Boundary Lubrication by Synovial Fluid in TMJ Disc and Condylar Cartilage

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Introduction: The temporomandibular joint (TMJ), which provides for smooth articulation of the jaw, is the only diarthrodial joint in the human head. It consists of the temporal fossa and mandibular condyle, separated by an intra-articular fibrocartilaginous disc. An increase in TMJ friction associated with lubrication impairment has been linked to disorders such as disc dislocation [1] and damaging shear stresses at the cartilage-bone interface [2]. Consequently, the use of intra-articular injections of exogenous lubricants to restore joint lubrication and function within the intact TMJ has been proposed [3]. However, TMJ disc and condylar cartilage are structurally dissimilar (Fig. 1A, B), and the efficacy of boundary lubrication in the TMJ is not fully understood. Thus the aims of this study are 1) to evaluate and compare the time-dependent lubrication properties upon TMJ disc and condylar cartilage, and 2) to examine the lubricating ability of additive synovial fluid (SF).

Methods: Eight TMJs were harvested from mature porcine heads, chosen due to structural and functional similarities to human joints [4]. Three 5 mm cylindrical plugs were excised from each TMJ disc and condyle in the intermediate zone, aligned in the lateral-medial direction. A custom-built microtribometer (Fig. 1C) [5] was employed to determine friction coefficients under a 3 N normal load at a sliding speed of 2 mm/s. The sample was bathed in either SF (aspirated from porcine knee joints) or PBS during testing. A glass slide was compressed onto the sample with specified normal load, and sliding over a 4.5 mm track was achieved by reciprocation of a linear stage at the bottom (Fig. 1D). The reciprocation of a cartilage plug against a glass slide provided for a stationary contact area modality, in which the contact area remains static, as boundary lubrication is best evaluated at conditions in which the interstitial fluid lubrication (IFL) [6] has subsided. The test was performed for four hours or until the friction force reached equilibrium. Minimum and equilibrium friction coefficients were recorded, along with the time-dependent frictional response. Paired sample t-tests were utilized to compare the results, with significance indicated by p < 0.05.

Results: Due to fluid depressurization associated with the stationary contact area configuration, the friction coefficient was time-dependent and increased with testing time, following a typical creep pattern. Condylar cartilage achieved steady state within 10000 s. As TMJ disc did not reach equilibrium within four hours, tests were truncated at 10000 s. Examination of the average temporal response curves showed distinctly different trends for TMJ disc and condylar cartilage (Fig. 2A, B). Condylar friction displays a sigmoidal temporal shape, with friction beginning very low and asymptotically rising rapidly towards equilibrium. The curves from SF and PBS lubricants are similar. Conversely, disc friction increases nearly linearly over time, rising slowly and displaying large differences between SF and PBS conditions. For both TMJ disc and condylar cartilage, SF provided significantly lower minimum friction values compared to PBS (disc: 0.024±0.003 vs. 0.038±0.013, p < 0.05; condyle: 0.020±0.002 vs. 0.028±0.004, p < 0.01) (Fig. 3A). Although the disc never reached equilibrium, lubrication with SF resulted in a lower friction coefficient after 10000 s than PBS (0.109±0.029 vs. 0.156±0.035, p < 0.05).
In contrast, no significant difference was detected between equilibrium friction coefficients for condylar cartilage (0.219±0.038 vs. 0.236±0.027, p = 0.35). The minimum friction coefficients of condylar cartilage are significantly lower than those of disc. However, the friction coefficient of the disc after 4 hours of sliding is still lower than the equilibrium value from condylar cartilage, indicating a striking boundary lubrication capability in the disc.

**Discussion:** The significant effect of SF in reducing disc friction, both minimum and equilibrium, and the shape of the temporal response curve, as it deviates significantly from those of condylar cartilage or typical hyaline cartilage [7], suggests that the disc is strongly reliant upon boundary lubrication. This supports a previous hypothesis [8] that a major role of the disc is to increase boundary lubrication within the TMJ. As the friction coefficient keeps rising in a linear fashion during 4 hours of sliding on the disc, it is conjectured that interstitial fluid depressurization may not be primarily responsible for the increase in friction. SF has little beneficial effect on the long-term lubrication of condylar cartilage, suggesting that IFL is dominant for condylar lubrication. Although the significant difference observed between SF and PBS in condyle minimum friction appears to indicate some basic ability of SF to promote boundary lubrication, the lack of any detectable difference in condylar friction at equilibrium is surprising and bears further analysis.

**Significance:** The study provided valuable insight into the distinct lubrication mechanisms for TMJ disc and condylar cartilage. IFL is dominant for condylar lubrication but almost negligible for the disc. Unlike in hyaline cartilage, the friction coefficient of the TMJ disc increases slowly and linearly, indicating a unique and powerful boundary lubrication capability of this unique tissue which is superior to that of hyaline cartilage.
Figure 3. Minimum (A) and equilibrium (B) friction coefficients for TMJ disc and condylar cartilage, with PBS and SF employed as lubricants. * indicates p < 0.05.