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ORIGINAL RESEARCH

STRUCTURAL EVALUATION OF CHITOSAN-BIOACTIVE GLASS COATING ON WE43 MAGNESIUM ALLOY: A PRELIMINARY IN VITRO STUDY
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ABSTRACT

Background: Orthodontic mini implants are conventionally made from materials such as Titanium, Stainless steel Cobalt-Chromium alloys, ect. This study was conducted to evaluate the displacement of anterior teeth when using three different mini-implant materials for direct anchorage in a Finite Element Model.

Methods and Materials: A Cone beam computed tomography (CBCT) of maxillary arch was used to generate a 3 Dimensional model. The position of the mini-implant was planned between the roots of the second premolar and molar to provide anchorage for anterior retraction. The force levels were simulated at 250g per side. Three Finite element models were generated for the use of different mini implant materials- I: Titanium (Ti6Al4V), II: Stainless steel, III: Magnesium alloy (WE43 alloy).

Results: In the sagittal and vertical plane, the greatest anterior tooth movement was seen using Magnesium, followed by Titanium, and least with Stainless steel. In case of posterior teeth, all three groups presented in the same range of minimal movement, in sagittal and vertical planes.

Conclusion: The simulation of retraction of anterior teeth using Finite Element Modelling allows a standardized simulation of biomechanical outcomes. Further clinical and invitro studies can correlate the findings of this simulation.

Keywords: Chitosan, Magnesium alloy, Mini implants, Stainless steel, Titanium.

INTRODUCTION

Orthodontic implants—also referred to as mini-implants, temporary anchorage devices, or TADs—are frequently utilized to augment support for tooth movement. These temporary sources of anchorage are positioned in the cortical bone of the maxilla/mandible to increase the anchorage value and resist undesired tooth movements during active orthodontic treatment.¹ One of the earliest documented uses of mini implants was in animals by Creekmore and Eklund, who placed vitallium based mini screws to facilitate orthodontic tooth movement in dogs.² These devices of absolute anchorage are now being manufactured from Titanium based alloys, Cobalt-Chromium, or Stainless Steel.³ One of the greatest limitations to using these conventional materials as TADs is their increased tendency to leach

metal ions into the immediate environment, causing varied

adverse reactions of the local peri-implant tissues.⁴ Following their duration of intended use for orthodontic anchorage, these TADs manufactured from conventional materials also require a procedure for their retrieval. A greater chance for implant fracture has been noted during these implant removal procedures.⁵

Magnesium, and its alloys have shown biomechanical qualities similar to that of adult cortical bone in humans when compared to conventional Stainless steel or Titanium. Along with the mechanical properties, Mg based alloys, such as WE43 alloy, have been studied extensively for their superior biocompatibility and their bioresorptive behavior

when placed in mineralised tissue.⁶ To make use of these properties of Mg, while controlling its rate of material degradation in the oral cavity, Mg alloys like WE43 are being considered as potential bio implant materials as alternatives to conventional non resorbable TADs made of Stainless steel or Titanium.⁷⁻⁸

Untreated surfaces of Mg alloys, when exposed to moisture have been known to produce Hydrogen gas, and stimulate adverse effects of the local tissues.¹⁰⁻¹¹

To optimize the properties of the material while reducing the rate of resorption, and consequently controlling Hydrogen gas formation, surface treatment of the metal is considered as an effective alternative.⁸⁻⁹ Chitosan (CS), has been documented extensively for its use in tissue engineering, cell regeneration, stimulation of wound healing, and its antimicrobial nature.¹²⁻¹⁵ At pH below 6.5, CS based formulations are highly water soluble and demonstrate suboptimal mechanical properties.¹⁶⁻¹⁷ To overcome this, CS based formulations are usually combined with composite materials for various clinical applications.¹⁸

Bioactive glass, BG, is an oxide-based biomaterial that is used as a versatile coating material in biomedical applications. This is attributed to its uniform particle size, and superior surface adhesion properties in the presence of irregular molecular structures.¹⁹ BG

has also demonstrated release of ions in the presence of moisture, altering the local pH and thereby contributing to the antibacterial activity in the peri-implant region. BG coated materials also allow local osteoinduction and rapidly form bone-like structures around the metal substrate.²⁰

The aim of this study was to coat WE43 alloy of Magnesium (Mg) with Chitosan-Bioactive glass (CS-BG) and evaluate the coated alloy as a preliminary in vitro study of the material, to study its scope as a potential bioimplant material.

MATERIALS AND METHODS

This preliminary in vitro study was conducted during the period of March-May 2024. Since the study design was in vitro, it was not eligible for ethical committee approval, and no patient consent was required. In accordance with studies conducted by Hua et al., sheets of pure Mg substrate were sliced into dimensions of 20mm x 30mm x 5mm.²¹ The Mg surface was abraded with Silicone Carbide abrasive of grit 800 and 1000 progressively. 0.01g of powdered bioactive glass (BG) and 0.05g of dehydrated Chitosan powder (CS) were dissolved in 60mL of distilled water to produce a solution for coating the Mg alloy samples. The polished samples were air dried and immersed in CS-BG solution for 2 hours at 0.10V, 0.05A, to produce a CS-BG coating on Mg alloy. (Figure 1a-1b, Figure 2).

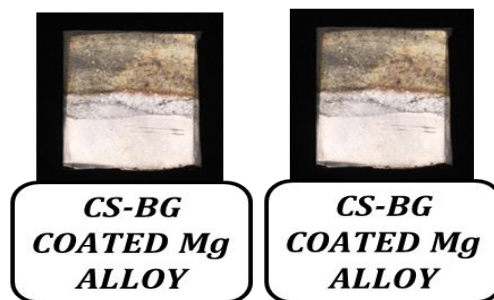


Figure 1a: Uncoated Mg alloy, **Figure 1b:** Chitosan-Bioactive Glass coated Mg alloy.



Figure 2. Coating of Mg alloy with Chitosan-Bioactive Glass at 0.10V, 0.05A.

These coated samples were examined and compared with the uncoated samples as follows: 3 coated and 3 uncoated samples were evaluated for all the tests mentioned. The obtained data was expressed in mean and processed using analysis of variance (ANOVA) and statistically significant level was set at $p < 0.05$. The surface of CS-BG coated Mg samples was characterized using X-Ray Diffraction and Fourier Transform Infrared Spectroscopy (FTIR).²²

XRay Diffraction

X-ray Diffraction was used to verify the compositional state of the CS-BG coated WE43 Mg alloy and the main component of chitosan. Two beams of light are placed incident upon the sample at the same angle. Diffraction occurs when the wavelength of Xrays is similar to the interatomic spacing.

Fourier Transform Infrared Spectroscopy:

In FTIR spectroscopy, an Infrared light source is incident on the coated sample. The molecular arrangement of the CS-BG coated sample produces a characteristic interference pattern of radiation. This signal of interference waves - interferogram- is converted and interpreted using the Fourier Transformation equation.

RESULTS

XRay Diffraction: The uncoated Mg sample had a crystallinity of 58.8%. After coating with CS-BG, the crystallinity of the sample increased to 89.7%. In addition, C, O, and N peaks were also noticed, confirming the presence of the chitosan matrix. (Figure 3a-3b)

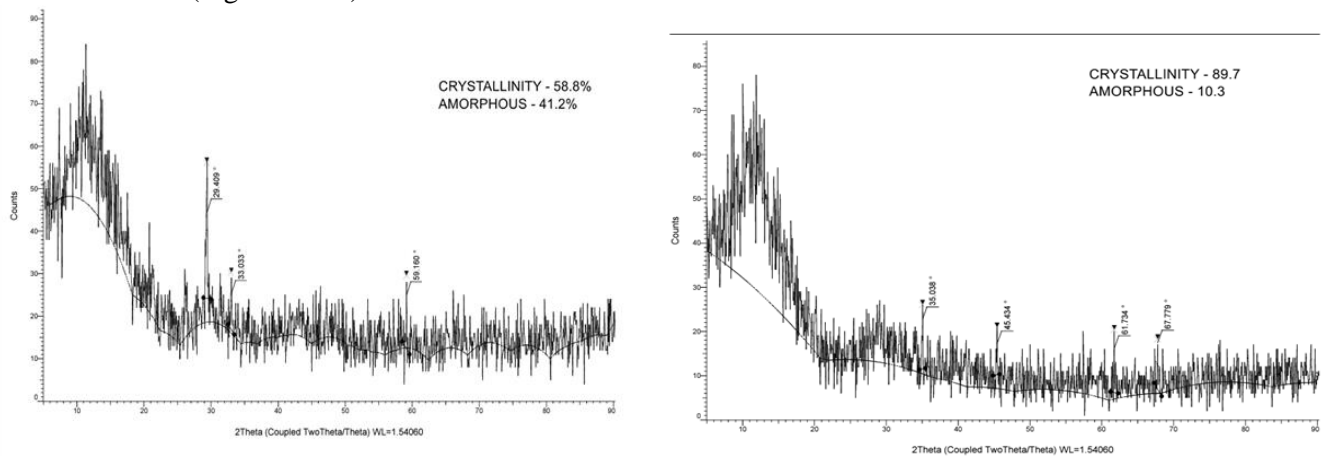


Figure 3. Xray Diffraction pattern produced by 3a- uncoated Mg alloy and 3b- CS-BG coated Mg alloy.

Fourier Transform Infrared Spectroscopy: FTIR results show peaks between the range of 500-1000 cm inverse, confirming the presence of the compositional groups in the samples. (Figure 4a-4b).

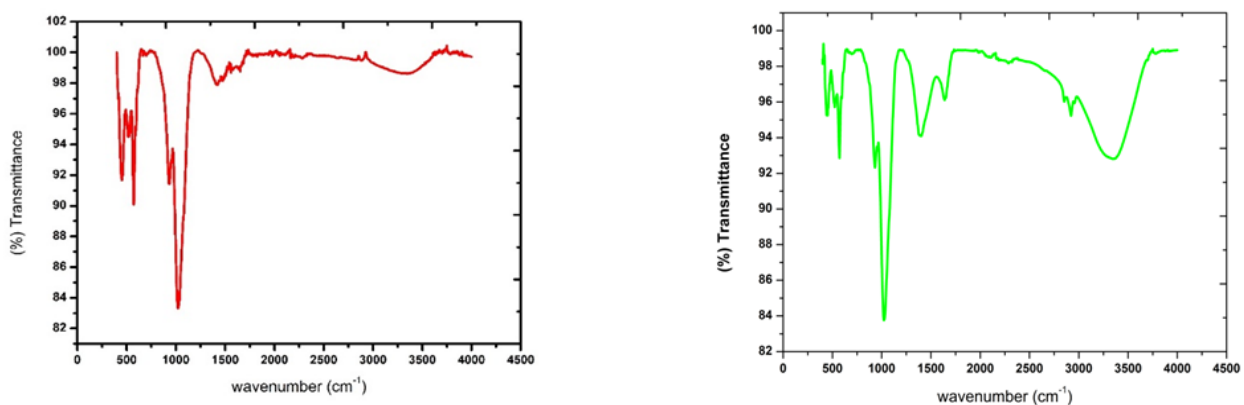


Figure 4. FTIR peaks produced between the range of 500-1000 cm inverse. 4a- uncoated Mg alloy, and 4b- CS-BG coated Mg alloy.

DISCUSSION

However, reports of metallosis have been documented due to excessive wear or corrosion of the metallic surfaces. Structurally, metallosis is a result of leaching of metal ions into the peri-implant tissue, producing a local inflammatory reaction. This triggers a series of local and systemic adverse reactions. Of these, the most clinically significant effect is on osteosynthesis and metabolism of mineralized tissue in the peri-implant region. This could potentially compromise the primary stability of the orthodontic mini implant.²³⁻²⁵ An animal study was conducted to evaluate metal toxicity and leaching of metal ions from implants made of Titanium alloys (Ti-6Al-4V) and Cobalt-Chromium implants. The release of metal ions from Titanium triggered a larger release of inflammatory mediators, particularly prostaglandin E2, when compared to Cobalt-Chromium implants.²⁶

This in vitro surface characterization of the Mg alloy revealed an increase in the contact angle of the sample after CS-BG coating. Wassman et al., reported an association between the hydrophobic nature and average surface roughness of the coated metal, with microbial adhesion, and biofilm formation on the metal. The microbial biofilm that forms on the implant surface may be influenced by the hydrophobic nature of the coated sample. Surface modification procedures, like abrasive polishing and nanoparticle coating of the alloy could also influence the biological response from the body.²⁷⁻²⁸ An animal study conducted by Bumgardner et al., comparatively evaluated the effects of CS coatings and Calcium Phosphate coatings on Titanium implants and concluded that once a clinically significant stability of the implant had been achieved with satisfactory healing in the peri-implant region, the persistence of the surface coating on the metal may not be crucial.²⁹ In case of surface modification of the implant material, micro roughened metal surfaces have been reported to have a higher contact at the bone-implant interface. Clinical evaluation further reported a greater force required to dislodge or retrieve the implant with higher surface roughness than those with smoother surfaces.³⁰

A systematic review evaluated the surface modification of Titanium based orthopedic implants with Bioactive glass coatings. Satisfactory bone mineralization was reported around the region of BG coated Titanium implants. BG coated oral implants demonstrated better mineralization with osteoid formation, and greater bone density was observed radiographically after a period of 6 months.³¹ Ideally, BG within the weight percentage of 40-60% Silicon Oxides can promote bone formation. Increased concentrations of BG in the surface coating has shown a more rapid and uncontrolled release of ions into the surrounding bone, which could potentially limit

the mineralization at the bone-implant interface.³²

The qualities of the metal surface could vary depending on the length of time the coating is applied for. The nature of the biopolymer coated on the surface could play a potential role on the porosity and rate of degradation of the Mg surface.³³ Further studies using alternative metal oxide based biopolymer coatings can be done to evaluate the performance of CS and other polymers for clinical applications. Correlation and in vitro verification of the quality and behaviour of the surface must also be considered under various time constraints. Additionally, to confirm the effectiveness of these nanoparticle-coated structures in a biologically active setting and to track changes in these parameters over time, clinical studies are required. This could provide key insight for the development of newer implant materials to be used as orthodontic anchorage devices through bioresorbable implants.

CONCLUSION

The surface properties of CS-BG coated Mg alloy were characterized using X-Ray Diffraction and Fourier Transform Infrared Spectroscopy (FTIR). Following the coating procedure, the CS-BG coated Mg alloy samples showed increased crystallinity. The results of FTIR confirmed the presence of the compositional groups in the CS-BG coated WE43 alloy. The CS-BG coating on WE43 alloy of Mg was evaluated to assess the scope of its future use as a novel bioimplant material.

DECLARATIONS

No funding was received from any financially supporting body.

Consent for publication

Informed consent was obtained from every participant for documentation and examination.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was granted by the Institutional Human Ethical Committee

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