Investigation of corrosion properties of metals for degradable implant applications

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Abstract

Degradable metallic implants are a new class of biomaterials with potential to replace permanent materials in temporary applications to reduce the risk of long term adverse effects. This thesis focuses on in vitro testing of zinc and magnesium based metals. As new degradable metals are developed, screening of new materials within in vitro test methods is an attractive option to avoid unnecessary, time consuming and expensive animal studies. The influence of factors such as ionic composition of the test solution, buffer system, strain and alloy composition was investigated. By employing electrochemical in situ techniques such as impedance spectroscopy it is possible to study the metal-solution interface and determine the properties of the corroding surface. Ex situ surface characterization techniques such as scanning electron microscopy and infrared spectroscopy were then used to complement the results of the electrochemical measurements. The importance of appropriate selection of the test solution is highlighted in this work. Zinc was found to corrode in Ringer’s solution by a mechanism closer to in vivo corrosion than in a phosphate buffered saline solution (PBS). Ringer’s solution is therefore the more appropriate test environment for long term evaluation of zinc based metals. When evaluating the corrosion of Zn-Mg and Zn-Ag alloys in Ringer’s solution selective dissolution was found to occur for both types of alloys. Local precipitation and formation of a porous, less protective, layer of corrosion products was found for Zn-Mg alloys. The selective dissolution of Zn-Ag alloy caused an enrichment of AgZn₃ on the surface which may affect the biocompatibility of the alloy. The use of HEPES to maintain the pH of the test solution increased the corrosion rate of magnesium due to formation of a less protective layer of corrosion products. Magnesium corrosion should therefore preferably bestudied in solutions where the pH is maintained by the biological buffer system CO₂/H₂CO₃. In addition to saline solutions human whole blood and plasma were evaluated as more clinically relevant in vitro environments. They were found to produce reproducible results and to be suitable for short term experiments. Formation of a corrosion product layer comprised of both organic and inorganic material was detected on zinc in both plasma and whole blood. During anodic polarization the adsorption of organic species on the zinc surface was found to increase the surface coverage of Zn ions in whole blood. The increased surface coverage then allowed for precipitation of a protective layer of Zn₅(PO₄)₃ and a subsequent decrease in corrosion rate at higher potentials. When subjecting zinc samples to strain the organic/inorganic corrosion product formed in whole blood was observed by impedance spectroscopy to prevent micro cracking and premature failure. The cracking of magnesium alloy samples under applied strain was also characterized by impedance. Changes in surface properties due to crack initiation
Key Words
biodegradable, metal, zinc, magnesium, corrosion, electrochemistry