Cartilage Multiscale Lubrication

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An original numerical formulation is presented to deal with lubrication between cartilage tissues. Particular attention is paid to the contact multiscale features and, in particular, to the mixed lubrication regime occurring in articular joints. The formulation is based on a homogenized Reynolds equations and accounts for the tissue porosity. Numerical outcomes, corroborated by experimental results, allow us to understand the original causes of cartilage dehydration and rehydration.

Keywords : cartilage tribology, soft porous lubrication, rehydration

Movement, our most basic human function, relies fundamentally on joints articulation and, thus, on cartilage, which ensures exceptional mechanical properties in terms of high resilience, considerable load-carrying capacity and remarkably low friction. These features are related to the peculiar cartilage biphasic structure, comprising synovial fluid in a fibrous collagenous scaffold: during loading, interstitial fluid is pressurized to support the load and lubricate the contact hydrostatically, but, at the same time, starts to flow out continuously from the tissue. As schematically reported in Figure 1, there exists, thus, a correlation between fluid loss from excessive periods of static loading and joint space thinning. The latter causes cartilage osteoarthritic degradation, with massive social and economic costs estimated equal, in the USA alone, to 140 billion dollars each year [1]. Fortunately, in physiological conditions, during articular motion, joints reverse exudation due to a sliding-induced rehydration mechanism. The latter is vital for our health, but a comprehensive theory on the process and on its implications, in terms of load carrying capacity and friction, is still missing.

In this work, we aim at theoretically explain the rehydration phenomenon by developing a numerical theory to assess the lubrication, occurring at multiple scales, between cartilage tissues [2]. In particular, we rely on a homogenized formulation of the Reynolds equation, properly modified to consider the flow that porous cartilage exchanges with the remaining lubricating fluid. Our results, based on experimental measures of the cartilage surface roughness, show how the lubricating flow pressure and the film thickness influence such a porous flow. In particular, rehydration is shown to have purely hydrodynamic origins and, thus, it depends on the relative sliding speed between the contacting bodies. Interestingly, the rehydrative rates predicted by our methodology are consistent with experimentally measured values and corroborate the robustness of our methodology.

In addition to the theoretical interest, related to the rehydration theory, this work provides a practical tool for the analysis of healthy joint mechanics under realistic tribological conditions. Furthermore, understanding biphasic material lubrication will significantly contribute to engineer new self-lubricating biphasic materials, with marked impact in joint replacement and, in the industrial field, in slow-moving boundary lubricated bearings encountered in many engineering applications.

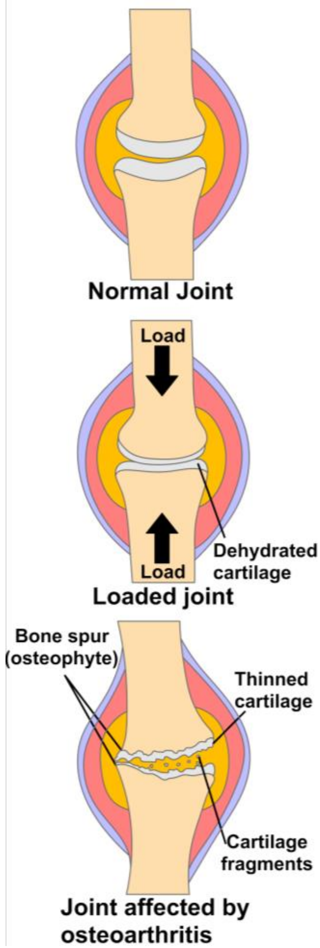

Figure 1. Schematic of the exudation process occurring in cartilage and reversed by sliding induced rehydration.

References

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