constraint. The degeneration of the AOL could have a critical impact on the overall joint kinematics and joint articulation as OA progresses. Previous research indicated that joint contact center shifts from the palmar-ulnar to dorsal-radial side during the TMC OA progression. Therefore, the objective of this study was to further provide a qualitative and quantitative spatial mapping of cartilage integrity through imaging of AC surfaces and mechanical testing of biphasic properties, including hydraulic permeability and equilibrium modulus, of the MC and TR surfaces under healthy and OA stages. We hypothesize that certain areas of the MC, specifically the palmar half, and TR, specifically the palmar-central region, will experience significant degenerative changes during OA progression as evidenced by attenuated cartilage integrity and altered biphasic viscoelastic properties.

METHODS: Fresh-frozen human cadaver hands (all female, aged 28-75) were collected through an organ procurement site organization (approved by MUSC Institutional Review Board for Human Research). Lateral and Robert's view x-rays were obtained for each specimen to grade the severity of OA using Eaton-Littler classification. There were three experiment groups for this study: young healthy/early-stage (YH) [n=3, age >50, Grade 0-II], elder healthy/early-stage (EH) [n=3, age <50, Grade 0-II], and advanced osteoarthritic (OA) [n=3, no age requirement, Grade III-IV]. The joint was dissected into palmar and dorsal aspects that were then divided into a radial, central, and ulnar portion, resulting in 6 total sections for each articular surface (Fig. 1). An Anton Paar UNHT^3 indenting machine with a 0.5 mm radius ruby ball probe was used to perform creep tests on the AC. A preload of 200 µN with a relaxation period of 400s, followed by a creep load of 5000 µN with a relaxation period of 600s was applied. Following the creep test, the sample thickness was then measured using a dissection microscope. The AC thickness and deformation response to the creep load was then used for curve fitting. Hydraulic permeability and equilibrium modulus are extrapolated out from the displacement vs time curve. Two-way ANOVA and Student's t tests were performed to determine the significance of the change in mechanical properties between the groups.

RESULTS: A change in cartilage integrity could be seen within the different groups (Fig. 1). In the YH group, the cartilage remained smooth and unaltered in most regions on both the MC and TR surfaces, with very little texture seen in palmar-ulnar region of the MC in some specimens. In the EH group, we began to see cartilage degeneration beginning in the palmar-ulnar region of the MC and in the palmar-central region of the TR. In the OA group, we discovered more severe cartilage degeneration that had spread past the palmar-ulnar region and into the central region, as well as somewhat in the dorsal-radial region, of the MC while cartilage degeneration continued to spread centrifugally in the TR. The mechanical data collected showed trends that support these qualitative findings. Significant differences between YH and OA, as well as between YH and EH, were seen for equilibrium modulus in the palmar-radial region of the MC ($p<0.05$). Additionally, significant differences between YH and OA, as well as between EH and OA were seen for permeability and equilibrium modulus in the palmar-central region of the TR ($p<0.05$). In all other regions of the palmar half of the MC, we saw an increase in permeability going from YH to EH followed by another decrease from the EH to OA group. The reverse trend was seen for equilibrium modulus. The same trends for both permeability and equilibrium modulus were seen in the other palmar regions of the TR (Fig. 2).

DISCUSSION: The increase in permeability and decrease equilibrium modulus between the YH and EH groups in all palmar regions of the MC and palmar-central region of the TR indicates that the articular cartilage degeneration initiates from the palmar region adjacent to the AOL insertion side. It is likely that there was a bigger difference in the radial region on the MC because the AC in that region maintains its integrity in all healthy and early-stage specimens, while in some specimens we observed the beginning of AC degeneration in the ulnar region. It is possible that, based on both the imaging of the AC surfaces and mechanical data, a notable change in AC integrity takes place before full advanced OA is reached, meaning it is occurring between the young and elder healthy/early-stage group. Our previous research has proven that there is a loss of mechanical and structural integrity in the anterior oblique ligament, specifically at the MC insertion that is ulnarly located, as OA progresses. This ligament degeneration can lead to an increase in ligament laxity and, therefore, increase in overall subluxation of the joint which could explain the spreading of cartilage wear seen as OA progressed. The increase seen in permeability and decrease seen in equilibrium modulus between EH and OA group is most likely due to the transition from thin cartilage to eburnated bone that will then display different mechanical characteristics than a healthy layer of AC. Some of the variation in the mechanical data can be explained by the Eaton-Littler classification system, as radiographs do not account for cartilage thickness or integrity. An increase in sample size may bring more noticeable differences between disease group and region that were not seen in this data.

SIGNIFICANCE/CLINICAL RELEVANCE: This study aids in closing the gap in TMC OA pathomechanics by providing a more detailed spatial mapping of AC properties that will eventually aid in linking the effect of AOL laxity or detachment on OA progression and subsequent articular cartilage wear and degeneration.

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IMAGES AND TABLES:

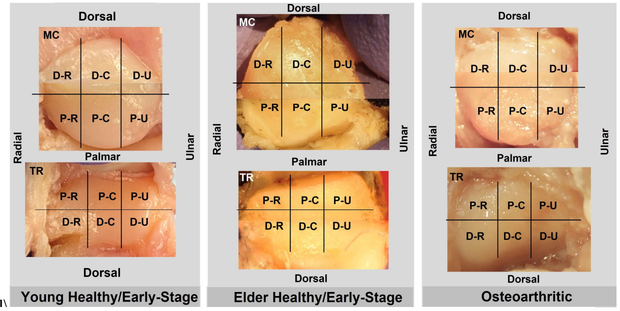

Figure 1. Schematic showing sectioning of MC and TR surfaces and corresponding cartilage integrity as OA progresses.

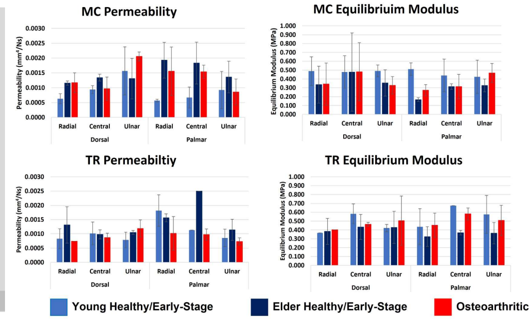

Figure 2. Permeability and equilibrium modulus values for the different sections of the MC and TR as OA progresses.