lubricants

Editorial

Editorial: Friction and Lubricants Related to Human Bodies

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Biolubrication plays a crucial role in assisting the sliding contacts in many organs in the human body. Notable examples are the joints, the skin surface, the eye, the mouth and gastrointestinal tract, the lungs and the red blood cells. In all cases, reduced lubrication leads to increased friction and adhesion between the surfaces in contact, which may lead to the surfaces becoming stuck and damaged, ultimately leading to irritation, pain and trauma. Over the past few decades, major advancements have been achieved in the accumulation of knowledge on the subject.

Joint lubrication has been shown to involve a complex and probably adaptive set of lubrication mechanisms involving the smoothness of the cartilage lining of the bone surfaces, the properties of the synovial fluid, which is a lubricating hydrogel of collagen fibrils, hyaluronic acid, glycoproteins (lubricin) and water, and a weeping mechanism by which joint pressure releases synovial fluid into the interspacing liquid film separating the cartilage surfaces.

The lubrication of epidermal surfaces such as the skin, eye, mouth, lung and gastrointestinal tract follows different mechanisms. The relatively dry surface of the skin and hair is protected and lubricated by a thin coating of sebum in which moisture plays a critical role. On the one hand, moisture reduces the sliding resistance by providing suppleness, elasticity, plasticity, flexibility and softness to the deeper layers of the skin, but on the other, it increases the adhesive properties, friction and microbial proliferation of the outer surface. Loss of skin surface lubricity can lead to unpleasant sensations of contact with clothes, fabrics and solid surfaces, and can lead to uncomfortable stickiness, irritation, trauma and wounds such as decubitus. The naturally moist mucosal surfaces of the eyes, mouth, lung, gastrointestinal tract and vulva are kept in a lubricated state by specific biolubricants, i.e., glycoproteins (mucins), (phospho-)lipids and water. Insufficient lubrication can lead to various discomforting and clinical conditions such as the eyeball sticking to the eyelid or to contact lenses, xerostomia (dry mouth syndrome, due to a reduced salivary flow or quality, resulting in difficulty in swallowing and speaking), pleuric rub caused by various lung diseases, difficulty in sexual penetration, bowel irritation and trauma which can ultimately lead to cancer development. A special aspect of the biolubrication of the mouth is in the way it affects sensory and texture perception. The effect is strongly related to the perception of smoothness, creaminess and the opposite of roughness and astringency, which probably have the biological function to test the quality of the food material for the way it affects the lubrication of the mucosal lining of the alimentary tract, giving feedback to food preference and eating behavior (speed, subsequent food selection during a meal).

In relation to the various symptoms of imparted lubrication, various studies are focused on specific lubricants and moisturizers that can correct the malfunctioning of the various organs. To measure and interpret the function of these products, fundamental studies in the physics of tribology and the biophysics and biochemistry of the involved compounds are being conducted.

The Special Issue "Friction and Lubricants Related to Human Bodies" of the MDPI open-access journal *Lubricants* reviews the fundamentals of lubrication theories and polymer biophysics and describes in vitro and in vivo experiments and measuring tools. It comprises six publications which are introduced in more detail below.

An author consortium from Italy reports on pleural lubrication [1]. Pleural relates to membranes in the lung; the pleural fluid acts as a lubricant between the two membranes. During breathing, the pleural surfaces of the lung and chest wall slide against each other continuously without damage. The surfaces of the pleural space consist of a single layer of delicate mesothelial cells covered with microvilli up to 6 μm long. Pleural liquid and lubricating molecules protect the mesothelium from shear-induced abrasion. Porta et al. [1] report a coefficient of kinetic friction of about 0.02 in rabbit parietal pleura sliding against visceral pleura in vitro at physiological velocities and under physiological loads [1]. Two models are currently used to attempt to explain this coupling: in the first, the pleural surfaces are separated by a uniform, relatively thick (20 μm) layer of pleural liquid, whereas in the second, the average thickness of the pleural liquid is less than 10 μm.

Little is known about the friction of ski fabrics on snow. The injury risk is decreased for high-friction garments when sliding on snow. Authors from Innsbruck, the main city of Tyrol, a western federal state of Austria, where winter sports are highly prominent, report on the kinetic friction of sport fabrics on snow [2]. The purpose of their study is to demonstrate a novel approach to study the snow friction of different fabrics used for ski garments with respect to fabric roughness, speed, and contact pressure. After falls, skiers or snowboarders often slide on the slope and may collide with obstacles. Thus, the skier's friction on snow is an important factor to reduce the incidence and severity of impact injuries. The three types of fabrics investigated comprise commercially available ski overall material, a smooth downhill racing suit and a dimpled downhill racing suit. Linear tribometers were used, and the snow in the experiments had a temperature of −4.3 °C, a density of 400 kg/m^3 and grain sizes of approximately 250 μm. Friction coefficients were between 0.19 and 0.48—this is clearly above the ones for skis against snow. The friction coefficient tended to increase with the increasing roughness of the fabrics, especially at high contact pressures. The main friction mechanism for the fabric turned out to be dry friction. Only the fabric with the roughest surface showed friction coefficients which were high enough to sufficiently decelerate a sliding skier on beginner and intermediate slopes. These results provide important information for the manufacturers of ski garments.

The medicinal field is touched upon in three contributions in the current Special Issue. Authors from Portugal investigated the friction of human skin against different fabrics for medicinal use [3], a team from the US presents a quantitative analysis of retrieved glenoid liners [4] and authors from Switzerland and Germany report on the development of a synthetic synovial fluid for tribological testing of joint prostheses [5]. Friction between the human skin and textiles is a critical factor in the formation of skin injuries which are caused if the loads and shear forces are high enough and/or take place over long periods of time. The coefficient of friction (COF) of textiles against skin is mainly influenced by the nature of the textile, the skin moisture content and the ambient humidity. Human skin is a nonlinear viscoelastic material. Therefore, Amonton's law of friction, in which the friction force is directly proportional to the normal force and independent of the contact area, does not apply. Rather, skin friction follows a two-term friction model consisting of an adhesion and a deformation component. According to Adams and coworkers [6], adhesion is considered as the main contribution to the friction of human skin, whereas deformation plays a minor role. Research topics such as tactile perception and haptics in relation to skin tribology are largely unstudied and poorly understood. The topic is very interesting for the design of surfaces with a predefined tactile feel (such as smooth or soft). Vilhena and Ramalho [3] investigate four types of hospital fabrics: a reference hospital material that is used in bed linen, a foam dressing, an adult diaper and a bed protector made from soft, non-slip, waterproof polyethylene. The coefficient of friction (COF) was tested for these four materials at the ventral forearm of a 42-year-old male volunteer. They show that, compared to natural skin conditions, the COF was always increased by applying a layer of Vaseline to lock moisture into the skin. Skin friction of fabrics is influenced by parameters such as the fiber material, structure and finish. Moisture can accelerate and promote the formation of pressure ulcers. The COF varies with the human body region and physiological skin conditions. Furthermore, the COF of wet skin exceeds those in the natural skin by a factor of more than two. As the authors show, natural skin conditions (dry skin) produce the lowest COF for the different body regions.

In total joint replacement devices with a polyethylene bearing, failures are often due to excessive polyethylene wear. Total shoulder arthroplasty comprises a stem, head and glenoid liner as components. Glenoid refers to the concave side of the joint of the shoulder blade and the upper arm bone. The study of glenoid liners, which are typically made of cross-linked, ultra-high-molecular-weight polyethylene, retrieved from revision surgery may allow for insight into common wear patterns and improve future product designs. Childs and co-workers [4] recruited multiple analysts to evaluate glenoid liners. Currently, there is no standard for numerical wear analysis protocols. Integrating a numerical wear classification scheme is valuable for making direct comparisons among various implants. Nine modes of damage (as proposed by [7]) were investigated in the study: delamination, pitting, scratching, abrasion, burnishing, deformation, complete wear-through, embedded debris and complete fractures. All liners were examined and scored by four independent observers, and this resulted in inconsistency of observer evaluations, corroborating the need for more objective analysis schemes.

Authors from Switzerland and Germany address the development of a synthetic synovial fluid for preclinical wear tests predicting the in vivo performance of joint prostheses [5]. Usually, wear tests of joint prostheses are performed using various bovine sera, with different protein concentrations and compositions. Additionally, the viscosity of such sera differs from the viscosity of synovial fluid. This yields poor reproducibility of results between laboratories. The fluid developed by the group mimics the genuine synovial fluid by consisting of hyaluronic acid, lyophilized protein bovine serum albumin, immunoglobulin and lecithin. Tribological tests performed with ultra-high molecular weight polyethylene pins sliding against CoCrMo discs on six different test fluids for two million cycles each resulted in the final selection of one fluid which has clinically relevant friction and wear coefficients and is furthermore cost effective. This is an important factor because litres of test liquids are needed for the preclinical tests.

Topographic surface patterns on the micro- and nanoscale can yield a significant reduction of the COF and bacterial adhesion. The key issue is to understand the connection between a material's properties, the structures of different scales (nanoscale, microscale, macroscale) and the resulting macroscopic properties [8]. Some structured surfaces not only prevent the attachment of bacteria, but also show active bactericidal activity. Specific surface structures/patterns might be key in creating unique antimicrobial, adhesive or frictional properties. Structured or hierarchical surfaces can be produced by various methods. Researchers from Germany in this Special Issue treat direct laser interference patterning as a tool for tailoring the contact area for frictional and antibacterial properties [9]. This method uses at least two coherent laser beams that are superimposed to create a defined intensity distribution, thus resulting in a certain surface topography: typically, periodic surface patterns with feature sizes in the micrometer range. The authors, however, create Penrose patterns, which do not have a three-dimensional translation symmetry, making them interesting tools for tribological applications under dry friction due to reduced geometrical interlocking [10,11]. Antibacterial surface structures for implant materials may prevent bacterial attachment after insertion of the implant. An inspiring idea for the realization of such physical structures that actively destroy bacteria comes from living nature. Needle-like structural features in cicada wings with a diameter of 60 nm, a height of 200 nm and a spacing of about 170 nm stretch the bacterial envelope until it tears [12]. Similar effects were observed in titanium coatings. The group accomplished such structures in the micrometer and sub-micrometer range by laser interference structuring—with the fantastic result of 80% less bacterial attachment in initial tests. Direct laser interference patterning looks to be a highly promising method for the generation of optimized surfaces for biological applications in terms of tribological and antibacterial properties.

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