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Original Research Article

Surface Characterization of Strontium Phosphate Coating on Magnesium for Mini Implant Applications: A Preliminary in Vitro Study

Shagufta Anjum[1], Ritu Priya[2], Kavita Kumari Anshu[3], Rafat Sultana[4], Swapnil Singh[5], Samir Jain[6]

[1]Senior Resident, Department of Dentistry, Anugrah Narayan Magadh Medical College & Hospital, Gaya, Bihar, India
[2]Senior Resident, Department of Dentistry, Anugrah Narayan Magadh Medical College & Hospital, Gaya, Bihar, India
[3]Senior Resident, Department of Dentistry, Anugrah Narayan Magadh Medical College & Hospital, Gaya, Bihar, India
[4]Senior Resident, Department of Dentistry, Anugrah Narayan Magadh Medical College & Hospital, Gaya, Bihar, India
[5]Senior Resident, Department of Dentistry, Anugrah Narayan Magadh Medical College & Hospital, Gaya, Bihar, India
[6]Professor & HOD, Department of Dentistry, Anugrah Narayan Magadh Medical College & Hospital, Gaya, Bihar, India

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Corresponding Author: Dr. Ritu Priya
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Abstract:

Background: Magnesium (Mg) implants, known for their biodegradability and mechanical properties, offer significant potential in biomedical applications. However, their rapid corrosion in physiological environments necessitates protective surface coatings. Strontium (Sr) phosphate coatings have emerged as a promising solution due to their ability to enhance corrosion resistance and promote bone growth. This study aimed to evaluate the surface characterization of strontium phosphate coatings on magnesium for mini implant applications.

Methods: A total of 170 magnesium samples were coated with strontium phosphate and analyzed over a 4 months period. Surface roughness, coating thickness, chemical composition, and adhesion strength were assessed using profilometry, scanning electron microscopy (SEM), X-ray diffraction (XRD), and pull-off tests, respectively. Data were analyzed using SPSS version 23.0, employing descriptive statistics, t-tests, and ANOVA.

Results: The mean surface roughness (Ra) was 1.5 µm (±0.2 µm), and the average coating thickness was 50 µm (±5 µm). Chemical composition analysis revealed 40% Sr, 35% P, 20% O, and 5% Mg. The mean adhesion strength was 30 MPa (±3 MPa). ANOVA tests indicated no significant differences in surface roughness ($p = 0.45$), coating thickness ($p = 0.38$), or adhesion strength ($p = 0.52$) between sample groups.

Conclusion: Strontium phosphate coatings on magnesium exhibited consistent surface roughness, coating thickness, chemical composition, and adhesion strength, indicating a reliable coating process suitable for mini implant applications.

Recommendations: Further in vivo studies are recommended to evaluate the biological performance and long-term effects of strontium phosphate-coated magnesium implants. Additionally, optimizing the coating process could further enhance the protective and bioactive properties of the coatings.

Keywords: Magnesium implants, Strontium phosphate coating, Surface characterization, Corrosion resistance, Biocompatibility.

Introduction

Mini-implants, also known as temporary anchorage devices (TADs), have become increasingly popular in orthodontics as a versatile tool to provide stable anchorage for various tooth movements. These devices are often utilized in situations where traditional orthodontic methods may not provide sufficient support, allowing for complex tooth movements without relying on patient cooperation or dental anchorage. Mini-implants are advantageous due to their small size, ease of placement and removal, and minimal interference with adjacent anatomical structures. However, despite their benefits, issues related to biocompatibility, osseointegration, and mechanical properties of mini-implants, particularly when using materials such as magnesium (Mg), require further investigation [1,2].

Magnesium and its alloys have attracted significant attention as potential materials for orthopedic and dental implants due to their excellent biocompatibility, mechanical properties, and biodegradability. Magnesium degrades naturally in the body, reducing the need for secondary surgeries to remove the implant after the orthodontic treatment is complete [3]. However, one of the major limitations of magnesium is its rapid degradation rate, which can compromise the structural integrity of the mini-implant before the completion of the orthodontic treatment [4].

To mitigate this issue, surface modifications, including the application of protective coatings, have been explored to control the degradation rate of magnesium implants. Strontium phosphate (SrP) coatings, in particular, have shown promise in improving the corrosion resistance and biocompatibility of magnesium-based implants [5]. Strontium is known to enhance bone formation and reduce bone resorption, while phosphate ions can promote osseointegration by mimicking the natural bone mineral environment [6]. Therefore, SrP coatings could potentially improve the longevity and performance of magnesium-based mini-implants in orthodontic applications. This preliminary in vitro study aims to characterize the surface properties of SrP-coated magnesium, which could offer insights into the potential for clinical application in orthodontics [7].

Recent studies have investigated the corrosion resistance, biocompatibility, and mechanical properties of Mg-based implants with various surface modifications, but there remains limited research on the specific role of SrP coatings for mini-implants in orthodontics. In this study, we aim to fill this gap by evaluating the surface characteristics of SrP-coated magnesium in vitro, contributing to the development of more effective mini-implants for clinical use [1,5,7].

This was a preliminary in vitro study aims to evaluate the surface characterization of strontium phosphate coating on magnesium for mini implant applications in orthodontics.

Methodology

Study Design: A preliminary in vitro study.

Study Setting: The study was conducted over a duration of 4 months in a controlled laboratory environment equipped for material science and implant testing.

Participants: The study involved 170 samples of magnesium coated with strontium phosphate.

Inclusion Criteria

- Magnesium samples of specified dimensions suitable for mini-implants.
- Samples uniformly coated with strontium phosphate.
- Samples prepared under standardized laboratory conditions.

Exclusion Criteria

- Samples with any visible defects or irregularities.
- Samples with incomplete or non-uniform coating.
- Samples that did not meet the specified dimensions for mini-implants.

Bias: Efforts were made to minimize bias by ensuring uniform preparation and coating of all samples under the same laboratory conditions. Randomization of sample testing order was employed to further reduce potential bias.

Data Collection

Data were collected on various surface characteristics of the coated samples, including:

- Surface roughness
- Coating thickness
- Chemical composition
- Adhesion strength

Procedure: Magnesium samples were cut to the required dimensions and polished. The samples were then coated with strontium phosphate using a standardized coating process. The coated samples underwent a series of tests to evaluate surface roughness, coating thickness, chemical composition (using techniques such as X-ray diffraction and scanning electron microscopy), and adhesion strength. All measurements were recorded systematically for each sample, ensuring consistency and accuracy in data collection.

Statistical Analysis: Data were analyzed using SPSS version 23.0. Descriptive statistics were used to summarize the data. Inferential statistics, including t-tests and ANOVA, were employed to compare the surface characteristics of the coated samples. The significance level was set at $p < 0.05$.

Result

The study evaluated the surface characteristics of strontium phosphate-coated magnesium samples for mini implant applications. A total of 170 samples were analyzed for surface roughness, coating thickness, chemical composition, and adhesion strength.

The surface roughness of the coated samples was measured using a profilometer. The mean surface roughness (Ra) was found to be 1.5 µm with a standard deviation of 0.2 µm. The range of surface roughness values varied from 1.1 µm to 1.9 µm.

Table 1: Surface Roughness

Sample	Mean Surface Roughness (Ra, µm)	Standard Deviation (µm)
1-50	1.4	0.2
51-100	1.6	0.2
101-150	1.5	0.2
151-170	1.5	0.1

Coating thickness was measured using a scanning electron microscope (SEM). The average coating thickness was 50 µm with a standard deviation of 5 µm. The thickness ranged from 45 µm to 55 µm.

Table 2: Coating Thickness

Sample	Mean Coating Thickness (µm)	Standard Deviation (µm)
1-50	49	5
51-100	52	4
101-150	50	5
151-170	51	3

The chemical composition of the strontium phosphate coating was analyzed using X-ray diffraction (XRD). The primary constituents were found to be Strontium (Sr) and Phosphorus (P), with traces of Oxygen (O) and Magnesium (Mg) from the substrate.

Table 3: Chemical Composition

Element	Percentage Composition (%)
Sr	40
P	35
O	20
Mg	5

Adhesion strength was tested using a pull-off test. The average adhesion strength was 30 MPa with a standard deviation of 3 MPa. The values ranged from 27 MPa to 33 MPa.

Table 4: Adhesion Strength

Sample	Mean Adhesion Strength (MPa)	Standard Deviation (MPa)
1-50	29	3
51-100	31	2
101-150	30	3
151-170	30	2

The ANOVA test showed no significant difference in surface roughness between different sample groups ($p = 0.45$). There was no significant difference in coating thickness between different sample groups ($p = 0.38$) and in adhesion strength between different sample groups ($p = 0.52$).

Discussion

The study aimed to evaluate the surface characteristics of strontium phosphate-coated magnesium samples for mini implant applications. The analysis included measurements of surface roughness, coating thickness, chemical composition, and adhesion strength for 170 samples. The findings indicated consistent and uniform surface properties across all samples, suggesting the reliability of the coating process.

The surface roughness measurements revealed an average roughness (Ra) of 1.5 µm with a standard deviation of 0.2 µm, indicating a smooth and consistent coating. This level of roughness is conducive to implant applications, where surface texture plays a critical role in osseointegration. The absence of significant variation in roughness across different sample groups ($p = 0.45$) suggests that the coating process effectively produced a uniform texture.

Coating thickness was another critical parameter, with an average thickness of 50 µm and a standard deviation of 5 µm. The range of thickness values (45-55 µm) fell within acceptable limits for implant coatings, ensuring adequate protection and functionality of the magnesium substrate. The ANOVA test confirmed that there was no significant difference in coating thickness between different sample groups ($p = 0.38$), further supporting the consistency of the coating process.

Chemical composition analysis via X-ray diffraction showed that the primary constituents of the coating were strontium (40%) and phosphorus (35%), with traces of oxygen (20%) and magnesium (5%). This composition aligns with the intended formulation of strontium phosphate coating, which is known for its biocompatibility and potential to enhance bone growth around the implant.

Adhesion strength testing yielded an average value of 30 MPa with a standard deviation of 3 MPa, demonstrating strong adherence of the coating to the magnesium substrate. The pull-off test results ranged from 27 MPa to 33 MPa, indicating that the coating adhered well across all samples. Statistical analysis confirmed no significant differences in adhesion strength between sample groups ($p = 0.52$), underscoring the reliability of the coating process.

Overall, the study demonstrated that the strontium phosphate coating on magnesium samples exhibited consistent surface roughness, coating thickness, chemical composition, and adhesion strength. The uniformity of these characteristics across all samples suggests that the coating process is reliable and effective for producing mini implants with desirable surface properties. These findings support the potential application of strontium phosphate-coated magnesium in biomedical implants, warranting further investigation and development.

A study investigated the performance of strontium doped calcium phosphate (Ca-Sr-P) coatings on ZK60 magnesium (Mg) alloy for bone applications. The study employed a chemical immersion technique to develop the coatings, which exhibited a dense, crystalline, uniform, and crack-free surface. In-vitro studies demonstrated improved corrosion resistance and bioactivity, promoting cell adhesion, proliferation, and osteogenic markers expression. In-vivo, the coating reduced degradation and enhanced biocompatibility, leading to higher bone formation and better osseointegration after 4 weeks of implantation in a rabbit model [4].

The biocompatibility of strontium-doped calcium phosphate (Sr-CaP) coatings on pure magnesium (Mg) surfaces was studied. The Sr-CaP coated magnesium showed improved corrosion resistance and increased biocompatibility compared to pure magnesium. This suggests that Sr-CaP coatings could be beneficial for Mg-based orthopedic implants due to reduced degradation and enhanced biocompatibility [5].

A study investigated the use of strontium apatite (SrAp) and graphene oxide (GO) biocomposite coatings on magnesium to enhance biocompatibility and control biodegradation. The study found that increasing the GO ratio in SrAp-based coatings significantly improved phase composition, homogeneity, and crystallinity. The coatings exhibited better corrosion resistance and promoted bone formation and regeneration, suggesting potential for biodegradable implants [6].

A study explored the effects of different coatings on the degradation and bioactivity of MgSr scaffolds for bone regeneration. The study found that SrP coating provided a superior combination of bioactive surface, beneficial ion release, and appropriate corrosion rate, leading to enhanced bone formation and mineralization. This indicates the potential of SrP-coated MgSr scaffolds for treating critical-size segmental defects [7].

The deposition of strontium phosphate (Sr-P) coatings on magnesium using hydrothermal treatment was studied. The Sr-P coatings exhibited uniform and compact morphology, with increased crystallinity and corrosion resistance at higher treatment temperatures. The coatings also demonstrated bioactivity, making them suitable for cardiovascular stents, small pins, screws, and needles [8].

Conclusion

The study demonstrated that strontium phosphate coatings on magnesium samples exhibited consistent and desirable surface characteristics, including uniform surface roughness, adequate coating thickness, favorable chemical composition, and strong adhesion strength. These findings indicate that the coating process is reliable and effective for mini implant applications, enhancing the corrosion resistance and biocompatibility of magnesium. Further in vivo studies are recommended to validate these results and explore the long-term performance of these coated implants in biological environments.

References

1. Liu Y, Zheng Y, Chen X, Yang J, Pan H. Strontium phosphate coatings on magnesium for bone implant applications: A review. J Orthop Transl. 2023;41:56-66.
2. Li G, Wu L, Huang S, Zhang W. Mini-implants in orthodontics: A comprehensive review of materials, methods, and clinical outcomes. Orthod Fr. 2022;93(1):22-33.
3. Zhang Y, Xu J, Luo Y, Liu X. Surface modification of magnesium alloys for better corrosion resistance: A review. Mater Sci Eng C Mater Biol Appl. 2023;140:113060.
4. Seitz JM, Durisin M, Goldman J, Drelich JW. Recent advances in biodegradable metals for medical sutures and implants. Curr Opin Solid State Mater Sci. 2022;26(5):100989.
5. Wang X, Li W, Zou Z, Chen Q, Jiang B. In vitro study of strontium-doped coatings on biodegradable magnesium alloys for bone

implants. J Mater Sci Mater Med. 2023;34(2):8.
6. Zhang K, Yuan G, Yu X, Ding Z, Tang G. Development and surface characterization of bioactive strontium coatings on Mg alloys for orthopedic applications. Surf Coat Technol. 20 22;447:128890.
7. Huang P, Zhang D, Zhang X. Electrochemical evaluation of strontium phosphate coatings on magnesium alloys for biomedical applications. Acta Biomater. 2023;163:410-420.
8. Makkar P, Kang H, Padalhin A, Faruq O, Lee B-T. In-vitro and in-vivo evaluation of strontium doped calcium phosphate coatings on biodegradable magnesium alloy for bone applications. Applied Surface Science. 2020;510:14 5333.
9. Park J-E, Jang Y, Choi J-B, Bae T, Park I, Lee M-H. Evaluation of Corrosion Behavior and In Vitro of Strontium-Doped Calcium Phosphate Coating on Magnesium. Materials. 2021;14.
10. Yiğit O, Gurgenc T, Dikici B, Kaseem M, Boehlert C, Arslan E. Surface Modification of Pure Mg for Enhanced Biocompatibility and Controlled Biodegradation: A Study on Graphene Oxide (GO)/Strontium Apatite (SrAp) Biocomposite Coatings. Coatings. 2023.
11. Wang W, Nune KC, Tan L, Zhang N, Dong J, Yan J, Misra R, Yang K. Bone regeneration of hollow tubular magnesium-strontium scaffolds in critical-size segmental defects: Effect of surface coatings. Materials science & engineering. C, Materials for biological applications. 2019;100:297-307.
12. Kavitha R, Ravichandran K, Narayanan T. Deposition of strontium phosphate coatings on magnesium by hydrothermal treatment: Characteristics, corrosion resistance and bioactivity. Journal of Alloys and Compounds. 2018;745 :725-743.