CARBONATE BASED CONVERSION COATING ON MG ORTHOPAEDIC IMPLANTS: IN VITRO STATIC AND FLOW DEGRADATION STUDIES

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Keywords:

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Introduction:

Magnesium-based alloys offer significant advantages as orthopaedic implant materials compared to conventional options like Co-Cr, stainless steel, Ti-based alloys, and emerging Zr-based alloys. These advantages include their lightweight nature, minimal stress shielding, biodegradability, biocompatibility (cytocompatibility and hemocompatibility), infection resistance (especially when alloyed with Zn, Cu, Ag), and the elimination of secondary surgery for implant removal.

Magnesium's role in human metabolism underpins its appeal as a biomaterial. It is the fourth most abundant element in the human body, with about 25 g in a typical adult, evenly distributed between soft tissues and bone. As the second most prevalent intracellular cation, it is vital for over 300 enzymatic reactions. Normal serum magnesium levels range from 0.7 to 1.05 mmol/L, regulated by renal and intestinal homeostasis. Hypermagnesemia, defined as serum magnesium levels exceeding 1.05 mmol/L, can cause respiratory issues, diarrhoea, hypertension, and muscular paralysis, with levels of 6-7 mmol/L potentially leading to cardiac arrest. Magnesium implants degrade into non-toxic, excretable compounds but rapid corrosion can lead to hypermagnesemia and hydrogen gas evolution, causing inflammation and compromising mechanical integrity before bone healing.

Research has focused on controlling magnesium alloy corrosion. While early alloys contained harmful elements, newer biocompatible alloys (Zn, Ca, Sr, Mn, Ag) offer improved safety. Coatings and surface treatments, including bio glass and bio ceramics, have been explored to enhance biocompatibility, low degradability, and osteogenesis. This study investigates calcium carbonate-based coatings, inspired by marine crystal growth, characterized using FTIR, XRD, and FESEM-EDAX, and evaluates biodegradation and mechanical performance through in vitro testing and X-ray nano-CT scans.

Objectives:

Objectives of the project are

- Achieving Carbonate based coating on Magnesium (Mg) alloy.
- Long term static corrosion performance of the coating.
- Flow assisted degradation studies of the coatings in in vitro Bioreactors.
- Characterization of the as prepared coating and corroded sample.

Methodology

The carbonate salts weakly soluble in the water are dissolved through carbon dioxide infusion to obtain M^{+} and HCO_3^{-}. The magnesium alloys will be immersed in this solution and carbonate-based coatings will be obtained through precipitation. These coatings will be characterized using X-ray diffraction (XRD), Fourier Transform Infrared (FTIR) spectroscopy and Field emitting scanning electron microscopy (FESEM) for their structural, functional and morphological features. Further, long-time cyclic and flow assisted in vitro degradation behaviour of the implants in the simulated body fluids (SBF) will be evaluated in the incubator and bioreactors respectively. Corrosion products, changes in the SBF will be characterized. Samples tested in the incubator and bioreactors will also be characterized using uCT scans to understand the volumetric corrosion behaviour.

Results and Conclusion

Magnesium alloys hold significant promise as biodegradable implants for orthopaedic, maxillofacial surgery, urethral stents, and cardiovascular stents. However, their high degradation rates, hydrogen evolution, and mechanical integrity loss limit their practical applications. This study demonstrates the potential of novel, environmentally friendly coatings inspired by natural mineral growth in marine environments to address these limitations.

The microstructural analysis of Mg-2Zn alloy shows α-Mg grains with Zn-rich secondary phases at grain boundaries, indicating a coring effect due to slow cooling. Coating morphology reveals uniform, interlocking brick-like crystals, with elemental mapping confirming a Ca-based composition. FTIR spectra identify CO3- peaks analogous to CaCO3 precursors. Corrosion mechanisms involve magnesium oxidation, hydrogen evolution, and pH changes, with coatings significantly reducing reactivity compared to bare alloys. pH monitoring shows lower reactivity in coated samples, attributed to inhibited magnesium/calcium carbonate and phosphate precipitation, enhancing surface bioactivity.

Long-term performance evaluations over 650 hours indicate lower reactivity and greater stability of coated samples. Nano-CT scans reveal localized corrosion in uncoated samples under static and flow conditions, while coated samples exhibit protection. Volumetric corrosion rates for coated samples are significantly lower (0.044 mm^3/day) compared to uncoated samples (0.104-0.264 mm^3/day), highlighting the coatings' effectiveness in preserving mechanical properties under physiological conditions.

In conclusion, magnesium alloys' potential as biodegradable implants is enhanced by innovative coatings that mitigate corrosion and maintain mechanical integrity. Further research into these coatings could advance the clinical utility of magnesium-based biomaterials in regenerative medicine.

Description of the innovation in the project

The innovativeness of the project is mentioned below:

- we have analysed the corrosion coating behaviour in nano level by using nano CT.
- we have achieved nature inspired bio coatings.
- our methodology for conversion coating is unique and novel.
- we have customised bioreactors for invitro testing of samples in simulated body fluids.

Future work scope

Future research should focus on optimizing coating compositions and application methods to enhance uniformity, adherence, and biocompatibility of magnesium alloy implants. Detailed studies of corrosion mechanisms, including the interaction of ions and organic molecules with the alloy, are essential. Long-term in vivo studies are necessary to evaluate biocompatibility and mechanical integrity under real-world conditions. Advanced surface modification techniques, such as nanostructured coatings and laser surface modification, should be explored to improve corrosion resistance. Integration with drug delivery systems could enable localized treatment to facilitate healing and reduce infection risks. Evaluating mechanical properties under dynamic loads will provide insights into durability for load-bearing applications. Advanced characterization techniques, including synchrotron X-ray tomography and in situ microscopy, can offer a detailed understanding of degradation mechanisms. Personalized medicine approaches should also be investigated to customize implants based on patient-specific factors, enhancing their effectiveness and reliability.