Nanostructured Surface Modification and Coatings for Orthopaedic and Dental Implants

Jack E. Lemons
University of Alabama at Birmingham

Considerable interest continues specific to nanostructured surface modifications and coatings of biomaterial surfaces to enhance properties for orthopaedic and dental implant devices. Over decades, a focus has been on surface conditions to reduce wear (debris generation) for articulating joint prostheses; and, separately, to increase attachment(s) between devices and tissues (primarily bone). Many compounds and elements have been evaluated in an attempt to obtain a combination of optimal physical, mechanical, chemical, electrical and biological properties. Additionally, time for cost for fabrication and longer term stabilities during in vivo function have been key considerations. Techniques have ranged from ion implantation into the near surface zones (nm) to chemically deposited coatings (hundreds of µm.) In recent years, many of the coatings have included nanostructured conditions and dimensions to further enhance coating and device properties. Also, several compounds considered as coatings have also been introduced, or are being introduced, as bulk solids (e.g., alumina and titania ceramics, diamond, ceramo-metallics, etc.).

In all cases, biocompatibility testing has included the bulk materials, plus particulates of any surface modification and the substrate (worst case considerations). Although extensively studied and promoted, large-scale applications have not dominated the market (usage) over time and experience. In part, limitations have been associated with relative benefits specific to overall clinical outcomes; loss of some surface modified regions due to third body wear; and loss of some coatings due to tensile and shear properties at the substrate-to-coating interfacial zone.

Examples of applications include nano- to micro-meter depth nitrogen ion implantations, titanium nitride reaction zones, vapor deposited diamond and plasma spray deposited alumina onto alloy surfaces intended to increase hardness and wetting while decreasing wear. Experience has shown that third body related wear phenomena was a central issue because of degradation of modified surfaces and exposure of the softer, deeper zones of the substrate (e.g. Ti-Al-V alloy). Integrity of the attachment between coatings and metallics has also been a concern for some vapor deposited and plasma sprayed coatings of alumina, diamond-like and calcium phosphate-based materials.

On the positive side, numerous surface modifications (e.g. nitrides, oxides, calcium phosphates, etc.) have provided intended outcomes and longer-term in vivo functionality. Some have significantly decreased wear phenomena while others have resulted in increased tissue integration.

Therefore, a key issue is benefit-to-risk ratios and many believe that the advantages of nanostructured and biomimetic biomaterials will be significant for future devices. In some situations, e.g., ceramo-metallics with diamond-like, boron and other surfaces, it may be possible to have articulations that would be even more resistant to damage and wear phenomena.

References:

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