VIGYAN 2047 Volume 3 No. 2 February 2026 Pages 19–23

Bio Tribology

Kamal Mukherjee

Initial application of tribology was on metals and their lubrication, automotive & other industries. Later on, it has manifested towards every aspect of the society & continuous research into field has led new areas on human such as dental science, ocular science, heart valves, orthopaedics, sports and many more, where knowledge of tribology is utilized to create new breakthroughs—bio tribology.

Biomedical (Bio-tribology)

The application of tribology in biological systems is a rapidly growing field and extends well beyond the conventional boundaries. Biomedical tribological systems involve an extensive range of synthetic materials and natural tissues, including cartilage, blood vessels, heart, tendons, ligaments, and skin (Fig.-1). These materials operate in complex interactive biological environments.

Bio-tribologists incorporate concepts of friction, wear, and lubrication on the design of joints and prosthetic devices, the wear of screws and plates in bone fracture repair, wear of denture and restorative materials, wear of replacement heart valves, and even the tribology of contact lenses for eyes.

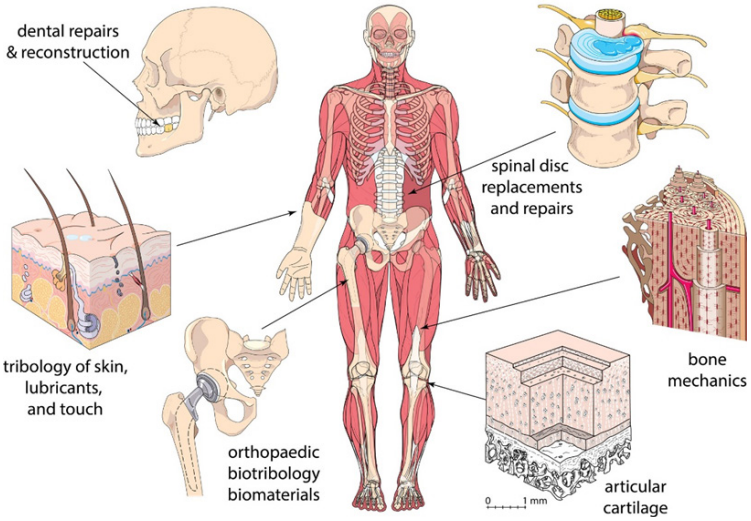


Fig.-1: Human related tribology

Oral/food tribology

The food which enters in the mouth is subjected to a series of mechanical processes by the lips, tongue, teeth and palate in order to facilitate digestion. Different types of feeling due to different size, shape etc. of food & its various process are shown in Fig-2. Thus, oral processing of food is a dynamic multistage process consisting of complex stages of biting, chewing, saliva incorporation, bolus formation, swallowing, and mouth coating.

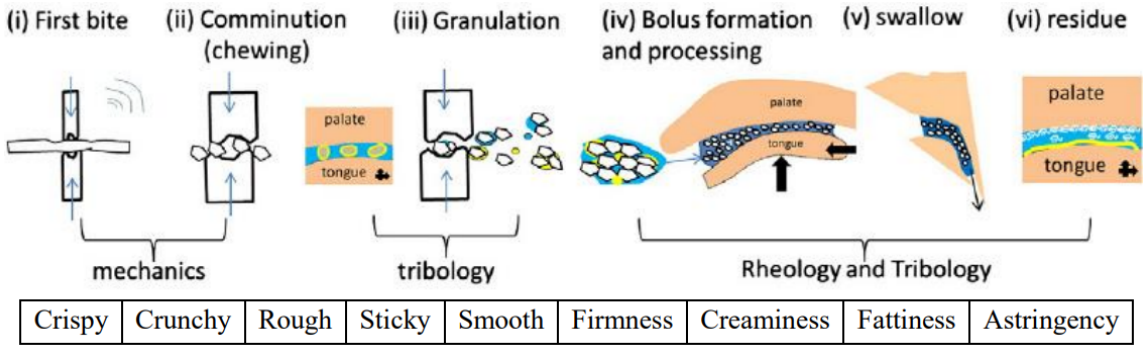


Fig-2: Visualisation of the six stages Stoke et al proposed occur during oral processing of solid food (ref. Fig 3. from Stokes et al. (2013))

Many macroscale pits and grooves are present in the tongue surface & they contain your taste buds, the things that help you taste everything from sour lemons to sweet peaches. The friction properties depend on many factors

including the lubrication properties of saliva, the oral surfaces involved (which differ between individuals depending on age, sex, health etc.) and the food itself.

Role of tribology in food products

a) General problem related to soft drinks: Consumers generally prefer regular (sugary) soft drinks over diet (sugar free) soft drinks. Diet drinks are a healthier option than regular drinks but consumers often complain about the taste difference. This is achieved by two ways e.g. changing food texture and mouthfeel which are of huge interest to food tribologists; **b) Dairy products:** Ice-creams, milk bars with higher milk content will have higher lubrication effect and are soft and smooth. Ice-creams, milk bars with 50 percent milk content will have higher friction coefficient but using tribological and rheological solutions, the friction values are reduced to products containing 80 percent and 100 percent milk. The research is further extended to sports drinks and fruit juices.

So, tribology of real food samples is not to replace sensory analysis in food industries, but it helps to navigate product development in the right direction.

Tribology uses in cardiovascular devices

Stents and grafts: These are used either to correct by strengthening it or bypass a blockage or defect entirely by creating an alternate (new) pathway for your blood to flow through (Fig.-3, a & b).

1) Stents are cylindrical metallic frames (more of a coil) to strengthen it from clogging which are expanded at high pressure inside a blood artery to keep the passageway open.
2) Grafts are tubes that are shaped like blood vessels, used as a bypass path to the blockage—to make a continuity of blood flow.

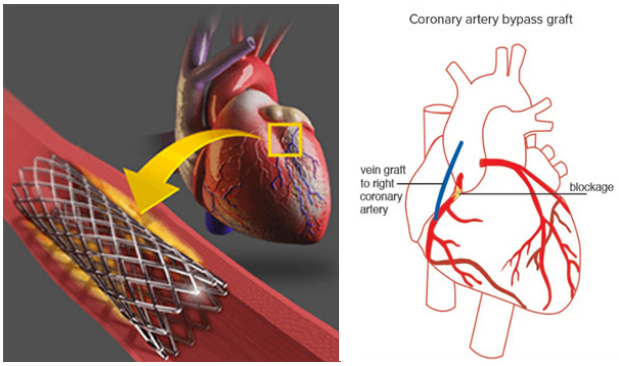


Fig-3: (a) Stent; (b) Coronary artery bypass graft surgery (CABG) is done mainly to relieve angina symptoms.

The material used for stents and grafts have low friction, wear and low corrosion characteristics as they are in continuous contact with the soft tissues in the region and the endothelial cell layer of the heart. Nitinol which is a Nickel Titanium alloys are generally used to manufacture stents. Characteristics such as super-elasticity, shape memory effect, corrosion resistant, low friction & wear makes it a prime choice. Stents are also coated with biocompatible coatings or polymer-free coatings which help achieve low friction & wear. UHMWPE (Ultra high molecular weight polyethylene) and ePTFE (Expanded PTFE) are the most preferred graft materials as both have low coefficient of friction and anti-wear capabilities.

Artificial heart valves: It is a device implanted in the heart of a patient to replace a malfunctioning natural valve. Mechanical heart valves (MHV) are commonly used as artificial heart valves. The material used for manufacturing of MHVs are strong, durable, low friction & wear resistant. Pyrolytic Carbon or PyC is a fatigue resistant, biocompatible, durable material which is normally used for manufacturing MHVs. Biocompatibility and excellent tribological properties of Diamond-like carbon DLC coating provide long durability to MHV's material.

Tribology of hair

Tribology is applicable to our own hairs where friction, wear and lubrication persist. The hair care product industry focuses on characterization of friction and wear properties of hair and their lubrication so that a high-quality product such as shampoo, conditioner, hair lotion, hair spray are developed.

The hair shaft consists of: **a) Cuticle:** it's the outermost layer of the hair and is responsible for creating the shine and smoothness, **b) Cortex:** It's the middle layer of the hair and contains melanin pigment responsible for providing elasticity and natural colour & **c) Medulla:** It's the innermost layer and is not involved in salon services (Fig-4).

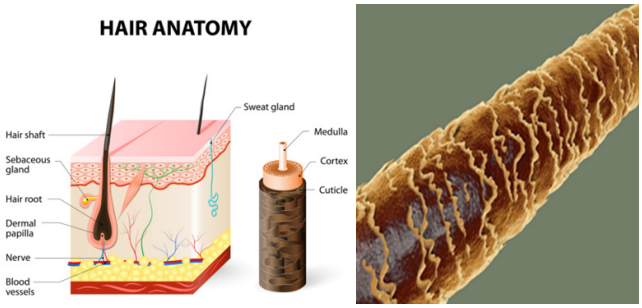


Fig.-4: Topology of hair

Let's talk about the three main processes present in hair:

- **Friction:** Processes like combing of hairs via thin spaced comb or plastic comb and environmental conditions like dust, dirt, humidity, sweat also contribute towards friction between hairs.
- **Wear:** Processes like blow-drying, excessive rubbing for drying it after taking bath, chemical hair dyes, hair colorants and hair straighteners leads to hair damage or wear of hairs.
- **Lubrication:** Hair shampoos and conditioners provide cleaning and lubricating functions.

Tribology of hair conditioners

Having healthy hair means having a smooth and unbroken outer layer called the cuticle, which protects the hair. This smoothness comes from a natural fatty acid layer on the cuticle's surface (Fig.-5).

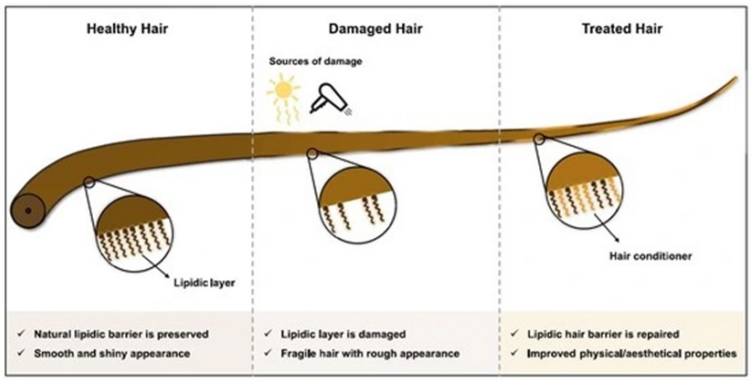


Fig.-5: Schematic representation of healthy, damaged and treated hair

Since hair is made up of cells that cannot repair themselves, people use hair conditioners to temporarily fix the cuticle by adding special molecules. Surfactants have multiple roles, such as being emulsifiers, wetting agents, foaming agents, and dispersants. Simply put, a surfactant is a molecule that has a water-loving part and a water-repelling part. To address the environmental concern, there is a push to enhance the biodegradability of conditioner ingredients. Bio-ingredients sourced from renewable, plant-based origins, such as biosurfactants and amino acid-based surfactants (AAS), offer a promising solution due to their biocompatibility and biodegradability. Cationic AAS, synthesized from natural amino acids, particularly stand out for their positive impact on hair.

Role of Tribology in hair: Particularly for rinse-off hair conditioners, the ultimate goal is to offer maximum wet lubrication by significantly reducing the coefficient of friction and enhance hair lubricity.

Dental tribology

The current world population is undergoing a transition towards becoming a geriatric society. According to the World Population Prospects 2019, the data suggest that the percentage of people aged 65 and over would rise from 1 in 11 in 2019 to 1 in 6 by 2050 (Lee, H., et al 2022) The tooth loss is the common feature of oral health among the elderly. Dental implants have the benefits over natural teeth e.g. safety & preservation of adjacent teeth and bones, improved speech and chewing, enhanced oral health and better quality of life. Typical materials used for dental implants are metal alloys, including stainless steel, cobalt–chromium alloy, and titanium-based alloy etc. Titanium alloys are mostly preferred implants due to their ability to strike a balance between mechanical performance and biological compatibility, ensuring the success and longevity of medical implants. The success rate of titanium dental implant surgery can exceed 90%, however, there is still a failure probability of approximately 10%. In order to reduce the failure rate, implant surface treatments play a crucial role in enhancing the healing process following implant placement, which is called "**osseointegration**" (Fig.-6). Osseointegration is defined as the direct structural and functional connection between the living bone and the surface of a load-bearing implant. Some of the latest surface modification techniques for dental implants on osteoblast and bone formation are—Titanium, Dental implants, Osteoblast, Anodization, Sandblasting, Acid etching, Laser radiation, HA coating, Chitosan etc.

In healthcare, nano-coatings serve as essential anti-bacterial agents to prevent infections & possess anti-abrasive qualities, providing strength to materials in scenarios where lubricants are not employed.

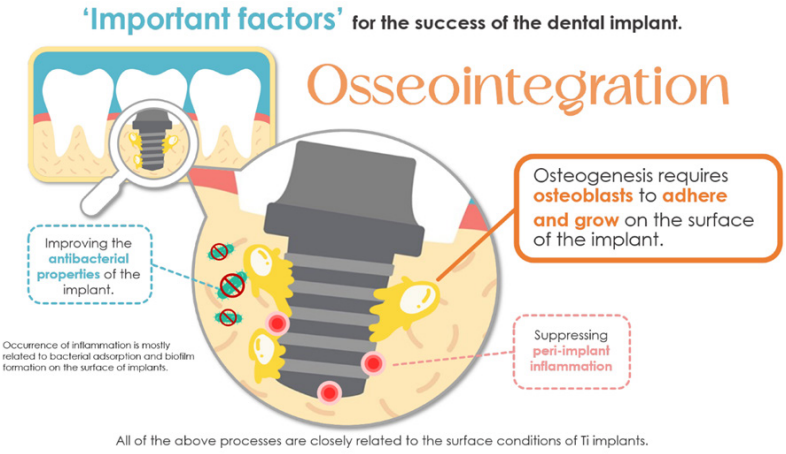


Fig.-6: Important factors for the successful osseointegration following dental implant placement

Tribology of bone joints

With the aging of the population, the incidence of orthopaedic diseases has increased, and the use of orthopaedic implants has increased rapidly.

Knee joint tribology

Many defects are seen in knee joint, particularly cartilage damage leading to Osteoarthritis (OA), due to changes in lifestyle. Total knee replacement surgery is a common solution offered. It involves the use of implants made from bio-compatible metals and ceramics. This procedure is commonly performed on individuals aged 45-65 who suffer from osteoarthritis. Lifespan of the implants can range from 15 to 20 years. Surgeons typically use materials such as stainless steel, titanium alloys, Co-Cr alloys, tantalum alloys, composites, ceramics, and polymers for these implants. An implant is surgically attached to the knee joint (Fig-7). While these implants provide relief to patients, daily activities can gradually lead to wear between the implants. As a result, wear debris affects the knee joint and causes pain for the patient. To address this problem, excellent results have been achieved in orthopaedic implants, promoting bone growth and reducing complications by nanotechnology i.e. applying a thin film or coating of bio-compatible material on the implant.

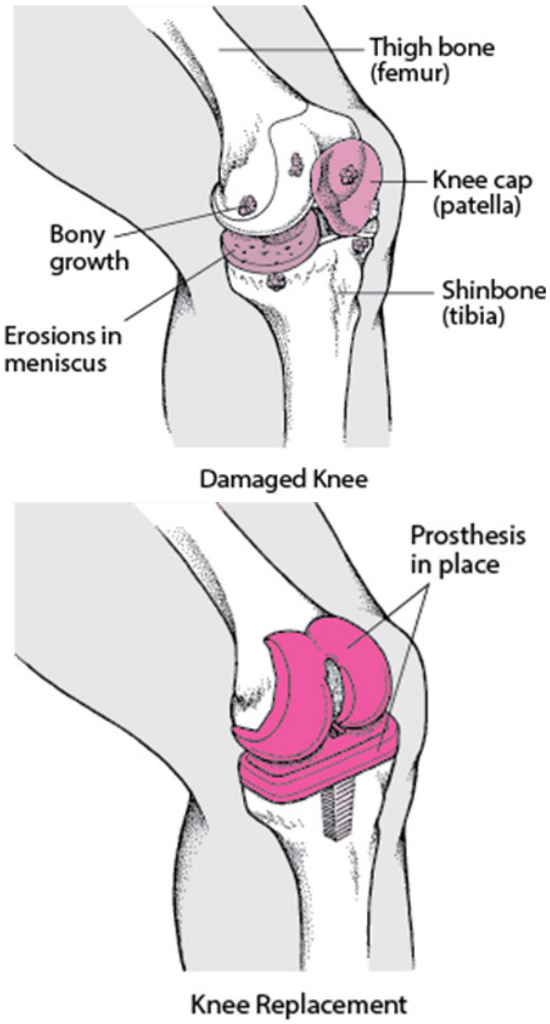
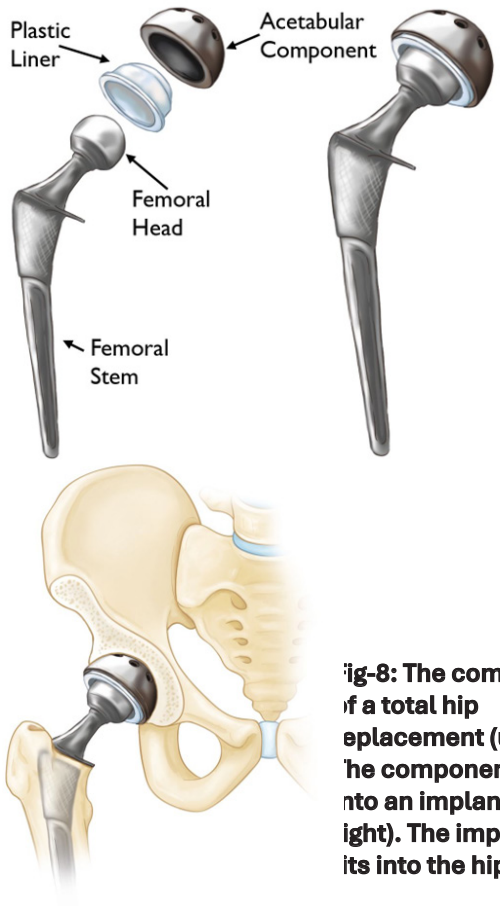


Fig-7: The figure showing the cartilage damage in the knee joint, and the implant (Prosthesis) replaced at that joint



ig-8: The components f a total hip eplacement (upper left). he components merged nto an implant (upper ight). The implant as it its into the hip (below)

The hip joint

It is a joint between femur and acetabulum of pelvis. The primary function of hip joint is to support weight of the body in both the static and walking postures. Excessive degradation of a hip joint often requires replacing it with an artificial joint, known as hip joint prosthesis. In such replacements, the 'femoral head' is replaced with a "metal ball", having a metal stem to be anchored into the hollow space inside the femur bone with bone cement; and the worn out 'acetabular (socket)' is replaced with "artificial socket" (Fig.-8 & 9). The majority of current hip implants utilize a material combination of ultrahigh molecular weight polyethylene UHMWPE articulating against either a metallic or ceramic component. These man-made bearings can sometimes last approx. 20 years in the body without failure.

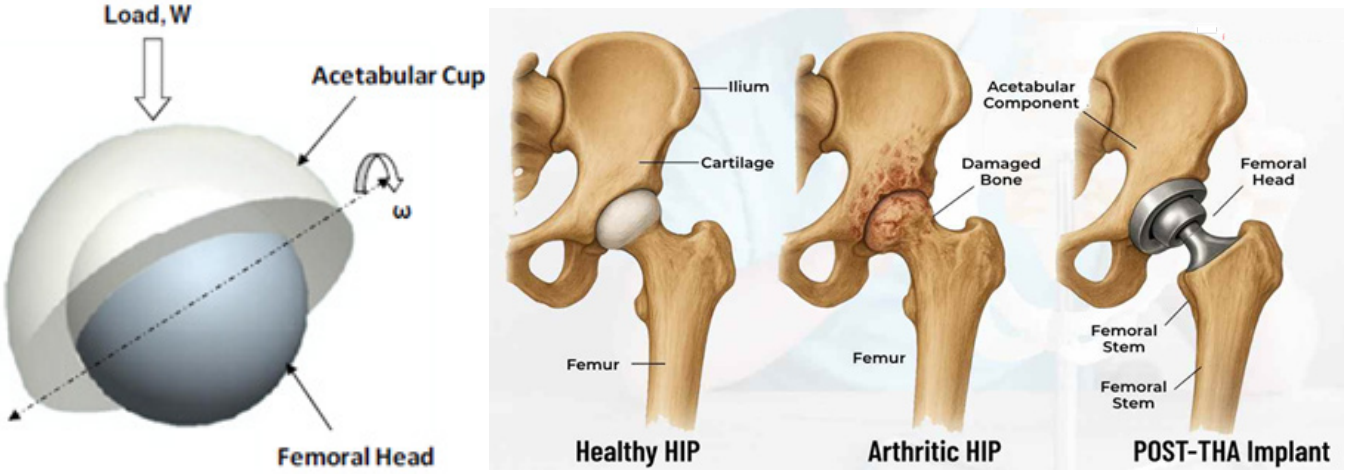


Fig-9: (a) 3-D view of Artificial Hip Joint; (b) A Closer Look at Total Hip Replacement (Total Hip Arthroplasty)

Various types of Hip prostheses are a) Metal-on-metal (MoM), THR. b) Metal-on-polymer (UHMWPE / XLPE), THR, c) MoM resurfacing THR & d) Ceramic-on-ceramic, THR

Various types of ACETABULAR CUP are: UHMWPE, Cross linked UHMWPE, Co Cr, Alumina, Polyurethane, Alumina Composite etc.

Various types of FEMORAL HEAD are: Stainless Steel, CoCr, Alumina, Alumina Composite Zirconia, etc.

How to overcome this challenge—Nano coatings

At the Nano level, materials exhibit unique properties that are impossible to achieve at the micro level. Nano coatings enhance material functionalities, including reducing friction, improving corrosion resistance, extending the lifespan of medical implants, and incorporating anti-bacterial properties.

Tribology for eyes

Eye blinking speed varies from zero speed (at rest) up to approximately 400 mm/s. Eye balling effect—the liquid around the eye is such that it keeps the eye boll rolling very freely in all directions. Even a very tiny dust particle (almost not visible to the eye) if it enters the eye—it is very irritating & have a painful rubbing sensation. Therefore, the IOL (Fig.-10) or contact lens are designed with precision so that one can have the eye-balling effect otherwise one can't move the eye balls freely. An intraocular lens (IOL) is a small, artificial lens implanted inside the eye to replace or supplement the natural lens. Designed to correct refractive errors and restore clarity These lenses are made from biocompatible materials, ensuring they remain functional and stable within the eye.

Bio-tribology—the study of friction, lubrication, and wear as it occurs in the body, is helpful in a product design and solve the related faults. ◆

Prof. Kamal Mukherjee, *a prolific science writer and nutritionist, is an active member of the Tribological Society of India and has held executive leadership roles in major national organizations. He can be contacted at kamalcbm28@gmail.com.*

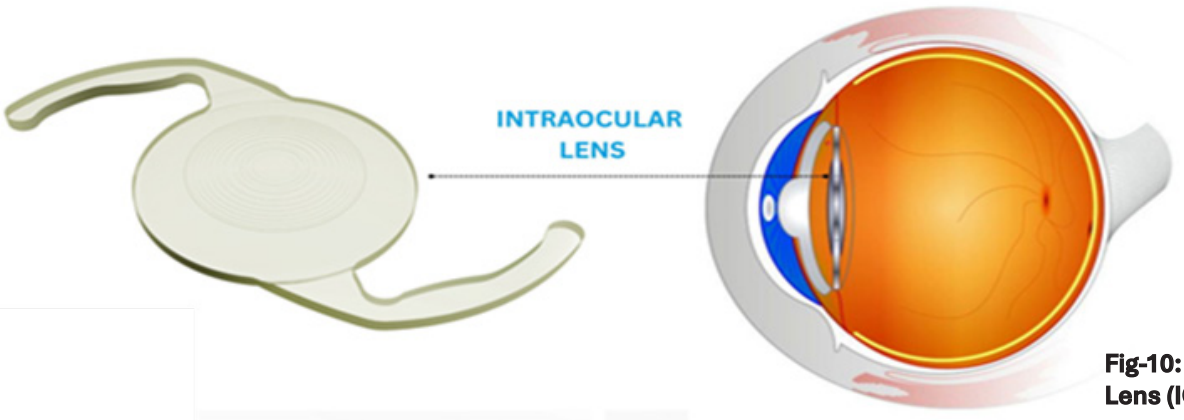


Fig-10: Intraocular Lens (IOL)