INTRODUCTION: The temporomandibular joint (TMJ), similar to the knee joint, is composed of two articulating bones covered by cartilage and an articular disc in between. The rotation and gliding actions of TMJ allow us to talk, chew, and yawn. The dislocation of the disc or the degeneration of the cartilage can severely ruin the congruity and integrity of TMJ and further leads to TMJ disorders (TMD). Histology studies showed that the composition and structure of condylar cartilage do not resemble any other fibrocartilages [1], and the disc is also a unique connective tissue [2]. Our recent study found that the condylar cartilage is much softer than the cartilage in other diarthrodial joints [3]. Little is known about the frictional coefficient of the cartilaginous tissue in TMJ. In this study, using a custom-built tribometer, we propose to investigate: 1) the frictional coefficients of condylar cartilage and disc at five regions, and 2) the dependency of frictional coefficient on loading magnitude and sliding speed.

METHODS: TMJ specimen (Fig. 1A) were extracted from fresh porcine heads (n = 4). Using a custom-designed tribometer (Fig. 1B), both mandibular condyle and disc were tested for frictional coefficients at five locations (central, anterior, posterior, lateral, and medial regions) and two sliding directions (Anterior-Posterior and Lateral-Medial). The central region in the AP direction was also tested under different normal forces or sliding speeds. The normal forces include 25, 50, 75, 100, 125, and 150 mN, and sliding speeds were .05, .10, .25, .50, 1.0, 2.0, and 5.0 mm/s. For other regional and directional dependence tests, normal force of 100mN and sliding speed of 2.0 mm/s were used. A hemi-spherical stainless steel ball (φ = 3.2 mm) was fixed on a cantilevered beam as the counter body. Deflections of the beam were recorded by two orthogonal calibrated capacitance sensors to measure both frictional and normal forces. The friction coefficient µ is calculated as the average of the forward friction force Ff and the reverse force Fr divided by the normal force Fn (µ=(Ff+Fr)/2Fn). Data of force was taken from the central 200 µm of the wear track at the equilibrium state. A 1500µm path length piezoelectric positioning stage was used to reproduce the sample, and a 250µm piezo stage was used to position the cantilever beam for load-controlled testing. During each test, the sample was lubricated with 0.15 mol PBS infused with a protease inhibitor cocktail. To determine difference between two sliding directions, one-tailed paired t-test was used for each set of regional data. One way ANOVA with Tukey post-hoc test was performed to analyze the statistic difference related to location, normal force and sliding speed.

RESULTS: The measured frictional coefficients were summarized in Fig. 2. In all regions on disc, the frictional coefficients are higher in the lateral-medial direction. Statistical significance was detected in the anterior, lateral and central regions. Visual inspection of the disc shows that the collagen fibers are arranged uniformly in the anterior-posterior direction, in which the friction coefficient is smaller (Fig. 1A). No significant difference was detected between different locations on either disc or condylar cartilage. After combining the data from different regions, the disc shows significantly higher frictional coefficients than condyle in both directions (Fig. 3). AP direction on disc shows significantly lower frictional coefficient than LM direction. No directional difference was detected on condyle head. Overall the frictional coefficient of TMJ tissue is on the higher end of those from knee cartilage and meniscus determined with a similar setup [4]. The frictional coefficient decreases as the normal loading force increases (Fig. 4A&B). This correlation can be perfectly described with an exponential curve (Y = 0.99). A similar trend was found between the frictional coefficient and sliding speed (Fig. 4C&D). Under higher sliding speed, the friction is significantly smaller. Both trends revealed in Fig. 4 are consistent with those reported in literature [5]. In the future, more TMJ samples will be tested to increase the power of statistical analysis, and more important conclusions are expected.

SIGNIFICANCE: This study reported the regional- and directional-dependent frictional coefficients of TMJ disc and condyle cartilage. The exponential dependency of frictional coefficient on sliding speed and loading magnitude was also reported. The data should help understand the biomechanics and etiology of TMD.

Figure 1: (A) A porcine TMJ sample with the disc lifted from the condyle head. Five regions as marked are tested for frictional coefficients. (B) Schematic of the tribometer. The sliding between disc and condyle head is achieved by the movement of the bottom positioning stage.

Figure 2: Regional and directional dependent friction coefficients of (A) disc and (B) condyle head. No statistical difference was detected between regions. (*: p<0.05) (n=4)

Figure 3: Comparison of frictional coefficients between disc and condyle in two perpendicular sliding directions. (n=20)

Figure 4: Frictional coefficient vs normal force at 2 mm/s sliding speed for (A) disc and (B) condyle. Frictional coefficient vs sliding speed at 100 mN for (C) disc and (D) condyle. * denotes statistical significance with the first data point in curve (25mN or 50μm/s) (p<0.05, n=4).

REFERENCES