Micro-CT visualization and indentation properties of whole meniscus following mercury exposure

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Introduction

• A major risk factor for knee osteoarthritis is meniscal injury or excision.[1] Therefore, surgeons now advocate for meniscal repair or allografts rather than excision.[2]

• Clinical assessment of repair or transplant success is limited to magnetic resonance image (MRI) analysis of meniscal extrusion.

• The efficacy of replacement and repair may also be assessed in-vitro with pressure sensitive film and mechanical transducers.[3,4]

• Our laboratory has also developed methods of measuring regional strain in menisci using micro-computed tomography imaging (µCT) and small implanted beads.[5]

• Strain measurements could be augmented with a volume measurement of the meniscus. Determining the volume of the meniscus requires manual segmentation that could vary between researchers, particularly near capsular attachments.

• The first objective of this study was to investigate whether mercury exposure improves visualization of the entire meniscus in µCT images which would facilitate automated segmentation.

• The second objective was to determine if alterations to the mechanical response of the meniscus would occur after exposure to mercury through indentation testing.

Methods

• One pair of porcine knee joint menisci were secured to a rigid base using the ligaments and abaxial capsular attachments.

• Automated indentation was performed at multiple sites on the surface of the intact meniscus, using a Mach-1 Mechanical Testing System (Biomomentum Inc. Laval, QC) with a six degree of freedom load cell.

• Indentations were applied to 0.5 mm (25.4% strain) and 0.75 mm (39.5%)at a rate of 1mm/s.

• Stiffness was calculated by selecting the force at specified displacements of 0.5 mm and 0.75 mm of indentation.

• Both menisci were incubated in a mercury solution of 75 mg/250 mL water for two hours at room temperature. After incubation, the indentation was repeated at the same sites.

• µCT images were taken pre and post mercury incubation (GE eXplore Locus 45 micron resolution).

• A paired t-test was used to compare stiffness pre and post mercury incubation (Statistica v.9).

Results

• The isosurface reconstruction of the menisci following mercury incubation is shown in Fig. 1.

• The stiffness pre and post mercury incubation is shown in Fig. 2 for the medial meniscus and Fig. 3 for the lateral meniscus. There are significant increases in the stiffness post mercury incubation in the medial meniscus at 0.5 mm displacement (p=0.0038) and 0.75 mm displacement (p=0.0015).

• The lateral meniscus shows a trend towards an increase in stiffness at 0.5 mm (p=0.0603) but not at 0.75 mm displacement (p=0.3519). The µCT scan of the medial meniscus post mercury incubation is shown in Fig, 4.

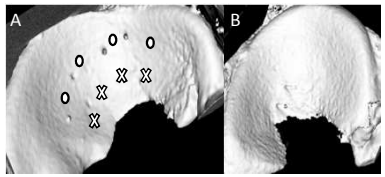

Fig. 1: Isosurface reconstruction of menisci A) Lateral B) Medial. Approximate indentation placement shown in A, inner sites (x) in the white zone and the outer sites (o) in the red zone.

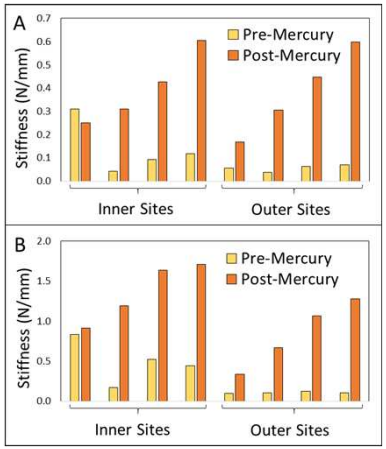

Fig. 2: Stiffness (N/mm) of the medial meniscus pre- and post-mercury, displacements of (A) 0.5 mm (B) 0.75 mm.

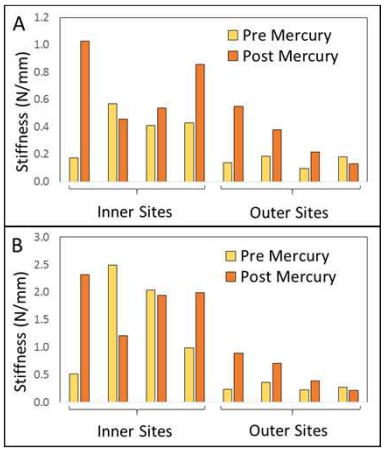

Fig. 3: Stiffness (N/mm) of the lateral meniscus pre- and post-mercury, displacements of (A) 0.5 mm (B) 0.75 mm.

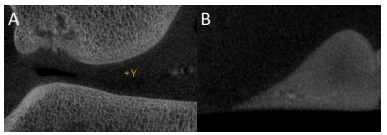

Fig. 4: µCT scan of medial meniscus A) Pre mercury incubation B) Post mercury incubation

Discussion

• Mercury incubation allows for visualization of the meniscus using µCT as shown in Fig. 4, but causes changes in the stiffness of the tissue.

• Increasing visualization can lead to analysis including potential automated segmentation methods or volume measurements.

• This study had a limited sample size of two menisci. Further work is required to determine if shorter incubation would lead to decreased changes while still enabling increased visualization.

Significance

• This is the first study to investigate indentation of a full intact meniscus and to evaluate the use of mercury to allow for visualization of the meniscus in µCT [6-10].

• Improved contrast from mercury exposure will allow automated segmentation of the meniscal volume, which would add a valuable in-vitro tool to assess the efficacy of meniscal repair and allograft transplant.

Acknowledgements

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References

1) Roos *et al*. (1998) *Arthritis Rheum* 41-4:687-93. 2) Xu *et al.* (2013) *Knee Surg Sports Traumatol Arthroscop.* 3) Muriuki *et al.* (2011) *JBJS(Am)* 93(12)1089-1095 4) Starke *et al.* (2013) *Arthroscopy* 29(2)205-12. 5) Tschirthart *et al.* (2011) J Bone Joint Surg Br 93-B no. SUPP III 248. 6) Jurvelin *et al.* (1995) *J Biomech* 28(2), 231-235. 7) Baro *et al.* (2012) *Osteoarthritis* 51-2:232-240. 8) Sweigart *et al.* (2005) *J. Engineering in Medicine* 219-PartH:53-62. 9) Moyer *et al.* (2013) *Acta Biomaterialia* 9-5:6624-6629. 10) Sweigart *et al.* (2004) *Annals of Biomedical Engineering* 32-11:1569-1579.