Development of Hard Antibacterial (TiN/Ag) Coatings on Orthopedic Instruments Fabricated from Ti-alloys

University: University of Toledo	
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Need and Industrial Relevance:

The broad theme of this proposed effort is to provide bi-functional coatings on orthopedic instruments fabricated from titanium (Ti) and related alloys (Ti6Al4V). This theme is dictated strong industrial needs, as justified below. The "Bi-functionality" as referred to herein relates to achieving high surface hardness while providing local bactericidal properties. Fabricating orthopedic instruments out of Ti/Ti6Al4V has been the conventional industrial practice for decades due to their high strength, chemical stability, and the availability of machining expertise. However, there are two major issues in their successful operations.

First, a frequent problem associated with these instrument is bacterial colonization of their surfaces. If such colonies persist, bacteria can spread even further causing surgical site infections (SSIs). SSIs linked to contaminated surgical instruments have been reported on various occasions and the infection risk is certainly increased when contaminated instruments are used for surgery. To deal with such situations, systemic antibiotic administration is helpful. However, it is easy for the bacteria to create implant adhering biofilms due to their ability of self-producing polysaccharides, and can exhibit superior resistance to even larger doses of systemically administered antibiotics. Furthermore, several antibiotic resistant strains of bacteria exist now. Therefore, an alternative strategy to antibiotic treatment needs to be sought.

The strategy to be pursued here is the introduction of an inorganic element, silver (Ag) on the surface of the instrument. The demonstrated antibacterial properties of elements such as Ag, Cu, Zn is well-accepted in the literature. Among them, silver, with a broad-spectrum of antimicrobial activity against gram-positive, gram-negative bacteria as well as fungi and yeasts, and excellent biocompatibility, has been used in several studies. For surgical instruments, silver can inhibit bacteria attachment onto them at very low concentrations over a long period. If successful, this strategy will eliminate the problems associated with the systemic delivery of antibiotics, as described in the above.

Second, in spite of excellent mechanical properties of Ti/ Ti6Al4V, the surface hardness values of many orthopedic instruments such as bone saws, drills, reamers, and repositioning equipment are not hard enough. For their successful uses, these instruments need even harder ceramic coatings. Typically, nitrides and carbides of transition metals can provide such high hardness values. Indeed, Titanium Nitride (TiN) has been used as a coating material for high-speed cutting tools in machine-tool industry for quite some time. TiN provides a hardness value of approximately 23OO (VN), resulting in high speed operation, long term cutting edge sharpness without the need to use any oil lubricant. On the other hand, the presence of nitrogen in the coatings helps in bacterial infection. Hence, is the need for bi-functional coatings with high hardness and antibacterial properties.

Project Aims (including Hypotheses):

The main hypothesis here is to render the hard coating of TiN antibacterial by incorporating Ag in them. While we are aware of only one study in the literature (Moseke et al.), it is not clear, what is the state of Ag in the coating that facilitates the slow release of Ag. It is of great significance to understand the "Structure-Property-Processing" correlations in these coatings. Since the coatings will be deposited using magnetron sputtering, it will important to correlate the sputtering conditions to the structure of TiN/Ag coatings. The structures of the coatings can be subsequently correlated to the Ag release kinetics and antibacterial properties data. The deposition parameters will be optimized by evaluating the silver content and uniformity in coatings, their adhesion, morphology, micro/nano-hardness, as well as Ag release kinetics, and antibacterial properties using standard protocols.

Specific aim 1: To determine and optimize the parameters for magnetron sputtering process to produce TiN/Ag coatings on Ti6Al4V substrates, by evaluating the coating integrity by XRD, SEM, micro- and nano-hardness and comparing the data to commercially available TiN coated orthopedic instruments.

Specific aim 2: Examine the antibacterial properties by correlating Ag^{+} release kinetics with the zone of inhibition and colony forming units with common bacteria such E. Coli.

Specific aim 3: Determine the impact of repeated autoclave cycles of the coated substrates/instruments on the antibacterial properties.

Methods:

Process: Magnetron Sputtering (MS) is a Physical Vapor Deposition (PVD) process which combines plasma (to create the pool of electrons) and magnetic field (enhance the propagation of electrons) to fabricate compact coatings on substrates. In this study, MS will be employed to develop TiN coatings on Ti6Al4V substrates. Further, to enhance the antibacterial functionality, Ag ions will be doped into the TiN coatings. Processing parameters such as arc current, nitrogen pressure, and sputter times will be varied. Contents of Ag will also be used to study its effect on antibacterial functionality.

Characterizations: (i) X-ray diffraction (XRD) will be employed to characterize the phase compositions, lattice structures of the fabricated coatings with different process conditions. Further, the extent of Ag doping will be studied by analyzing distortions. **(ii)** Morphology of the MS deposited coatings will be studied by a thorough scanning electron microscopy (SEM) analysis. **(iii)** Micro Vickers Hardness tester, and an AFM will be used to analyze the hardness and quality of deposited coatings, **(iv)** In order to study the Ag-ion release and its sustainability, we will use Inductive Coupled Plasma (ICP) technique.

In vitro evaluation of antibacterial properties: The antibacterial evaluations will be performed by determining the zone of inhibition (ZOI) and colony forming units with common bacteria such E. Coli.

Milestones:

1. Successfully achieve crack-free coatings of TiN and subsequently TiN/Ag by adjusting the various sputtering parameters. The characterization protocols by XRD, SEM, hardness testing are fully developed (Nov 30, 2017)
2. The protocols for Ag-release kinetics and the zone of inhibition, and colony forming units with common bacteria such E. Coli are fully developed (Jan 31, 2018).
3. Evaluate the integrity of coatings using AFM, before and after autoclaving (March 31, 2018).
4. Optimize the processing parameters, as dictated by the data gathered, to successfully obtain bi-functional coatings (August 31, 2018).

Deliverables (must include):

Quarterly presentation updates:

- *December 2017 – conference call*
- *Spring 2018 – Spring Symposium @ UT (conference call option for non-UT teams)*
- *June 2018 – conference call*
- *September 2018 – Fall Symposium @ UCSF (conference call option for non-UCSF teams)*

Final written report including results – November 2, 2018

Specific work product (Orthopedic devices with hard antibacterial coatings)

General Budget Outline:

Personnel	$25000
Supplies	$ 7000
Specimens	$ 2000
Imaging	$ 2000
Total Direct	$ 36000
Indirects (10%)	$ 3600
Total	$ 39600

Start Date: October 15, 2017

End Date: September 15, 2018

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