The Tribological Behavior Of Degenerated Articular Cartilage Is Independent Of Its Biomechanical Properties

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DISCLOSURES: None

INTRODUCTION: Despite of multifarious research efforts throughout the last decades, there is still no holistic therapy available addressing knee joint osteoarthritis (OA). Therefore, researchers still strive to find new therapeutic strategies which aim to restore the unique properties of the affected articular cartilage (AC). It is widely accepted, that OA progression can affect the biomechanical properties [2] of AC and its tribological function [3]. There is growing evidence that cartilage friction is not only a simple surface phenomenon but also depends on its mechanical integrity. Indeed, for healthy animal AC it was recently shown that the biomechanical properties can be used to predict its tribological behavior [1]. However, it is not known whether this is also true for degenerated human AC. Therefore, the aim of this study was to correlate the compressive and friction properties of degenerated human AC samples.

METHODS: Six (72 ± 6 years; 3 male, 3 female, KL score: 3-4; ICRS score 1-2) degenerated human tibial plateaus were collected from patients undergoing total knee arthroplasty (IRB 228/20). First, normal indentation relaxation tests (indentation amplitude = 0.2 mm, indentation velocity = 0.2 mm/s, relaxation time = 20 s) were performed at four standardized (anterior, posterior, middle, cartilage to cartilage contact area) locations on the lateral tibial plateau using a multiaxial testing machine. At each point the cartilage thickness (t in mm), the maximum applied force (F_{max} in N), the instantaneous modulus at t = 1 s (IM in MPa) and the initial viscous response (E_{t20s} in MPa, [2]) were determined. Following, cylindrical samples were extracted at the exact same four locations using a 6 mm trephine drill. Then, the friction properties of these cylindrical samples (in total n = 24) were tested in an AC against glass configuration using an established tribometer [4]. Based on previous studies on degenerated human cartilage samples, the following loading profiles were randomly applied to each sample: I (velocity (v) = 40 mm/s, Axial force (F_A) =25 N; [4]), II (v = 80 mm/s, F_A =2.5 N; [4]), III (v = 1 mm/s, F_A = 6.3 N; [3]) and IV (v = 0.5 mm/s, F_A =1.8 N; [5]). The samples were lubricated with 0.1 ml of the patient's specific synovial fluid. Friction was quantified according to Coulomb's law at the timepoints t = 1 s (μ_{t1s}) and at t = 20 s (μ_{t20s}). Relationships between the friction coefficients (μI, μII, μIII, μIV) at both time points and the biomechanical parameters (t, F_{max}, IM, E_{t20s}) were analyzed by determining the Spearman correlation coefficient r. $p \leq 0.05$ was considered statistically significant.

RESULTS SECTION: The biomechanical tests revealed a median cartilage thickness of 2.2 mm (Figure 1 A). The IM indicated a median value of 1.1 MPa, while the median E_{t20s} was 0.19 MPa. F_{max} showed a median value of 0.27 N. Friction was highest under loading profile III and lowest under loading profile II and IV (Figure 1 B). Except for the correlation between μI_{t1s} and t (r: -0.53, $p < 0.05$) and μI_{t20s} and t (r: -0.48, $p < 0.05$), no significant correlations were identified between friction and the biomechanical parameters (Figure 1 C).

DISCUSSION: To be best of our knowledge this is the first combined biomechanical / tribological study using four different loading regimes and patient specific synovial fluid as lubricant. The present friction results are comparable to findings of previous studies on degenerated cartilage lubricated with healthy bovine synovial fluid or phosphate-buffered saline [3,5]. This suggests that OA related changes in the synovial fluid might have a minor influence on cartilage friction. Despite of being in the range of previously published data [2,4,5] our findings indicate that the tribological behavior of degenerated AC is independent of its biomechanical properties. One reason for this could be the multifactorial OA pathology, thus unpredictable progression of the disease which is likely to lead to individual AC degeneration patterns with associated changes in tissue properties. The negative correlation between μI and t can be interpreted in a way that a certain AC thickness is required to maintain the low friction environment in the knee under high loaded stance phase conditions. Like any other in-vitro study, also this study is not without limitations. The AC tissue was tested in different conditions: Initially the compression mappings were conducted leaving the tibial AC intact, while AC plugs were subsequently extracted for friction testing. Because of the hydrophobic nature of AC swelling of the extracted tissue with an associated increase in water content is very likely. This might have altered the respective outcome of the tribological investigations. In order to overcome this, future studies should combine biomechanical and friction measurements using the tibial AC tissue composite.

SIGNIFICANCE: This study indicates no correlation between the compressive and frictional properties of degenerated human AC under the here investigated conditions. Therefore, no cross-predictions can be made for the biomechanical properties or the tribological function of human OA AC.

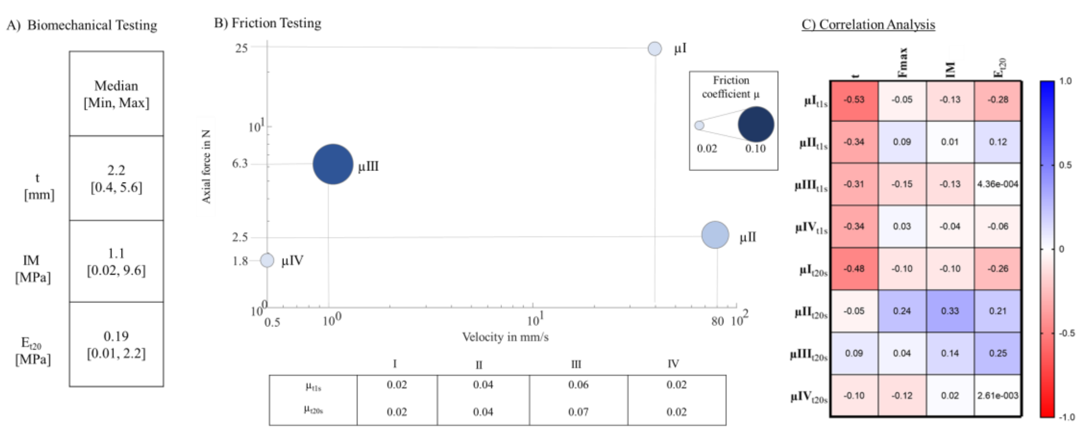

Figure 1: A) Results of the biomechanical testing B) Results of the friction testing. The friction coefficient μ is displayed for the applied loading conditions I, II, III and IV by circles, whereby the size of the circle represents the magnitude of μ. C) Spearman correlation matrix of the friction coefficients and biomechanical parameters.

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