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Joint Tribology: a Supramolecular Chemistry

Pankaj Tomar

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Pankaj TOMAR
https://orcid.org/0000-0002-7040-2844
IGDTUW/GGSIPU, India
Email; pankaj_12343@rediffmail.com

Abstract
The perceptible friction at articulating cartilage is a complex phenomenon of biomolecular digestion of interfacial TRIBO environment or superficial zone lubricin discontinuous coat. The friction stress at the mating interface is in scarcity of lubricin, imperfection of natural lubrication over joint articulation due to biomechanical degradation, and residual biomedical indicators. The healthy articulating joints provide an ultra-low friction coefficient that is relatively lesser than bionic interfaces and interphases.

Keywords: Heterogeneity, Energy balance, Viscoelasticity, Synovial biomolecules

1. Introduction
The cartilage lubrication is a soft tribology that provides ultra-low friction at the joint with synovial fluid, cushioning, and distributes interfacial force that arises in load-bearing applications. The nominal stress at acetabular cartilage is reported for two implanted instrumented femoral heads in gait and stumbling despite a significant difference in gender, morphology, mobility, and coordination [1]. The resultant hip joint loadings, orientation, and the moments are reported during walking/running in terms of body weights over the first few months after implantation for interpretation of human joint kinematics and kinetics [2]. Static mechanical loadings at the hip joints are included in terms of body mass index for perceptible frictional boundaries and undergoing artificial implantation for synergistic mechanical work during daily life [3]. Biomechanical assessment of tissue retrieved from a study of cartilage defects included quantitative biomechanical properties, the tensile strength of repaired tissue, and the integration strength of the joint defect environment [4]. Articular cartilage is a heterogeneous and anisotropic composite material consisting of 20-30 wt% of solid-phase mainly collagen Type II and proteoglycans while the rest is bio-lubricant [5]. The viscoelastic performance of synovial lubrication is expressed from biomechanical diffusion across permeable cartilage with equitable pumping of biological lubricant at the interface from the synovial cavity under quasi-static loadings during human locomotion. The endurance at articulating cartilage is regulated by the viscoelasticity of synovial fluid for rationalization of adhesion.

The mechanical and material properties of articular cartilage are expressed in terms of impact energy, speed, dynamic elastic modulus, and coefficient of restitution with variance [6]. Stribeck curve is structured for trifurcation of synovial lubrication regimes at articulating cartilage with operating parameters in consideration of ultra-low friction performance by lubricin [7]. Synovial is replenished due to the degradation of biological matter and permeability or fluid pressure diffused bio-lubricant for maintaining ultra-low friction coefficient [8]. Biomechanical diffusion is viable in the cartilaginous extracellular matrix for assessment of diffusivity in inhomogeneous tissues for transportation of fluid secreted by cellular membrane tension due to biomechanical factors [9]. The tribological rehydration at articular cartilage is presented as a function of physiological sliding speeds, hydrodynamics, and interstitial fluid pressure for preventing tissue material collapse in modeling cartilage as a tribological material [10]. Synovial fluid is viscoelastic as a function of mechanical strains in presence of hyaluronan macromolecules for prediction viscosity by the generalized power-law model [11]. The cellular membrane analogy is assumed for homogeneity and isotropic mechanical properties of cartilage materials whereas inhomogeneous/anisotropy in biological extracellular matrix [12-13]. The superficial zone of articulating cartilage is a tribological interface for preventing adsorption and maintaining ultra-low friction coefficient.

2. Biomechanics
The Fluid-Mosaic Model of Membrane resolves amphiphilic performance of cellular superficial zone in function, structure, and dynamics for an understanding of hydrophilic and hydrophobic linked macrostructure. A fluid-like plasma membrane can flow in response to tension gradients by mechanical loadings fundamentally an integral protein in a completely fluid bilayer liquid phase for explaining diffusivity across the membrane [14-15]. Modified Brinkman equation includes diffusivity in consideration of hydrodynamic interaction of cellular membrane by augmenting stokes

equation in drag term for interpretation of augmented stress [16]. Viscoelasticity of cartilage biomaterials is predicted by Kelvin-Voigt model in which an elastic spring and a viscous damper connected in parallel for identical strains with components included for fundamental information mechanism at the tribological interface of articulating cartilage [17]. The deviation of classical law of friction at articular cartilage due to viscoelastic rheology of interfacial matter, biomechanical diffusion of boundary lubricant for prediction of friction coefficient as per the requirement of the basic academic structure [18-19]. Friction is a complex phenomenon seen in daily life for the protection of life and personal liberty. Lubricin is initially identified in synovial fluid and termed superficial zone protein (SZP) later differentiated based on of molecular weights having amino and carboxyl functional groups terminals (~200 nm) macromolecular structure [20]. Lubricin binds and regulates immune receptors/anti-inflammatory expression at articulating joints for biomechanical integration of cartilage as boundary lubricants from the molecular synergy of a biological coating [21]. Hyaluronan in synovial biological lubricant is a linear polysaccharide consisting of an alternating units of $_{D}$-glucuronic acid *N*-acetyl-$_{D}$-glucosamine linked by β-1,3-and β-1,4-glycosidic bonds-a network of entangled coils in the form of gel-like viscous shock-absorbing bio-lubricant [27]. The phospholipids at articulating cartilage are responsible for maintaining an ultra-low friction coefficient in the boundary lubrication regime.

Lubrication efficacy attributed to a particular phospholipid, dipalmitoyl phosphatidylcholine, proven significant reduction of friction at articulating joint or protection of cartilage biomaterial [28]. Nature has evolved bio-lubricants for a balance of frictional boundaries in a spectrum of biology and diversity as per conservation of mass and energy principle profoundly lubricin is a joint lubricant produced in cells. Synovial lubricant is studied by researchers for providing boundary lubrication at articulating joint for the role of surface-active phospholipids in reducing biomechanical friction and outlined that phospholipid with the heterogeneous system is tribologically viable [29]. The surface-active phospholipid hypothesis in imparting thin hydrophobic outer lining to the normal articular surface is the boundary lubricant reducing friction to low level and the deficiency of a surface-active phospholipid might explain the biomechanical of joint from TRIBO perspective [30]. Phospholipids are ubiquitous macromolecule of synovial lubrication, a fundamental ingredient for biophysical mechanisms of the membrane, and amphiphilic nature in the spectrum of hydrophilic with hydrophobic concerning surface adsorption and influencing surface tension of bio-membrane [31]. Membrane phospholipid inherently contributes to boundary lubrication in synovial lubricant, pathogenesis from the perceptible domain from starvation, and provides tribology.

S. No	Mechanochemical properties	Indicators
A#1	Abnormal joint loading, degeneration, and gender	Morphology
A#2	Collogen, chondrocytes, and proteoglycans	Cartilage
A#3	Lubricin, HA, phospholipids among others	Synovial fluid
A#4	GAGs digestion and morphological change of superficial zone	Sticking domain
A#5	Linear polysaccharides, β-1,3-and β-1,4-glycosidic bonds	GAGs digestion

Table A; Biochemistry of cartilage TRIBO molecules [22-26]

3. Materials and energy balance

Hypercholesterolemia and hypertriglyceridemia are major risk factors for perceptible friction at articulating cartilage in terms of osteoarthritis reported by a cohort prospective study [32]. High fat consumption and improper lifestyle are the biomedical issues with global society in metabolic syndrome for monitoring of mechanical stress at articular joint [33]. Metabolic perturbations influence glyceric acid, cellobiose, fructose, and lactic acid quality in assessment of energy reservoir [34]. The surface properties and environmental factors regulate cartilage morphogenesis, growth, and maturation of inhomogeneous/anisotropic biomaterials for low friction bearing cartilage biomechanics [35]. The reducing static mechanical load for reversibility from chronic morbidity into rationality is presented for transformation in macronutrient and achievement of negative energy balance in fuel oxidation [36]. Positive energy balance may contribute to energy imbalance in spectrum of energy intake and energy expenditure in consideration of physiological/behavioral indicators [37]. Fuel oxidation of macromolecules is useful for achievement of negative energy balance. Biomechanics and energetics in dynamics are fundamentally included with reference to mechanical efficiency by exerting muscles traction for locomotion from energy cost of 1 kcal/kg.km along with economy for maximization of efficiency [38]. Net mechanical efficiency for chronically energy deficient individuals is interpreted for factor such as a higher proportion of slow muscle fibers/greater ergonometric efficiency may contribute to higher muscular efficiency with conservation of energy principle [39]. Negative energy balance for reducing static mechanical load is expressed for rational fuel oxidation.

Mechanical efficiency is investigated for muscle temperature on rate of oxygen intake during exercise/rest and stipulated respiratory quotient ~1.04 during elevated mechanical work; ~0.82 at rest; 20-25 percent of mechanical efficiency [40]. Normal weight sample (N=15) with percent body fat (16.0 ± 1.9) are relocated in range of 19-21 percent mechanical efficiency whereas overweight sample provide relatively lesser mechanical efficiency [41]. The lean heterogeneity of biomolecules, improper lifestyle, environmental factor, and diversity of biology have a synergistic relationship for modulation of frictional boundaries in formation of static mechanical load due to lesser mechanical work [42]. The physiochemical fuel oxidation of intake meal is an implicit corner for regulation of materials and energy balance at articular cartilage for rationalization of mechanical efficiency above resting [43]. Mechanical efficiency is quoted an indirect indicator (Fig. 1) for prediction of biological friction at mating interface from biomechanical TRIBO perspective.

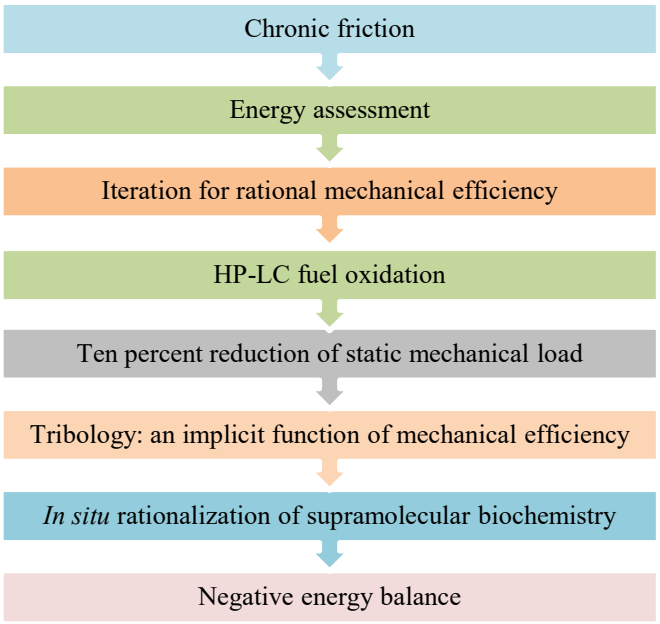

Fig. 1 Negative energy balance for favourable articular lubrication by iteration of mechanical work; Chronic friction is a biomechanical moderate risk domain of joint chronic pain; Energy assessment is an indirect way borrowed from anthropometry and lipid quality; Iteration of mechanical efficiency is periodical transformation of fuel quality and associated mechanical work on weekly basis; HP-LC fuel oxidation is pertaining to enriched protein macromolecules oxidation along with carbohydrate and fat for achievement of negative energy balance; Sustainability and bio-tribology for achievement of threshold mechanical efficiency in quasi-static human locomotion.

4. Bio-inspired Adhesion

Bio-inspired tribology is an emerging interdisciplinary scientific domain for re-searching towards model synovial lubricant, cell membrane inspired phospholipid biomaterial interface, and biocompatibilities for replicating natural synovial lubrication [44]. Artificial joint friction coefficient (more than 0.04) is summarized relatively more than natural synovial lubrication by comparing of articulating cartilage complex loading and motion with journal bearings in conventional tribology spectrum [45]. TRIBO performance of articular cartilage superficial zone may be predicted from the balancing of quasi-static mechanical forces by cell membrane tension profoundly every action creates equal and opposite reaction for harmony of classical mechanics-a balance of fluid and mechanical forces [46]. Boundary lubrication mechanism from third bodies molecular synergy/few molecular layers thick lubricant at interfaces reflected the scientific orientation towards resolving complexities of adsorption mechanism in improving tribological performance at biological replicating joints [47]. Friction and wear performance of 100 nm thick hydrophilic grafted polymer layers with lubricants are evaluated for low friction coefficient and high wear resistance from hydrated polyelectrolyte layer/polyethylene surfaces [48]. Lubricating biopolymer for rational functioning of articulating biomaterials studied with physiological processes, compressive and shear stresses in tissues, and protection of tissues biomaterials against wear or fatigue [49]. The CoCrMo wear tests have been carried out with 25 wt% bovine calf serum and human synovial fluid to investigate biotribology mechanisms in forming surface films during the tests to

understand their role in the lubrication process [50]. Wear of CoCrMo have been measured for a series of model synovial fluid samples including the effect of protein and phospholipid content content to replicate a range of healthy and diseased synovial fluid pathologies as a strong correlation with increasing protein content [51]. The mechanical, electrochemical, and biological functionalization inherently depend on tribological conditions in biomimetics articular joint.

5. Conclusions

The friction at articulating cartilage is a complex phenomenon predicted as an implicit function of genetic, epigenetic, environmental loadings, cartilage biomaterials morphology and mechanical properties, aging, and metabolic syndrome for an imbalance of fuel energy. Mechanical static loadings at articulating interface arise from anthropometry of body mass index for influencing biological lubrication inversely in aligned with positive energy balance. Cartilage-Cartilage interfaces with third bodies (PRG4/HA/Phospholipids etc.) enabled ultra-low friction coefficient (~0.001) for healthy articulation.

Author contribution

Author expressed a personal viewpoint of joint biomechanics in the form of a prospective study for achievement of performance indicators

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Conflict of Interests

None conflict of interests to declare

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Data availability statement

The elementary academic data is borrowed from the listed references

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