Surface Engineering of Biomaterials, Medical Devices and Regenerative Materials
Room Golden State Ballroom - Session MD-ThP

Surface Engineering of Biomaterials, Medical Devices and Regenerative Materials Poster Session

MD-ThP-1 Electrochemical and Antimicrobial Coating: Increasing the Ionic Charge on Titanium Surfaces as a Preventive Strategy for Titanium Implants*, **João Pedro dos Santos Silva**,* École des mines de Saint-Étienne, France*; Daniela Buenos Ayres de Castro, Mariana Mireski, Catia Sufia Alves Freire de Andrade, Maria Helena Rossy Borges,* Universidade Estadual de Campinas, Brazil*; Jean Geringer,* École des mines de Saint-Étienne, France*; Valentim Adelino Ricardo Barão,* Universidade Estadual de Campinas, Brazil

Peri-implant conditions and the electrochemical degradation of titanium (Ti) are critical factors in the failure of biomedical implant treatments. Developing functional surfaces to address these challenges is essential. Cationic coatings have proven to be an effective strategy for reducing biofilm formation and enhancing corrosion resistance. This treatment focuses on increasing the surface charge of implants and provides antimicrobial properties without the use of pharmaceutical agents, making the approach safer, more cost-effective, and sustainable. Thus, this coating was developed in two stages: (1) functionalization with hydroxyl groups (-OH) using plasma electrolytic oxidation (PEO), incorporating bioactive elements and enhancing surface functionalization; (2) silanization with tetraethylorthosilicate (TEOS) or 3-glycidyloxypropyltrimethoxysilane (GPTMS), which bind to alkaline surfaces and promote proton release through chemical reactions. Four groups (untreated Ti, PEO, PEO + TEOS, and PEO + GPTMS) were evaluated for surface characterization, electrochemical performance, and antimicrobial activity. Micrographs showed distinct morphologies in the silanized groups, with the alkalinization step generating pores that enhanced topography and roughness. The superhydrophilic affinity created by alkalinization evolved into hydrophobic (TEOS) and superhydrophobic (GPTMS) characteristics after silanization. The presence of amine groups, detected by X-ray photoelectron spectroscopy (XPS), indicated an increase in surface charge, confirmed by zeta potential measurements. Positively charged surfaces demonstrated superior electrochemical performance and greater antimicrobial potential against Streptococcus mitis biofilm formation (24 h). In conclusion, cationic coatings show promise for implantable devices, offering improved resistance in adverse environments and antimicrobial properties.

MD-ThP-2 Flexible, Enzyme-Free, and Ultra-Sensitive Cholesterol Sensor Based on In-Situ Etched $Ti_3C_2T_x$ MXene Nanosheets*, **Sanjeev Kumar**, Jyoti Jaiswal, Rajesh Chakrabraty, Kulsuma Begum, Bitupan Prasad,* Rajiv Gandhi University, India

This work presents an enzyme-free cholesterol sensor based on $Ti_3C_2T_x$ MXene nanosheets, offering a highly sensitive detection platform. The $Ti_3C_2T_x$ MXene nanosheets were synthesized via in-situ LiF/HCl etching, and the sensing electrode was prepared by drop-casting a colloidal solution of the as-synthesized MXene onto a paper substrate. To investigate the quality and properties of the synthesized $Ti_3C_2T_x$ MXene nanosheets, microstructural and compositional studies were conducted utilizing FESEM, XRD, Raman spectroscopy, XPS, and EDS. These characterizations confirmed the successful synthesis of the $Ti_3C_2T_x$ MXene nanosheets. Cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) were performed to analyse the electrochemical behaviour of the $Ti_3C_2T_x$ MXene-based electrode. The responses of the fabricated electrode to different cholesterol concentrations were recorded using CV in phosphate buffer solution, exhibiting robust linear response ($R^2 \sim 0.99$) in the range from 1 to 250 nM. The MXene-based electrode exhibited good sensitivity (0.75377 ± 0.01107 mF nM^{-1}), a low detection limit (0.07 nM), high selectivity, practical reproducibility, and excellent cyclic stability, suggesting its potential for real-time cholesterol monitoring in biomedical and healthcare applications.

MD-ThP-3 Effect of the Thickness of Fibrous Cap and Compositions on the Rupture Behaviour of the Atherosclerosis Plaques*, **Jiling Feng**, Mohamed Abdulsalam,* Manchester Metropolitan University, U.K.

Atherosclerotic plaque rupture is the leading cause of the cardiovascular diseases (CVD) such as coronary arteries disease, stroke and heart attack. Early detection of the plaques which are prone to the rupture, also known as vulnerable plaque, can provide important clinical information to prevent the fatal cardiovascular event. The vulnerable plaques are commonly characterized as the large lipid core and thin fibrous caps with the thickness less than 65 µm. However, evidence showed that plaques with fibrous caps > 65 µm are also susceptible to plaque rupture or erosion and can cause acute myocardial infarction and sudden death [1]. The effect of the critical thickness of fibrous cap and compositions of the plaques on the rupture behaviour of the arterial plaques has not been fully investigated. In this study, the artificial plaques with a variety of the compositions (lipid core, calcium and collagen) and with a range of thickness of fibrous cap were fabricated. The mechanical properties of the plaques were tested by using the unconfined compression testing. Meanwhile, the deformation of the arterial plaques samples and rupture behaviours were also recorded by using the high-resolution of camera. The initiation and propagation of the rupture of fibrous cap were analysed using digital image correlation (DIC) software. The experimental results indicated that the thicker the fibrous cap, the stiffer the arterial plaque. This phenomenon was observed in the plaques with large lipid core and calcified plaques. The Young's module for the plaques with large lipid core (Figure 1a) ranges from 0.0235 to 3.7174 MPa which are compatible with the value of plaques in the human carotid arteries which were observed in the clinical findings. The plaques with higher percentage of collagen possess the the greater Young's modules (Figure 1b).

Reference

[1] Liu, X., He, W., Hong, X. *et al.* New insights into fibrous cap thickness of vulnerable plaques assessed by optical coherence tomography. *BMC Cardiovasc Disord* **22**, 484 (2022).

MD-ThP-4 Effects of Electrical Stimulation with Iridium Oxide Plasma Protein Hybrid Film on Nerve Cells*, **Po-Chun Chen**,* National Taipei University of Technology, Taiwan

Iridium oxide (IrOx) is a well-known material for neural stimulation, but its rigidity and lack of bioactivity limit its biomedical application. To address this, an IrOx film incorporating plasma proteins (IrOx-PP) was developed to enhance biocompatibility and promote neuronal growth. The addition of plasma proteins created bioactive sites that improved cell adhesion and differentiation while maintaining the electrochemical properties needed for neural stimulation. The IrOx-PP hybrid films showed significantly higher cell viability and metabolic activity, with electrical stimulation further enhancing cell growth and bioactivity. Neurite length increased significantly under electrical stimulation, with the IrOx-PP hybrid films showing the greatest enhancement. In addition, cells on IrOx-PP hybridfilms expressed higher levels of the neuronal markers, indicating their superior potential for promoting neuronal differentiation and neurite outgrowth compared to pure IrOx films. This result demonstrated that the IrOx-PP hybrid film can potentially serve as a platform for advanced neural interfaces, providing improved tissue integration.

MD-ThP-5 Antibacterial Coating of Additively Manufactured Biodegradable Implants *, **Jan-Ole Achenbach**, Rainer Cremer,* KCS Europe GmbH, Germany

Presently used metallic bioimplants are non-degradable and remain permanently inside the body, in some cases require a secondary surgery for removal.To overcome such problems, biodegradable metallic implants (Fe-Mn, Mg, Zn) are being developed around the world. Mg based alloys are recently being commercialized for dental, trauma and orthopedic applications. However, due to higher degradation rates and hydrogen evolution, their use is not being extended to applications that require implants to remain in the body for longer periods of time. The degradation rates of Mg based alloys can be reduced by incorporating fine grain structure and also with suitable coating.

The proposed study envisages the design of soft tissue anchors, the development of Mg and Fe-Mn alloy powders with suitable composition, and demonstration of additive manufacturing process for the manufacture of prototypes. The proposed work also involves detailed characterization (microstructural, mechanical and biological) of additive built and surface modified coupons as well as components.

The project is being worked on as part of the "Additive Manufacturing" call for proposals of the Indo-German Science and Technology Centre. In the sub-project "Antibacterial and corrosion-inhibiting coatings for soft tissue anchors" of the joint project, KCS Europe is working on the surface refinement of the anchors. Here, silver-based layers are to be developed using Physical Vapour Deposition and applied to biodegradable implants which, in addition to an antibacterial effect, can also guarantee the integrity of the anchors for a defined period of time.

MD-ThP-6 Copper-Based Biocidal Thin Film Characterised by X-Ray Photoelectron Spectroscopy*, Jonathan Counsell,* Kratos Analytical Limited, UK*; **David Surman,*** Kratos Analytical Inc., USA*; Heather Yates,* University of Salford, UK

The presence of pathogenic microbes on surfaces is a problem in healthcare environments, especially with the increasing prevalence of antibiotic-resistant bacteria. One solution is to develop anti-microbial surface coatings which for clinical and high traffic areas. Here we investigate the surface properties of anti-microbial copper oxides and photocatalytic titania on different substrates formed via chemical vapour deposition (CVD). The deposition is sequential with copper oxide deposited before the titania mimicking the industrial inline process. The surface properties were investigated using X-ray photoelectron spectroscopy (XPS). XPS was used to determine both lateral and depth information from the copper–titainia composite thin film. Despite titania deposition occurring after the copper oxide process, copper was observed at relatively high concentration, suggesting mobility through the titania and segregation to the near-surface region. Ion sputter profiling shows a significant depth distribution of the copper and titanium through the film. Herein, we highlight the insight provided by XPS and how the technique exposes the oxidation states of copper, the presence of contaminants, and the chemical bonding at both the surface and into the bulk.

MD-ThP-7 In vitro Comparative Study of Composite Coatings for Magnesium-based Bone Implants*, **Merna Abdrabo**, Abdelrahman Amin,* University of Tennessee at Chattanooga, USA*; Bryce Williams, Thomas McGehee, Alyssandra Navarro,* University of Arkansas, USA*; Vipul Patil,* University of Tennessee at Chattanooga, USA*; Mostafa Elsaadany,* University of Arkansas, USA*; Hamdy Ibrahim,* University of Tennessee at Chattanooga, USA

Magnesium (Mg) is a highly promising material for biomedical implants due to its biodegradable nature and its mechanical properties, close to those of human bone, when compared to the prevalent biomedical materials. Yet, its rapid corrosion rate in physiological environments poses a significant challenge. To address this, advanced coating technologies have been applied, aiming for improved corrosion properties. This study compares the effectiveness of various coatings applied to an ZK60 commercial Mg alloy, specifically micro-arc oxidation (MAO) coating, graphene oxide (GO)/MAO coating, sol-gel/MAO composite coating, and polycaprolactone (PCL)/MAO polymer coating. To evaluate their performance, characterization tests such as electrochemical corrosion testing, pull-off adhesion, water contact angle, microhardness and cytotoxicity were conducted. Results have demonstrated that the optimum corrosion resistance was achieved using the sol-gel/MAO composite coating. In addition, GO-layered particles were found to increase corrosion resistance. However, in terms of biocompatibility, MAO with PCL coating exhibited the most desirable results.

MD-ThP-8 Microfluidic Engineered Surface Modified Liposomes Encapsulating Mitochondria for Enhanced Cellular Uptake and Bioavailability in Cell Therapy*, **Yen-Chin Hsu**, Yu-Jui Fan,* Taipei Medical University, Taiwan

Mitochondrial dysfunction plays a crucial role in the development of degenerative diseases such as neurodegenerative diseases, cardiovascular diseases, and metabolic syndrome. Although mitochondrial transplantation offers a potential therapeutic solution, its clinical implementation is limited by obstacles such as mitochondrial degradation, poor cellular uptake, and immune system recognition. To overcome these challenges, this study introduced a microfluidic-engineered liposome encapsulation technology to enhance mitochondrial stability, bioavailability, and intracellular delivery efficiency for cell therapy applications.

The microfluidic system is used to manufacture liposome-encapsulated mitochondria, which can precisely control liposome size, charge, and encapsulation efficiency. By combining zwitterionic phospholipids (1,2-dioleoyl-sn-glycero-3-phosphocholine, DOPC) and cationic quaternary ammonium lipids, surface charge modulation is achieved, optimizing the electrostatic interaction between liposomes and mitochondrial membranes, and promoting efficient cellular uptake via the endocytic pathway. Dynamic light scattering (DLS), zeta potential analysis, fluorescence microscopy, and flow cytometry were used to characterize the structural integrity, surface charge distribution, and encapsulation efficiency of the engineered liposomes.

Cellular uptake and viability studies in AC16 cardiomyocytes and fibroblasts showed that liposome-encapsulated mitochondria exhibited improved viability compared with unencapsulated mitochondria after delivery into cells. The appropriate level of cationic charge facilitates membrane fusion and uptake, enhancing biocompatibility, which has been confirmed by ROS testing and live/dead staining assays.

The results indicate that microfluidics-based liposome engineering enhances mitochondrial transplantation by improving mitochondrial delivery efficiency and cellular bioavailability through surface charge tuning. Future research will focus on optimizing lipid composition, evaluating long-term mitochondrial stability, and performing in vivo validation to establish the translational potential of microfluidic-engineered liposome-encapsulated mitochondria in regenerative medicine.

MD-ThP-9 Forecasting the Degradation rate of in Vitro Ceramic Coated Magnesium Substrate based on a Machine Learning Approach*, **Abdelrahman Amin**, Hamdy Ibrahim,* University of Tennessee at Chattanooga, USA*; Ibrahim Emad,* Predictive Simulations & Modeling, USA

Recently, biodegradable metals have gained considerable attention due to their ability to degrade inside the human's body, qualifying them for temporary biomedical implant applications. Magnesium alloys particularly have favorable mechanical properties similar to human bones with fast corrosion rates. To address their fast corrosion rates, different techniques are utilized such as micro-arc oxidation (MAO) coatings. MAO controls the degradation rate by creating a complex ceramic coating layer on the magnesium surface. Research has shown that the corrosion behavior of ceramic-coated magnesium substrates is influenced by various factors, including alloy composition, process parameters, and other related variables. Despite the ability of FEA models to simulate key factors to predict the degradation rates, incorporating all relevant variables remains challenging due to the limitation in time and cost. Consequently, machine learning (ML) tools have emerged as a powerful alternative for forecasting corrosion rates based on various independent factors. Building on this capability, we expanded the ML models used to predict the corrosion of pure magnesium samples to develop a novel predictive model for MAO-coated samples. By gathering data from the literature, cleaning and transforming the data, applying the appropriate ML techniques, and analyzing the results, we uncovered complex relationships between input parameters and output responses, reducing reliance on time-consuming experiments and expensive FE methods. This study aims to introduce an innovative method for predicting the *in vitro* corrosion behavior of coated samples, complemented by experimental validation.

MD-ThP-10 Growth Mechanism and Cellular Response to Film Thickness Variations of Nanoporous Alkaline Titanate-Converted, Magnetron Sputtered Ti Thin Films*, **Matthew Wadge**,* Manchester Metropolitan University, UK*; Jonathan Wilson,* University of Nottingham, UK*; Kozim Midkhatov, Mahetab Amer,* University of Manchester, UK*; Louise Briggs, Timothy Cooper, Zakhar Kudrynskyi,* University of Nottingham, UK*; Reda Felfel,* University of Strathclyde, UK*; Ifty Ahmed, Colin Scotchford, David Grant,* University of Nottingham, UK*; Justyna Kulczyk-Malecka, Peter Kelly,* Manchester Metropolitan University, UK

The standard process for improving bioactivity of implant surfaces for natural fixation is reliant on high temperature (>1500 K) plasma spraying of hydroxyapatite (HA) [1]. However, these surfaces have been shown to spall due to their brittle nature, high internal stresses, and weak mechanical adhesion [1]. Bioactive titanate surfaces have been developed as a low-temperature, more simplistic alternative, however, their applicability is limited to titanium (Ti) and its alloys only via chemical conversion routes [1]. The present authors previously demonstrated the applicability of titanate surfaces generated from PVD Ti coatings [2], however, assessment of thickness variation on cellular performance is still required, due to potential unwanted effects such as poor cellular proliferation. This paper highlights for the first time the cellular performance of titanate films generated on various thicknesses of Ti coating. By varying the thickness of the PVD deposited Ti coating, one can influence the formation mechanism of the wet-chemically derived titanate surface produced, since the mechanism is diffusion dependant and material limited.

Magnetron sputtering was employed to generate the Ti coatings (ca. 50, 100, 200, 500 nm) owing to its excellent step coverage, relatively quick deposition rate, ability to coat onto, and from, a wide variety of materials. In the conversion process, Ti coatings are treated in NaOH (5 M; 60 ^{o}C; 24 h) to generate sodium titanate structures [1]. The resultant materials were characterised using SEM, EDX, XPS, XRD, as well as cellular assessments, in order to understand the formation mechanism, the resultant morphological (Fig.1&2), structural (Fig.3) and chemical (Fig.4) properties, as well as influence on cellular response. It was clear that the Ti coatings exhibited good step coverage. Following titanate formation, only the 200 and 500 nm coatings produced the characteristic nanoporous 'webbed' titanate structures, due to the lack of free Ti in the coating, as opposed to the conventional diffusion limitation (Na and O) of the titanate mechanism. Both XPS and XRD analyses confirmed the formation of titanate on all of the coatings tested, despite the morphological differences and irrespective of thickness. Through utilising sputtering, the applicability of these titanate materials in a biomedical context can be significantly improved due to its ability to coat most materials and matching the subsequent wet-chemical temperature conditions.

References

[1] M. Wadge, et al., International Materials Reviews, 68, 6, 677–724, 2022; [2] M. Wadge, et al., Journal of Colloid and Interface Science, 566, 271-283, 2020

MD-ThP-11 Corrosion Stability and Electrical Performance of Ti-Au Thin Film Electrodes for Biosignal Acquisition*, **Sara Inácio**, Carolina Durães, Ana Camarinha, Armando Ferreira, Cláudia Lopes, Filipe Vaz,* University of Minho, Portugal

Biosignal sensing plays a crucial role in research and healthcare, especially in e-health applications, as it provides extensive information about the health and emotional condition of individuals. In the same way, the existence of reliable and high-performing biopotential electrodes capable of monitoring for long periodsis vital since they enable reliable diagnosis of vital physiological functions. Traditionally, standard silver/silver chloride (Ag/AgCl) electrodes are valued for their low impedance and stable performance, ensuring high signal to noise ratios. However, their use in e-health applications and prolonged monitoring is severely hindered by several factors, such as gel dehydration and the occurrence of skin allergic reactions,highlighting the importance of novel dry electrodes.

In this study, the performance of Ti-Au thin films deposited onto flexible polymeric substrates as dry electrodes was investigated. Ti and Au are biocompatible metals, making them ideal for biomedical applications. Additionally, Au has excellent mechanical properties and high electrical conductivity, which are essential for low-amplitudebiopotential recordings. This work aimed to investigate the influence of the Au content and the growth geometries on the corrosion behavior and the overall performance of the electrodes. The Ti-Au thin films were deposited using the magnetron sputtering technique withGLancing Angle Deposition (GLAD) to produce different geometries/architectures.

Results showed that the Au/Ti ratios varied between 0.07 and 0.80, with the films exhibiting crystalline structures for Au contents lower than 0.08 and amorphous structures for higher contents. Also, the morphology was highly influenced by the Au content,with the films evolving from columnar growth (Ti-rich films) to a dense and featureless microstructure for Au contents (Au/Ti ≥ 0.12), with a high impact on the surface roughness of the final electrodes. The electrical properties showed that regardless the Au content, the films prepared in a conventional geometryexhibit an electrical resistivity around 5μΩ.m. However, for the films prepared by GLAD, with tilted angles higher than 60º, the electrical resistivity increases one magnitude order (25.33 μΩ·m). The assessment of the electrode's longevity was carried out by testing the Ti-Au thin films' corrosion behaviour in artificial sweat through open-circuit potential (OCP), electrochemical impedance spectroscopy (EIS), and potentiodynamic polarization (PD) tests.

MD-ThP-12 The Influence of Electrospun PLA/ZnO Coating on the Corrosion Resistance of Biomedical Ti-6Al-4V Alloy*, **Weronika Smok**,* Silesian University of Technology, Poland

New trends in the surface modification of titanium alloys for biomedical applications indicate that an interesting way to increase their biocompatibility, corrosion resistance and osteointegration is to apply coatings based on biopolymers, in particular PLA. Hence, the aim of this work was to modify the surface of the Ti-6Al-4V alloy with PLA/ZnO NPs nanofibers applied by electrospinning from solution. In order to characterize the morphology of the alloy surface before and after electrospinning, an analysis using scanning electron microscopy was carried out and a uniform distribution of nanofibers on the Ti-6Al-4V surface with visible ZnO nanoparticles in the PLA structure was found. The chemical composition of the developed biomaterials was confirmed by EDX spectroscopy. In addition, biocompatibility and corrosion behavior analysis was performed, which included potentiodynamic tests, open circuit potential measurements and the electrochemical impedance spectroscopy method. The carried out analisis allowed to confirm the non-toxicity of the nanofibrous coating and its beneficial effect on the corrosion resistance of the alloy.

MD-ThP-13 Surface Modification of AISI 316L Steel by Anodic Oxidation and Its Effect on the Viability of HFOb Cells*, **Luz Alejandra Linares Duarte**, Enrique Hernández Sánchez, Cintia Proa Coronado, Ángel Ernesto Bañuelos Hernández, Nury Pérez Hernández,* Instituto Politécnico Nacional, Mexico*; Raúl Tadeo Rosas,* Universidad Autónoma de Coahuila, Unidad Torreón, Mexico*; Yesenia Sánchez Fuentes,* Instituto Politécnico Nacional, Mexico

AISI 316L stainless steel is one of the low-cost materials that is suitable for medical applications. That condition is because of its high corrosion resistance and low response to human fluids. This study is on the surface modification of the austenitic stainless steel AISI 316L by the anodic oxidation technique and the effect of that on the biocompatibility of the steel. Three conditions of steel were evaluated: 1) non-treated material, 2) anodized samples, and 3) annealed-anodized samples, in which the samples were exposed to a thermal treatment at 600 °C for 8 min to promote the formation of a passive layer. The steel samples were exposed to the anodic oxidation technique with a constant work potential of 60 V and 30 min exposure time. Ethylene glycol, distilled water, and ammonium fluoride (NH4F) were used as the electrolytic fluid. Likewise, the effect of the analyzed surfaces on the cellular viability of human fetal osteoblast (HFOb) cells was evaluated using a resazurin reduction (Cell Titer Blue) assay. Scanning electron microscopy (SEM) and energy dispersive scanning (EDS) were applied to determine the morphology and nature of the microporous surface, showing a well-defined matrix of nanoporous on the AISI 316L steel, with diameter in the range of 100 to 140 nm. On the other hand, in-vitro assays indicated that after 72 h of culture, the best cellular viability was found with annealed-anodized samples. These results open the possibility of generating materials with better capability to promote cellular proliferation in the metallic materials.

Keywords: anodic oxidation, cell proliferation, biomaterials, nanoporous

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