Efficacy of Boundary Lubricants on TMJ Disc and Condylar Cartilage

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Introduction: The temporomandibular joint (TMJ), composed of a mandibular condyle, temporal fossa, and an intra-articular disc, is the only diarthrodial joint in the human head. Painful and debilitating disorders of TMJ, known as TMDs, impact an estimated 7% of the population [1]. A major cause of TMD is dislocations of the disc and the concomitant increase in friction. Injection of intra-articular lubricants is frequently utilized to reduce friction and alleviate pain, but the biomechanical mechanisms underlying such treatment and its effectiveness in reducing friction remains unclear. This study aims to i) examine the lubricating ability of hyaluronic acid (HA) compared to synovial fluid (SF) and PBS at microscale contact regions; and ii) to identify loading profiles associated with increased lubrication.

Methods: 5 TMJs were harvested from porcine heads (Fig. 1A), chosen due to structural and functional similarities with human joints [2]. In all testing, a custom-built microtribometer (Fig. 1B) [3] was employed to determine frictional coefficients at the central region in the anterior-posterior direction under 4 normal compression forces and 4 sliding speeds (normal force: 25, 50, 100, and 200 mN; speed: 500, 1000, 2000, and 3000 um/s). During testing, gauze wetted with PBS covered all but the central region of the sample in order to keep the tissue hydrated. A small amount of SF (obtained from porcine knee joints), HA (Healon, 10 mg/mL, Abbot Medical Optics, California, USA), or PBS was then added to the central region to serve as a lubricant. A hemispherical steel indenter (D = 6.4mm, roughness = 75nm) was compressed on the tissue with specified force and slide back and forth at a controlled speed. The friction coefficient was calculated as the average of the forward and reverse frictional forces divided by the average normal response force at equilibrium. Polynomial regression was used to determine correlations between friction coefficient and sliding speed and friction coefficient and normal force. One-way ANOVA with Bonferroni post-hoc was utilized to determine differences between lubricants. In all cases, significance was indicated by p<0.05.

Results: On both tissues, the dependence of frictional coefficient on normal force for both SF and HA was detected, but not for PBS. No relationship was determined between frictional coefficient and sliding speed on either tissue for any lubricant. Significant differences were detected between all three lubricants at 25 mN, and between HA and both SF and PBS at 50 mN, on condylar cartilage (Fig. 2A). The disc showed significance between all three lubricants at 25 mN and between HA and PBS at 50 mN (Fig. 2C). No difference between lubricants was detected at any speed on either condyle or disc when the force is fixed at 100 mN (Fig. 2B, D respectively). These trends are in agreement with results in literature [4-6], which have noted that intra-articular injection of lubricants may have limited tribological effectiveness for healthy tissue.

Discussion: The two main sliding modes in cartilage tribology are migrating contact area (MCA), where the contact area changes with time, as in this study, and stationary contact area (SCA), where the contacting area remains static, as in the case of a cartilage plug reciprocating against a glass slide. Previous studies have reported no differences between lubricants under MCA sliding with normal forces several orders of magnitude higher (~10 N). Migrating contact represents friction between healthy articulating surfaces, and the interstitial fluid pressurization mode of lubrication [7] dominates as long as the tissue is not degraded, leaving little room for lubricants to improve friction, as was seen. At extremely low normal forces, differences in frictional coefficient between lubricants become apparent, which may be a function of the properties of the lubricant or the dynamics of the contact.

Significance: This study has reported, for the first time, the frictional coefficients of TMJ condylar cartilage and articular disc during lubrication by synovial fluid, hyaluronic acid, and PBS under a variety of normal loads and sliding speeds. The dependence of frictional coefficient for HA and SF on normal force, and subsequent increase in friction, was demonstrated, a previously unknown effect of these lubricants at small loads. Interestingly, as noticed in a few previous studies, we also found that lubricants, such as HA and synovial fluid, have little benefits on the lubrication of cartilage under migrating contacting mode.

Acknowledgments:

Figure 2. Dependence of frictional coefficient on normal force and sliding speed can be seen for the condyle (A, B) and disc (C, D), respectively. A correlation between frictional coefficient and normal force was seen for HA and SF for both condyle and disc (n=5, p<0.05). No relationship was detected between friction coefficient and sliding speed for any lubricant or tissue.