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Current ORTHOPAEDICS

MINI-SYMPOSIUM: BIOMECHANICS FOR THE FRCS ORTH EXAM

(v) Biotribology

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Metal-on-metal;
Ceramic-on-ceramic

Summary
Basic principles of engineering tribology are briefly reviewed, in terms of surface metrology, contact mechanics, friction, lubrication and wear. In each of these topics, applications to artificial hip joints are discussed in detail. Various artificial hip joints with different bearing material combinations are considered, including ultra-high molecular weight polyethylene against metal or ceramic, metal-on-metal and ceramic-on-ceramic.

Introduction

According to the Concise Oxford English Dictionary, 'Tribo-'is derived from the Greek word 'Tribos', meaning rubbing and friction, and Tribology is 'the study of friction, wear and lubrication, and design of bearings, science of interacting surfaces in relative motion'. Tribology was introduced in 1966 in the Jost Report (Lubrication (tribology) Education and Research, Department of Education and Science, HMSO, 1966) and was formally defined as "The science and technology of interacting surfaces in relative motion and the practices related thereto". In short, tribology deals with lubrication, friction and wear, which can be involved with a number of basic engineering subjects such as solid mechanics, fluid mechanics, lubricant chemistry, material science, heat transfer, etc.

The importance of tribology in engineering is self-evident since virtually all engineering components and systems are involved with relative motion. Typical examples include ball bearings, gears, tyres, etc. The importance of tribology in biological systems is also clear. The term *bio-tribology* was introduced by Dowson and Wright[1] in 1973 to cover "... *all aspects of tribology related to biological systems*". The best-known example of the subject is the numerous studies of natural synovial joint lubrication and the design, manufacture and performance of various forms of total joint replacements. Wear of bearing surfaces in humans and

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animals can result in pain and restricted movement. The consequences of excessive wear of the bearing material (articular cartilage) in synovial joints are well known.

Typical examples of tribology applied to biology include:

- Wear of dentures[2,3]
- Friction of skin and garments, affecting the comfort of clothes, socks and shoes,[4,5] and slipperiness[6,7]
- Tribology of contact lenses and ocular tribology[8]
- Tribology at micro-levels—inside cells, vessels and capillaries such as lubrication by plasma of red blood cells in narrow capillaries[9]
- The wear of replacement heart valves[10]
- The lubrication of the pump in total artificial hearts[11]
- The wear of screws and plates in bone fracture repair[12]
- Lubrication in pericardium and pleural surfaces[13]
- Tribology of natural synovial joints and artificial replacements.[14,15]

This review will focus on the tribology of artificial joints, in particular to review studies of surface, friction, lubrication and wear.

It should be pointed out that tribological studies of bearing surfaces should ideally be considered in conjunction with biological studies of wear debris. This is particularly important in artificial joint replacements, since it is generally accepted that the major long-term factor limiting clinical outcome is loosening, caused by osteolysis and adverse tissue reactions to wear particles (see Ingham and Fisher[16] for a recent review). Therefore, it is important to eliminate or, if that is impossible, to minimize wear. However, since biological reactions mainly depend upon the number and the size of wear particles, the wear volume as well as the size distribution of wear particles are important. For example, in hip implants using metal-on-metal bearings, the wear volume is generally greatly reduced compared with polyethylene-on-metal. However, the size of metallic wear debris is generally much smaller.

Surfaces

All real surfaces are rough on microscopic scales. For example, typical atomic diameters are between 1 and 10 Å ($1\,\text{Å} = 10^{-10}$ m). The smoothest surface is achieved on mica, with irregularities in the order of 20 Å. The irregularities on quartz crystal are of the order of 100 Å. The smoothest bearing surface for artificial joints is usually found on ceramics, with irregularities in the region of 0.005 μm, while for metallic bearing surfaces, these are generally in the region of 0.01 μm.

The most common parameter used to characterise the roughness of a surface is the arithmetical mean deviation (or average roughness or centre line average), which is denoted by (R_a). The definition of other surface roughness parameters and application to artificial hip joints can be found elsewhere.[17] Roughness parameters are usually measured with a contacting Talysurf profilometer or non-contacting white light interferometer.

Typical (R_a) values for surfaces produced by different engineering production processes relevant to orthopaedic implants are given in Table 1 (taken from Dowson and Wright[18]).

Table 1 Typical (R_a) values for surfaces produced by different engineering production processes relevant to orthopaedic implants (taken from Dowson and Wright[18]).

Production process	R_a (μm)
Sand casting	12.5–25
Sawing	3.2–25
Forging	3.2–12.5
Drilling	1.6–6.3
Turning	0.4–6.3
Die casting	0.8–1.6
Grinding (coarse)	0.4–1.6
Grinding (fine)	0.1–0.4
Polishing	0.05–0.4
Super-polishing	0.025–0.2
Super-finishing	0.005–0.01

Table 2 Comparison of (R_a) values for surfaces between engineering and bioengineering applications (taken from Dowson and Wright[18]).

Components	R_a (μm)
Plain bearings in turbines	0.12–1.2
Rolling bearings in gear boxes	0.05–0.3
Gears in engines	0.25–1
Articular cartilage	1–6
Endoprostheses (metal)	0.005–0.025
Endoprostheses (plastic)	0.1–2.5

A comparison of the (R_a) between engineering and bioengineering components is shown in Table 2.

Typical (R_a) values for various bearing surfaces used in current artificial hip joints are summarised in Table 3, as well as the composite surface roughness defined as

$$R_a = \sqrt{(R_{a\_Head})^2 + (R_{a\_Cup})^2}. \tag{1}$$

Friction

Friction is loosely defined as the resistance to motion. Friction was first studied by Leonardo da Vinci (AD 1452–1519), (http://www.tribology-abc.com/abc/history.htm). There are three laws of dry friction:

I. The force of friction (F) is directly proportional to the applied load (W)
II. The force of friction (F) is independent of the apparent area of contact
III. The kinetic force of friction (F) is independent of the sliding speed (V).

The first two laws are attributed to Amontons who, in 1699, provided an explanation of friction as the work done to lift one surface over the roughness of the other, or from