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Commentary on the Lamellar-Repulsive-Slippage Lubrication

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Abstract

In this article, we evaluated surface topographical images of the bovine (cartilage/cartilage) pair friction. In healthy joints, the cartilage (AC) surface coated with phospholipid multi-bilayers is activated by the lamellar-repulsive-slippage lubrication mechanism. Hydrophilic and negatively charged (-PO_4^--) natural cartilage surface is covered by phospholipid bilayers. These phospholipids have been demonstrated to exert highly desirable characteristics on the surface of articular cartilage such as efficient lubrication, load processing, and semi-permeability for nutrient transport. We attempt to demonstrate phospholipids involvement in boundary lubrication of articular cartilage by: 1) the surface amorphous layer (SAL); 2) negatively charged surface; 3) lamellar-repulsive lubrication; and 4) lamellar-slippage mechanism in (cartilage/cartilage) pair lubrication. The secret of the super low friction and wear between the cartilage-bearing surfaces is lamellar-repulsive and slippage mechanism of lubrication. We also present the evidence that the superficial phospholipid bilayer covering the articular surface of cartilage has a primary function of creating a hydrophilic surface with wetting properties, and hence, of controlling interfacial properties under 7.4 pH values. We conclude that lamellar bilayers slippage, as well as the short-range repulsion between the interfaces of the negatively charged (-PO_4^-) cartilage surfaces, is a primary determinant of the low frictional properties of the joint.

Keywords

Cartilage Surface, Boundary Friction, Lamellar-Repulsive Hydration Lubrication, Slippage Mechanism

1. Introduction

According to Hills' "boundary lubrication model" and our "lamellar-repulsive-slippage mechanism", the surface amorphous layer (SAL) is named the main effective solid lubricant in diarthrodial joint [1] [2]. The amphoteric-hydrophilic cartilage with lamellar structures on its surface can facilitate functional slippage mechanism in (cartilage/cartilage) pair lubrication. The surface-active phospholipid coating on the articular surface possesses highly desirable lubricating properties for efficient joint function.

The surface of articular cartilage depends on rate of adsorption, hydration, liposomes, and phospholipid phases, and bilayer formation. The concentrations of phospholipids adsorbed (%) on the AC surface are as follows: phosphatidylcholine (PC) 41%, sphingomyelin (SM) 32% and phosphatidylethanolamine (PE) 27%, whereas the synovial fluid is dominated by PC (67%), sphingomyelin, lysophosphatidylcholine (16% and 10% respectively), PE 2.5% and 3.5% (PEp = phosphatidylethanolamine-based plasmalogens; PS = phosphatidylserine; PG = phosphatidylglycerol; Cer = ceramide) [3] [4].

In this paper, we attempt to demonstrate phospholipids involved in boundary lubrication of articular cartilage by: 1) the surface amorphous layer (SAL); 2) negatively charged surface; 3) lamellar-repulsive lubrication; and 4) lamellar-slippage mechanism in (cartilage/cartilage) pair lubrication.

2. The Surface Amorphous Layer (SAL)

Figure 1(a) shows the self-assemble of phospholipid bilayers as the outermost lubricating lining of the joint. The electron microscopic imaging clearly reveals the lamellar structure and bilayers similar to natural membranes. The bilayers of phospholipids namely the surface amorphous layer (SAL), covers the natural surface of articular cartilage. We conclude that a very high porosity (70% to 80%) is a critical factor in providing excellent hydration lubrication properties of articular cartilage [1] [3] [4].

3. The Negatively Charged Model of Cartilage Surface

Figure 1(b) shows the strong electrostatic interaction of phospholipid molecules by their quaternary ammonium positive ion (Me_3N^+-) to the proteoglycan molecules in the articular surface. The excess carboxylate anion, R-COO^- and sulphate ions [5] provide a hydrophilic model of the cartilage surface. The strong cohesion between phosphate ions and calcium (II) (-PO_4^--Ca-PO_4^--) make the close-packed hydrophobic solid layer and the surface is negatively charged (**Figure 1(b)**). At pH 7.4 condition, the surface is negatively charged. A very high porosity (75%) is a critical factor in providing an excellent hydration lubrication of the articular cartilage. The quaternary ammonium (QA) ions have strong electrostatic bond strength and thus, able to bind to surfaces with excess negative charge [6] [7] [8] [9] [10]. The friction coefficient of the bovine (cartilage/cartilage) tribological pair vs pH 1.0 to 9.5 buffer solution is expressed by a bell-shaped curve. Measuring the interfacial energy vs pH (1.0 to 9.5) of spherical lipid bilayers resulted in the "bell-curve" shaped with the isoelectric point

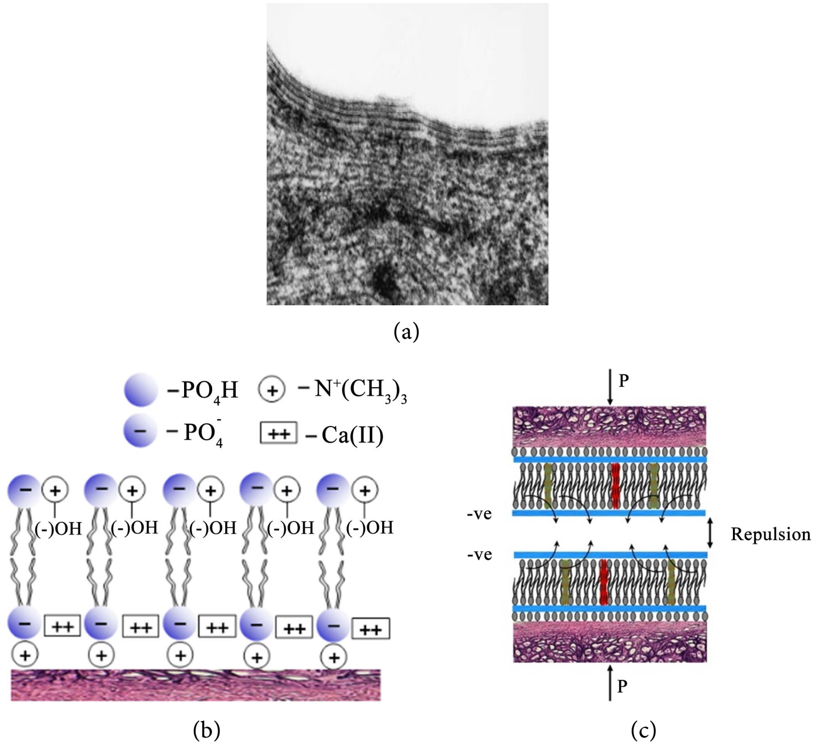

Figure 1. (a) The electron microscopic membrane lining of adsorbed phospholipid bilayers on cartilage surface; (b) The negatively charged model of cartilage surface; and (c) The biological lubrication mechanism facilitated by a "lamellar-repulsive" process [2].

about 4.0, this fact confirmed amphoteric character of a surface of articular cartilage [2].

4. Lamellar-Repulsive Hydration Lubrication Mechanism

In joints, lubrication is described by three words lamellar-repulsive-slippage mechanism [2] [8] [9]. **Figure 1(c)** shows the biological lubrication mechanism facilitated by a "lamellar-repulsive" process. Lamellar-repulsion slippage of bilayers is facilitated by: 1) fluid pressure at the interface described by McCutchen [11] and measured by Oloyede & Broom [12] as a mechanical component by weeping lubrication, and 2) hydration repulsion as the electrochemical (or charged) component (**Figure 1(c)**). The cartilage interfaces share a repulsive mechanism, fairly similar to that of the van der Waals and London (intermolecular) short-range repulsion, believed to be responsible for the low friction of the two negatively charged surfaces.

5. Lamellar-Slippage Mechanism in (Cartilage/Cartilage) Pair Lubrication

Highly hydrated phosphatidylcholine head groups at pH ~7.4, ($-PO_4^-$) are a main component of bilayer surface and synovial fluid components including hyaluronan, lubricin and PL micelles may reduce friction via lamellar-repulsive and slippage lubrication, **Figure 1(c)** and **Figure 2**. The goal of any lubrication

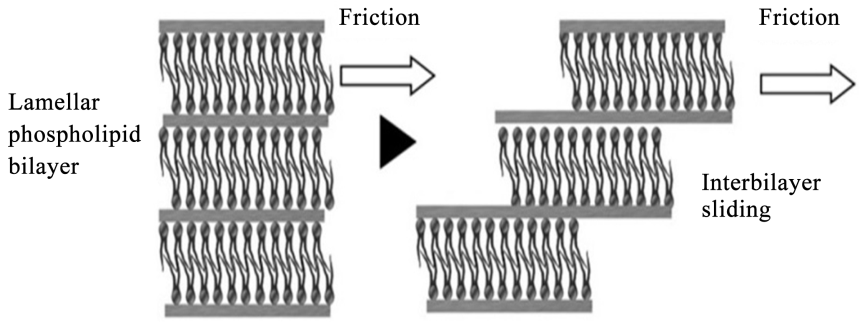

Figure 2. Illustration of lamellar-slippage mechanism in (cartilage/cartilage) pair [2].

approach is to separate the rubbing surfaces by a lubricant layer, in hydrodynamic lubrication, a thin film separates the surfaces from direct contact. In cartilage, the lubricants are bilayers of phospholipids (PLs). The term hydrodynamic lubrication does not define cartilage mechanism.

Slippage lubrication happens in our spine, neck (cervical spine) and lower back (lumbar spine), where the disc is a main lubricant, in case when the disc is losing water, we call this a spine disc disease [13]. Three or more bilayers (discs) exist on the surface of our cartilage but in osteoarthritic joint, the cartilage loses them gradually. By activating our joint (similarly to engine start), we can expect the highest wear. However, the design of our cartilage is based on the multi-bilayer structure and slippage lubrication supports the very low friction and low wear seen in articulating joints. The low friction of cartilage has been attributed to its negatively charged surface. The articular cartilage remains well lubricated over a lifetime of sliding and wear. The lipid-based boundary bilayer that renews continuously on cartilage surface is maintained by PLs.

6. Conclusion

We showed that phospholipid bilayers slippage facilitates an almost frictionless contact in the joint. Moreover, slippage of lamellar bilayers and short-range repulsion between the interfaces of the negatively charged cartilage ($-PO_4^-$) surfaces are critical determinants of the low frictional properties of the joint. The secret of the super low friction and wear between the cartilage-bearing surfaces is lamellar-repulsive and slippage mechanism of lubrication. We also present the evidence that the superficial phospholipid bilayer covering the articular surface of cartilage has a primary function of creating a hydrophilic surface, whose wetting properties, and hence, of controlling interfacial properties under 7.4 pH values. Thus, we conclude that lamellar bilayers slippage, as well as the short-range repulsion between the interfaces of the negatively charged ($-PO_4^-$) cartilage surfaces, is a primary determinant of the low frictional properties of the joint.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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