Coatings for Biomedical and Healthcare Applications
Room Pacific C - Session D1-1-MoM

Surface Coatings and Surface Modifications in Biological Environments I

Moderators: Mathew T. Mathew, University of Illinois College of Medicine at Rockford and Rush University Medical Center, USA, **Phaedra Silva-Bermudez**, Instituto Nacional de Rehabilitación Luis Guillermo Ibarra Ibarra, Mexico

10:00am **D1-1-MoM-1 Corrosion Evaluation of ZrO_2 Coatings Deposited on Biodegradable MgZnCa Alloy for Orthopedic Applications***, Benjamin Millan (bmillan@ciencias.unam.mx), S. Rodil,* UNAM, Mexico*; J. Victoria-Hernandez,* Helmholtz-Zentrum Geesthacht, Germany

The development of biodegradable of Mg-based devices for orthopedic applications has been limited due to its high corrosion rate in biological media, which is accompanied by hydrogen (H2) evolution. This could lead to alkalization of the media and H2 accumulation can cause osteolytic lesions. In a previous work, we reported that a ZrO2 coating deposited by RF magnetron sputtering on a MgZnCa alloy enhanced the corrosion resistance and reduced the H2 evolved. However, an optimization of the deposition parameters to enhance the protectiveness offered by the coating was not done. Therefore, we propose an experimental design that involves power, deposition time and oxygen flux fraction as independent variables. The effect of these variables on the corrosion performance of the coated samples was evaluated using electrochemical impedance spectroscopy (EIS) and H2 evolution assessment with gas chromatography. The charge transfer resistance R can be obtained from the impedance modulus at medium frequencies (0.99Hz). In Fig. 1d, R is summarized as function of the thickness including all the deposition conditions. The conditions A and C deposited at 400 W during 30 and 90 min improves substantially the R (refer to Table 1 for labels). According to H2 results, the corrosion process of the coated samples does not change significantly as the deposition power increases, Fig 2a. But, the higher the deposition time the lower the H2 evolved, Fig. 2b. Increasing the O2 flux fraction is detrimental for the corrosion resistance for the coated samples since the H2 evolved raises, Fig. 2c. Thus, the combined effect of deposition time and O2 flux fraction plays an important role in the amount of H2 evolved. However, the tendency observed in H2 evolution measurements in Fig. 2c does not corresponds to the R in Fig. 1d. We think that H2 evolution measurement with gas chromatography can determine more accurately the short-term corrosion resistance of the coated/uncoated samples since electrochemical techniques have some limitations for corrosion rate assessment of Mg alloys. In conclusion, the effect of the deposition parameters of a ZrO2 coating on the corrosion resistance of MgZnCa alloy was studied. The higher R corresponds to the B43, B49, C43 and C49 samples. The results form H2 evolution measurements indicate that the deposition time and O2 flux fraction are determinant parameters. The O2% flux fraction may induce different growth rates which can contribute to change the coating compactness. This is visible in Fig. 2c, where the ZrO2 coating deposited at 20% of O2 flux fraction shows a reduction of 44 % in the amount of H2 evolved.

10:20am **D1-1-MoM-2 Novel Duplex Treatments Prepared by HiPIMS and HVOF/Solgel on Biodegradable Magnesium Alloy for Biomedical Applications***, **Adrián Claver (adrian.claver@unavarra.es)**,* Universidad Pública de Navarra (UPNA), Spain*; I. Fernandez, J. Santiago,* Nano4Energy SL, Spain*; I. Quintana,* Fundación Tekniker, Spain*; L. Mendizabal,* Fundación Tekniker , Spain*; J. García,* Universidad Pública de Navarra (UPNA), Spain

Magnesium-based biomaterials have become a great candidate to be used in biomedical implants due to their great biocompatibility, biodegradability, and their mechanical properties similar to those of bones. However, Mg-based alloys corrode rapidly in aggressive environments such as human bodily fluids, losing their mechanical properties because of the uncontrolled corrosion and with the risk of infection in the body. In this study, duplex treatments consisting in TaN or TiN doped with Cu and Ag coatings deposited via high power impulse magnetron sputtering HiPIMS with positive pulses followed by a hydroxyapatite (HA) deposited via High Velocity Oxygen Fuel (HVOF) or Solgel top layer, were applied on biodegradable ZK60 magnesium alloy in order to improve the corrosion resistance, antibacterial properties and osteointegration properties of the substrate. Scanning electron microscopy (SEM), Energy-dispersive X-ray spectroscopy (EDS), Fourier transform infrared (FTIR) spectroscopy, and X-ray diffraction (XRD) were used to characterize the coatings. Scratch test and nanoindentation were performed to study the adhesion and hardness of the coatings, while contact angle measurements were carried out to compare the wettability of the surface. The samples were immersed in SBF to study the corrosion resistance, mass change and hydrogen evolution. Electrochemical tests were performed to estimate the corrosion behaviour of the samples. Furthermore, antibacterial tests were carried out. The treated surfaces showed better hydrophilicity than the uncoated samples, which improves the ability of cell attachment. The results of in-vitro corrosion tests showed that the duplex treatments improved the corrosion resistance of the uncoated magnesium alloy samples, while antibacterial tests showed an improvement of antibacterial properties of the treated samples. Duplex treatments exhibit suitable properties including high corrosion resistance, osseointegration capability, antibacterial properties, and biocompatibility, so that they can be considered as a promising option to be used in biodegradable magnesium implants.

10:40am **D1-1-MoM-3 Surface Properties Control Immune Response to Implanted Biomaterials***, **Rene Olivares-Navarrete (ronavarrete@vcu.edu)**,* Virginia Commonwealth University, USA **INVITED**

Implanting a material into the body generates an immune response, both from the surgical procedure and in response to the material surface. Following this initial insult, wound healing begins with the onset of hemostasis. Due to the range of physical and chemical properties of implanted biomaterials, the initial interactions between biological tissues and biomaterials are not fully understood. Following homeostasis, the inflammatory phase, predominated first by neutrophils and then by macrophages, begins. Furthermore, we have recently explored the affect of Ti surface characteristics in neutrophil behavior. Neutrophils are the most abundant immune cell in blood and arrive in scores to the injury site within minutes following trauma or biomaterial implantation. Neutrophils are known for their antimicrobial activity via phagocytosis, degranulation, enzymatic release, and the production of large DNA-based fiber networks called neutrophil extracellular traps (NETs). However, they are understudied in the context of biomaterials. New studies from our lab have demonstrated their key role during the inflammatory phase of biomaterial integration. Macrophages can be activated by biomaterials to release factors that alter the peri-implant microenvironment, directing the activation and recruitment of additional immune cells and/or progenitor cells. Macrophages exist along a broad spectrum with two opposite phenotypes. The pro-inflammatory (M1) phenotype is characterized by the release of factors such as IL1β, IL6, and TNFα that promote inflammation and secretion of chemokines (Ccl2, Ccl4, Ccl7) that recruit additional immune cells such as neutrophils and T cells. On the other end of the spectrum are the alternatively activated macrophages (M2 phenotype), which release immunomodulatory factors to reduce and resolve the inflammatory state and recruit progenitor cells for regenerative process. Biomaterial surface properties can be tailored to improve the healing response following implant placement. In this presentation, I will discuss how material surface properties can be tailored to control neutrophil and macrophage activation following biomaterial implantation and enhance subsequent recruitment of other immune and stem cells to the implant site to aid healing.

11:20am **D1-1-MoM-5 Metal Oxide Thin Films as Osteoinductive Coatings***, **Phaedra Silva-Bermudez (phaedrasilva@yahoo.com)**, M. Fernández-Lizárraga, D. Morquecho-Marín,* Unidad de Ingeniería de Tejidos, Terapia Celular y Medicina Regenerativa, Instituto Nacional de Rehabilitación Luis Guillermo Ibarra Ibarra, Mexico*; B. Millán-Ramos ,* Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México*; J. García-López ,* Unidad de Ingeniería de Tejidos, Terapia Celular y Medicina Regenerativa, Instituto Nacional de Rehabilitación Luis Guillermo Ibarra Ibarra, Mexico*; S. Rodil,* Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México

Biomaterials that exert an appropriate biological response and simultaneously meet biomechanical requirements are essential for orthopedic and dental implants. Mechanical properties of materials are mainly determined by the bulk material while the biological response is mainly directed by the surface properties. Thus, biocompatible coatings with functional properties, such as osteoinduction and osteoconduction, are interesting options to tailor the surface of mechanically- and degradation-wise appropriate bulk materials, to develop novel biomaterials for orthopedic and dental implants. ZrO_2, Nb_2O_5 and Ta_2O_5 are of great interest as coatings for orthopedic and dental implants, since they might promote adequate oseointegration, in a similar way as TiO_2.

Nanocrystalline TiO_2 andZrO_2, and amorphous Ta_2O_5 and NO_2O_5 thin films were deposited on Si(100) substrates, from pure metallic targets by magnetron sputtering, under reactive Ar/O_2 atmosphere, and using RF-power. The properties of the coatings were characterized by Optical Profilometry, Scanning Electron Microscopy, X-Ray Photoelectron Spectroscopy and Water Contact Angle. To characterize the biological response, human mesenchymal stem cells isolated from bone marrow (BM-MSC) were plated and cultured on uncoated and oxide-coated substrates; TiO_2-coated substrates were used as positive controls (osteoinductive and appropriate oseointegration). Cells were cultured at 37°C, changing the culture media every other day. Cell viability and metabolic activity was assessed at different days of culture by the Calcein-AM/Ethidium homodimer fluorescent kit and the Alamar Blue assay. At 7 days of culture, cells were fixed, dehydrated and evaluated by SEM. Potential cell differentiation towards the osteoblastic phenotype was qualitatively assessed by immunofluorescence assays against characteristic markers of the osteoblastic phenotype such as osteopontin, osteocalcin and Runx2, and quantitatively assessed by immuno ELISA assay against Osteocalcin and osteopontin, and colorimetric assays to evaluate phosphatase alkaline specific activity. All metal oxide coatings were biocompatible; however, results suggested that number of cells adhered on the substrate and cell differentiation was dependent on the coatings.

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11:40am **D1-1-MoM-6 Synergetic Effect of Porous Ta_2O_5 Surface With Zn/ZnO Core-Shell Nanoparticles on Antimicrobial Activity and Corrosion Resistance***, **Luísa Fialho (luisafialho@fisica.uminho.pt)**, C. Rebelo,* University of Minho, Portugal*; C. Alves,* Instituto Pedro Nunes, Coimbra, Portugal*; J. Castro,* University of Coimbra, Portugal*; P. Sampaio,* University of Minho, Portugal*; S. Carvalho,* University of Coimbra, Portugal

As an alternative to the conventional Ti dental implant surfaces, Ta surface biofunctionalization was investigated using different surface treatments to endow it with the microbicidal ability and enhance corrosion resistance. To achieve this innovative design, the adopted strategy was accomplished in two main steps: i) development of a bioactive surface based on the synergetic effect of anodic Ta_2O_5 with multilevel porosity (nano to micro) with osteoconductive elements incorporated; ii) development of an antimicrobial delivery system by deposition, by magnetron sputtering, of zinc/zinc oxide (Zn/ZnO) nanoparticles deposited onto the anodic Ta_2O_5 structured surface with or without an additional thin carbon layer.

First, a micro/nano-porous calcium phosphate-enriched Ta_2O_5 layer was developed by plasma electrolytic oxidation (PEO, also known as micro-arc oxidation - MAO) mimicking the bone morphology and chemical composition. Secondly, Zn/ZnO nanoparticles were deposited onto the porous Ta_2O_5 surface by DC magnetron sputtering to promote antimicrobial activity. In addition, the Zn/ZnO nanoparticles were encapsulated by a thin carbon layer to ensure the desired mechanical resistance and provide the antimicrobial agent-controlled release, and consequently improving corrosion resistance.

The antimicrobial effect and the molecular mechanisms involved in the antimicrobial action of Zn/ZnO nanoparticles were evaluated using *Candida albicans*, which is an opportunistic fungal pathogen present in the oral cavity that shows increased resistance to antifungal treatment agents. All the porous surfaces doped with Zn/ZnO nanoparticles showed a strong capability to inhibit cells growth and proliferation, revealing a significant antifungal activity. The surface with more Zn nanoparticles demonstrated a higher influence on cellular growth.

Morphological and chemical composition properties of the samples' surfaces were correlated with the corrosion behavior in artificial saliva. Right after the immersion, theporous Ta_2O_5 layer slowed the corrosion rate compared with the untreated Ta surface. The deposition of the Zn/ZnO nanoparticles decreased the corrosion rate and increased the corrosion resistance, indicating an improvement in corrosion behavior throughout the immersion time (14 days). OCP results showed an improvement on these surfaces between the first 2 and 24 hours of immersion, stabilizing afterward, which is related to zinc ions release profile.

Attributing to the excellent *in vitro* performance, this work is progress on the strategy to develop a new generation of dental implants surfaces to prevent implant's infection.

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