TRIBOLOGY OF JOINT REPLACEMENT IMPLANTS

J. B. Medley
Dept of Mechanical Engineering, Univ of Waterloo, Waterloo, ON N2L 3G1, CANADA;
e-mail: jmedley@konec.uwaterloo.ca

J. D. Bobyn
Jo Miller Orthopaedic Research Lab, Div of Orthop, Montreal General Hospital, Montreal, QC H3G 1A4, CANADA

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ABSTRACT
Joint replacement implants have limited the widespread deleterious effects of arthritic disease in humans over the last 40 years. There may be as many as 8 million people alive today with one or more joints replaced by orthopaedic surgeons using components made from engineering materials. The hip and the knee are the most commonly replaced joint but other synovial joints such as shoulders, elbows and ankles have also been replaced. So far, most tribological innovations have involved hip implants.

The wear of joint replacements is remarkably low and thus component failure due to excessive wear is not a major issue. However, a very significant long-term complication is a localized wear particle-induced osteolysis. This complication involves a biological chain of events in response to individual wear particles that usually culminates in bone resorption, loss of implant stability and revision surgery. Also, the systemic effects from the dissolution and dispersion of wear particles throughout the body have not been well established and remain a long-term concern.

The purpose of the present overview is to provide an appreciation of and a context for tribological developments in joint replacement implants.

CLASSIFICATION OF IMPLANTS
Three classifications of joint replacement implants can be made based on their "tribologically defining" component materials.

Implants involving polymers have them opposite a higher elastic modulus metal or ceramic. The most common configuration is conventional ultra high molecular weight polyethylene against wrought cobalt-based alloy. However, often this polyethylene is highly crosslinked and alumina ceramic may be used in place of the metal alloy. Prototype components using alternative polymers such as polyetheretherketone (PEEK) and elastomeric polyurethane have been fabricated but they have not been used clinically.

To reduce the volumetric wear, wrought or cast cobalt-based alloys have replaced the polymeric components in some implant pairings thus resulting in a metal-on-metal configuration. Attempts have been made to reduce the wear by applying surface coatings or layers but these efforts have been confined to the laboratory.

To further reduce volumetric wear and perhaps give particles that are better tolerated by the body, alumina and zirconia ceramics have been configured in ceramic-ceramic pairings. Ceramic "blends" of both alumina and zirconia have been formulated recently in attempts to optimise desirable material behaviour. These innovative efforts also extend to configuring ceramic against cobalt-based metal alloy.

TRIBOLOGICAL MECHANISMS
The key to understanding and improving the tribological clinical performance of joint replacement implants lies in the identification of the mechanisms, modelling their action and determining the controlling parameters that are available for manipulation. The lubrication mechanisms span the usual range of elastohydrodynamic lubrication (ehl), micro-ehl, mixed film, boundary lubrication and direct dry contact. However, wear mechanisms are also of considerable interest and are complex functions of lubrication, friction and material parameters.

EXPERIMENTAL APPROACHES
Because of the lack of quantitative knowledge of the operating environment and wear mechanisms, one approach to investigating the tribological mechanisms is to perform simulator studies (Fig. 1). This simulator approach, although slow and specific, remains the most powerful way to predicting implant performance compared with pure theoretical modelling and simple experiments. Clinical trials do provide the ultimate evidence but they are often difficult to interpret and ethically unsupported as a first approach.

CONCLUDING REMARKS
Clearly, the present overview has a complex topic to treat. Although implant use is widespread, the supporting tribological knowledge is deficient. In spite of this deficiency, there have been recent improvements. However, it is not yet possible to offer the active patient an implant capable of achieving the high performance levels of the natural product.