Evaluation on the Corrosion of Ti Alloys in Dental Implant With CeO₂ Composition

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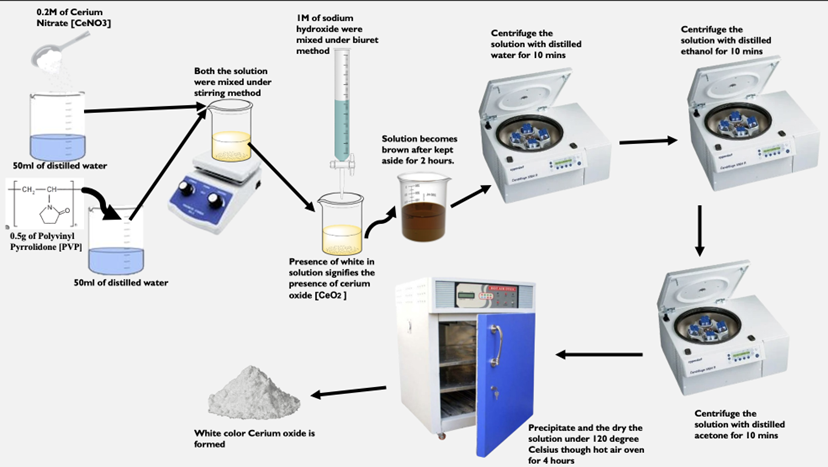
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**Abstract:** Corrosion resistance of titanium (Ti) Alloys in cerium dioxide (CeO₂) coated dental implants This work investigates corrosion resistance of titanium (Ti) Alloys immersed in cerium dioxide (CeO₂) coated dental implants. FTIR revealed the presence of characteristic absorption bands of CeO₂ at 545 cm⁻¹ whereas XRD showed CeO₂ peaks at 28.5°, 33.1°, 47.5°, and 56.3°, confirming the successful deposition of CeO₂ nanoparticles. As confirmed by phase angle measurements and impedance spectroscopy, Ti alloys were strikingly corroded on the bare alloy temp, but the corrosion resistance of the CeO₂ coated Ti alloys was significantly improved. According to the convergent beam electron diffraction (CBED), and selected area electron diffraction (SAED)patterns, the CeO₂ coatings were highly crystalline. Such results suggest that CeO₂ coatings markedly improve the corrosion resistance and structural stability of titanium alloys answering for dental implants. This study highlights the potential use of CeO₂ coatings for enhancing the functionality of dental implants. The study thus highlights the promise of CeO₂ coatings for improving clinical performance and prolonged longevity of dental implants in vivo, ultimately laying the groundwork for improved biomaterial innovations.

**Keywords** :Titanium alloys, Dental implants, Cerium dioxide (CeO₂), Corrosion resistance.

# Introduction

One of the methods to prevent peri-implantitis is the fabrication of titanium dental implants with a rough surface area adjacent to the neck[(Robles et al., 2023)](https://paperpile.com/c/sj7M9N/Rj5sn). Dental implants have emerged as a trustworthy solution for individuals with partial or total tooth loss**.**[(Wagner et al., 2022)](https://paperpile.com/c/sj7M9N/mkuw5). Nano-structured implants have broad applications, including for dental implants. The knowledge of biomaterials as well as the creative dental implant designs, including surface designs approaches like surface modification, biochemical anodisation and nanoscale sticky surfaces, provide critical solutions for the biomedical problems for these positions [(Kandavalli et al., 2021)](https://paperpile.com/c/sj7M9N/I3dNs). Titanium alloys are extensively used as implant materials owing to their better corrosion resistance and mechanical properties. Titanium is physiologically inert, meaning it does not bond with human cells[(“Surface Modification Techniques of Titanium and Titanium Alloys for Biomedical Dental Applications: A Review,” 2021)](https://paperpile.com/c/sj7M9N/RXGxk). Titanium is the primary material utilized for dental implants, but numerous surface modifications are being investigated to enhance osseointegration.Changes on the nanoscale and the activation of surfaces with biological compounds can potentially enhance healing, probably more rapidly than surfaces that are smooth[(Silva et al., 2022)](https://paperpile.com/c/sj7M9N/ekf2b). Owing to their unique blend of chemical, physical, and biological characteristics, especially biocompatibility, resistance to corrosion, and mechanical attributes, they are the preferred material for creating dental implants.[(Boffano et al., 2024)](https://paperpile.com/c/sj7M9N/fVqPY). Although technical advances have been made in preventing the corrosion of dental implants, the mechanisms of metal release and their relevance to peri-implant disease development remain to be elucidated[(Boffano et al., 2024; Nagay et al., 2022)](https://paperpile.com/c/sj7M9N/fVqPY+8vglr). Titanium is a non-reactive element due to its formation of a protective titanium oxide layer. However, when this titanium oxide shield deteriorates, the underlying bare titanium framework may become vulnerable and start to oxidize [(Kandaswamy et al., 2024)](https://paperpile.com/c/sj7M9N/hYGbq). A dental implant can experience malfunction due to the deterioration and exhaustion of the implant material or due to peri-implant ailments and the ensuing host inflammatory response1. In this report, we examine the significance of titanium and its alloys as materials for dental implants, as well as how surface characteristics influence bacterial colonization and the occurrence of peri-implant diseases[(Hasan et al., 2022)](https://paperpile.com/c/sj7M9N/1Coju). The creation of composite biomaterials that combine the flexible processing capabilities and eco-friendliness of polymers with the advantageous chemical traits of metal oxide nanoparticles opens up new opportunities for advancements in biomedical uses such as tissue repair, medication transport, gene treatment, diagnostics, and medical imaging[(Shcherbakov et al., 2021)](https://paperpile.com/c/sj7M9N/KZbos). The cerium oxide nanoparticles were synthesized using the coprecipitation process. Nanoparticles of synthesized CeO₂ as an antibacterial filler were introduced to the composite resin. Manual preparation of the experimental composite resin and addition of components[(Varghese et al., 2022)](https://paperpile.com/c/sj7M9N/ZJcNp). Cerium (Ce) is a rare earth element that is part of the lanthanide series. It has two oxidation states (Ce+3 and Ce+4) which give it the ability to act as a catalyst, provide antioxidant effects, exhibit antibacterial characteristics, and scavenge reactive oxygen species. The objectives of this study were to create ceria nanoparticles and assess their ability to scavenge reactive oxygen species as well as their compatibility with blood components[(“The Effect of CeO2 on the Crystallization of MgO-Al2O3-SiO2-ZrO2 Glass,” 2018)](https://paperpile.com/c/sj7M9N/ih32o). Research has shown that the addition of CeO₂ to glass-ceramic systems resulted in lower melting temperatures (Tm) and glass transition temperatures (Tg), as well as better coefficients of thermal expansion (CTE) [(Gawronski et al., 2014)](https://paperpile.com/c/sj7M9N/kzKNK). Such titanium-based dental implant biomaterials can possess antibacterial ability, because the coating of cerium oxide includes a higher fraction of Ce4+ valances. Precursor osteoblast cells or stem cells were seeded onto its disks with or without coating. In terms of the cell counting kit types and the cytometry experiments, the plasma-sprayed CeO₂ coating had higher cell viability as compared to the control. Qualitative and quantitative analysis of bacterial colonies in number showed the antibacterial activity of CeO₂ coated[(*Website*, n.d.)](https://paperpile.com/c/sj7M9N/DD5DT) [(Chokkattu et al., 2023)](https://paperpile.com/c/sj7M9N/n1Dj1), [(Laghari et al., 2023; Ramakrishnan et al., 2023)](https://paperpile.com/c/sj7M9N/RR91G+BSEUm), [(Muthuswamy Pandian et al., 2022)](https://paperpile.com/c/sj7M9N/xioV5) . The mechanical properties of acrylic resins with the addition of CeO₂nanoparticles were improved; however, as of now, no research has been published regarding the interaction of cerium oxide nanoparticles in a dental composite resin. This study developed an experimental antibacterial dental composite resin that can overcome most secondary caries-related issues associated with dental composite restorations[(Nelson et al., 2016; Vassie et al., 2017)](https://paperpile.com/c/sj7M9N/SPl6F+VA4JM)[(Adel et al., 2023)](https://paperpile.com/c/sj7M9N/hS4E2), [(Subramanian & Harikrishnan, 2023)](https://paperpile.com/c/sj7M9N/iXGf3), [(Solanki et al., 2023)](https://paperpile.com/c/sj7M9N/8S7IX). Although the mechanical properties of acrylic resins improved with CeO₂ nanoparticles, no published studies are available regarding coupling of cerium oxide with dental composite resin. Herein, we developed an innovative antibacterial dental composite resin-matrix which could potentially overcome the majority of secondary caries-induced issues with dental composite restorations[(K. Li et al., 2017)](https://paperpile.com/c/sj7M9N/Coyss). The desired surface coatings would enhance osseointegration but also reduce polymicrobial infection of the dental implant. Previous studies from our group showed the antioxidative activity of cerium oxide (CeO₂) which protects osteoblasts against oxidative stress by inhibiting shallow oxidative stress through maintaining intracellular antioxidants defense[(Secinti et al., 2011)](https://paperpile.com/c/sj7M9N/TV0yT). The formation of bacterial biofilm on implanted metal surface is a major clinical problem. The ability of silver ions to inhibit biofilm has long been recognized in their antibacterial and antifungal properties [(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/sj7M9N/B6IXZ+bKgJa+PYXtB), [(Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/sj7M9N/ULjKs+iLVqV), [(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/sj7M9N/VPE9P+VKPiA). The three morphologies of CeO₂-modified titanium presented outstanding antibacterial activities. Three types of different shaped nano-CeO₂ were synthesized via hydrothermal method after changing the reaction conditions, including nanorods, nanocubes, and nano-octahedrons. Nano-octahedron CeO₂ modified titanium exhibited the best anti-inflammatory effect. Therefore, CeO₂-modified Ti surfaces are also promising in further enhancing the antibacterial property of dental implants. A cutting-edge nano-octahedron CeO₂ (titanium) coating presented substantial therapeutic potential in the treatment and eradication of peri-implantitis[(Zhao et al., 2011)](https://paperpile.com/c/sj7M9N/tfpPq). CeO₂ coating, integrated into Ti alloy by spraying mechanism under the help of plasma, was reported to retain antioxidant defense mechanisms of H2O2-treated osteoblasts [(Marya et al., 2022)](https://paperpile.com/c/sj7M9N/NG0LC), [(Jain & Verma, 2022; Marya et al., 2022)](https://paperpile.com/c/sj7M9N/NG0LC+K8nBk), [(Wadhwani et al., 2022)](https://paperpile.com/c/sj7M9N/mIo4z). The ionic doping of Ce ions introduced through the network showed little cytotoxicity, good cell adhesion, increased extracellular mineralization, and improved protein adsorption, which resulted in a positive response in terms of new bone formation and osseointegration [(J. Li et al., 2018)](https://paperpile.com/c/sj7M9N/KIvbI). This study aims to assess corrosion resistance and antibacterial properties of titanium alloys used for dental implants modified by cerium oxide (CeO₂) coatings. Titanium alloys used for dental implants have good biocompatibility and mechanical properties, but also issues of peri-implantitis and corrosion as a result of wear of the titanium oxide layer. CeO₂ improves corrosion resistance, osseointegration, and shows promising antibacterial ability against biofilm formation.4.3 g fcerium e [Ce(NO₃)₃] was dissolved in 50 millilitres of distilled water for synthesis of cerium dioxide (CeO₂) nanoparticles. In parallel, 0.5 g of polyvinyl pyrrolidone (PVP) was dispersed in 50 ml of distilled water. For total blending, the two solutions were mixed and agitated at 80 °C and finally the two mixed solutions were treated with 1 M sodium hydroxide (NaOH) using the biuret method. After this step a white precipitate known as CeO₂ nanoparticles was obtained but after two h the precipitate changed to brown color indicating a chemical transformation. Subsequently, the solution was centrifuged in three successive steps for ten minutes at a rate of 3000 rpm: initially with distilled water to remove remaining contaminants, then a wash with ethanol to wash the nanoparticles and a second wash with acetone to speed up the drying process. After centrifugation, the precipitate was dried in a hot air oven at 120°C for four hours to confirm complete dehydration. In this regard, the technology was used for the successful synthesis of CeO₂ nanoparticles aimed for enhancing the corrosion resistance in titanium alloys as host materials for dental implants.

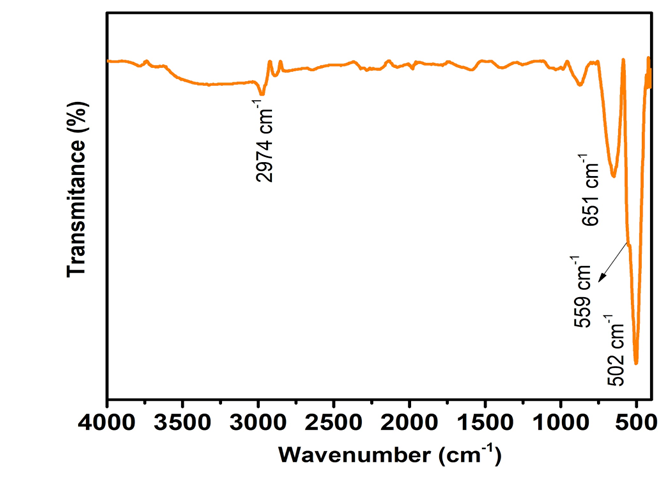


**Fig.1** Schematic Representation of synthesis of Cerium Oxide

# RESULTS AND DISCUSSION

## FTIR pattern of CeO₂ coated in Ti implant

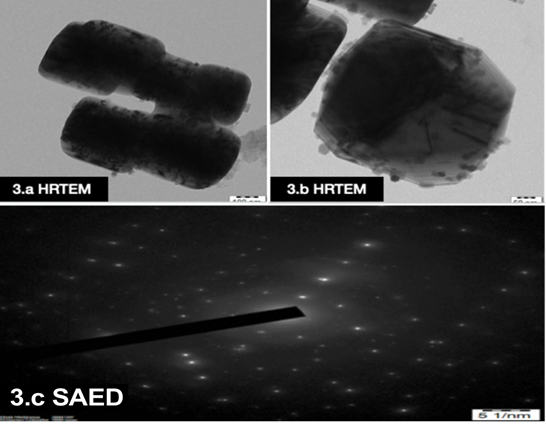
FTIR examination of CeO₂ layers on titanium implants indicated unique absorption features that validated the effective application of CeO₂. A wide peak detected around 2974 cm⁻¹ was linked to C−H stretching vibrations, probably due to organic contaminants or absorbed materials on the surface. The notable peaks at 651 cm⁻¹, 559 cm⁻¹, and 502 cm⁻¹ were associated with the vibrational characteristics of CeO₂, which confirmed its presence on the implant surface [[(Ioannou et al., 2023)](https://paperpile.com/c/sj7M9N/hiNDP)]. These particular bands emphasize the effective and adequate application of CeO₂ on the titanium implant. The existence of CeO₂ is vital for improving resistance to corrosion and guaranteeing that the implants are biocompatible. This integration is crucial for delivering the necessary long-lasting durability and stability for dental uses. FTIR analyses offer important information regarding the chemical makeup and validate that the coating method was successful, leading to enhanced performance and lifespan of dental implants.



**Fig.2.** FTIR pattern of CeO₂ coated in Ti Implant

## HRTEM & SAED Pattern of CeO₂ coated in Ti implant

The HRTEM pictures (Figs. 3.a and 3.b) and SAED patterns (Fig. 3.c) verify the crystalline nature of CeO₂ coatings on Ti implants(Nikalje et al., 2024) (Chehelgerdi et al., 2023). Individual CeO₂ nanoparticles with diameters ranging from 50 nm to 100 nm and rod-like and hexagonal forms are visible in the HRTEM pictures, suggesting a uniform and homogenous manufacturing process. The crystalline structure of the nanoparticles is confirmed by the well-ordered atomic arrangement shown by the distinct lattice fringes seen in the HRTEM pictures.This is further supported by the SAED pattern, which displays clear and brilliant diffraction spots that match the crystallographic planes of CeO₂ and reveal an ordered crystalline structure. These results highlight the effectiveness of the synthesis procedure and are consistent with other studies that observed the high crystallinity of CeO₂ particles [[(“Nanoparticles: Properties, Applications and Toxicities,” 2019)](https://paperpile.com/c/sj7M9N/Y8me9)]. CeO₂-coated titanium implants are more suited for long-term dental uses because of their crystalline structure, which is essential for improving corrosion resistance and biocompatibility [[(“Corrosion Resistance with Self-Healing Behavior and Biocompatibility of Ce Incorporated Niobium Oxide Coated 316L SS for Orthopedic Applications,” 2019)](https://paperpile.com/c/sj7M9N/HcNQe)].

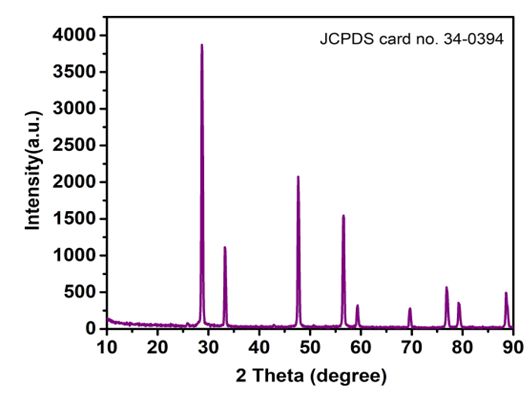


**Fig.3**.a. And fig.3.b HRTEM & fig.3.c SAED pattern change the image caption 3c saed Impedance Spectroscopy of uncoated and cerium oxide coated Ti implants

Electrochemical behavior substantially differs for uncoated and CeO₂ coated Ti implants, as indicated by the results of impedance spectroscopy. The Nyquist plots (Fig. 4 and Fig. 5) demonstrate that CeO₂–coated Ti implants have a significantly higher impedance than uncoated implants. However, the uncoated Ti implant showed different values of impedance (Fig. 3b). 4) are lower, indicating a more rapid corrosion rate and inferior protection from the corrosive environment. The smaller semicircle corresponds to low charge transfer resistance The CeO₂-coated Ti implant (Fig. 5) exhibits a wider semicircle in the Nyquist plot, indicating stronger charge transfer resistance and superior corrosion resistance. the phase angle curves for uncoated Ti and CeO₂-coated Ti implants (Fig. 9 c) indicated comparatively lower implant stability for uncoated and comparatively higher implant stability for CeO₂-coated Ti implants within the entire healing period. (5and 6) showed marked changes in frequency responsiveness.

## XRD Pattern of CeO₂ Coated in Ti Implant

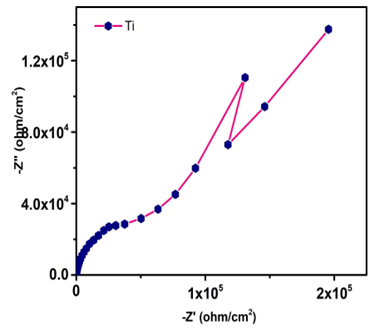
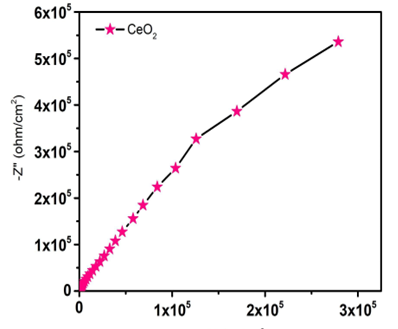
According to standard JCPDS card no. 34-0394[(X. Li et al., 2019)](https://paperpile.com/c/sj7M9N/qkwA2), the Ti alloy with CeO₂ composition had clear and obvious peaks at 2θ values of around 28°, 32°, 46°, 55°, and 65°, which corresponded to CeO₂ planes. The crystalline and phase-pure character of the synthesised CeO₂ nanoparticles, which are successfully incorporated inside the Ti alloy matrix, is confirmed by the sharpness of these peaks. A dominating CeO₂ phase is shown by the conspicuous peak at about 32°, which highlights the titanium alloy's excellent integration. By serving as a physical barrier to shield the titanium substrate from corrosive media, this embedding is essential for improving corrosion resistance [[(“Corrosion Resistance with Self-Healing Behavior and Biocompatibility of Ce Incorporated Niobium Oxide Coated 316L SS for Orthopedic Applications,” 2019)](https://paperpile.com/c/sj7M9N/HcNQe)]. In addition to extending the implant's lifespan, enhanced corrosion resistance guarantees biocompatibility and lowers negative responses in the oral environment [[(Parnia et al., 2017)](https://paperpile.com/c/sj7M9N/oXYUT)]. Achieving homogeneous CeO₂ distribution on the surface of the Ti alloy was largely dependent on the synthesis and coating parameters, including stabilisers such sodium hydroxide (NaOH) and polyvinylpyrrolidone (PVP) [[(Koczkur et al., 2015)](https://paperpile.com/c/sj7M9N/2LkW4)].



**Fig. 4.** XRD pattern of CeO₂ coated on Ti implant

## Impedance Spectroscopy of uncoated and cerium oxide coated Ti implants

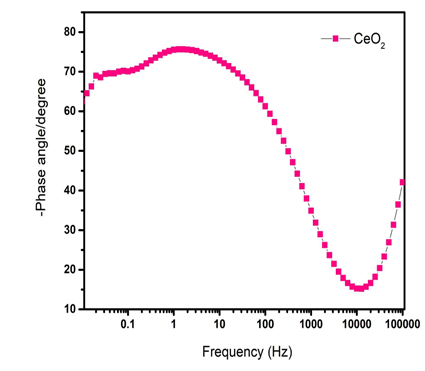
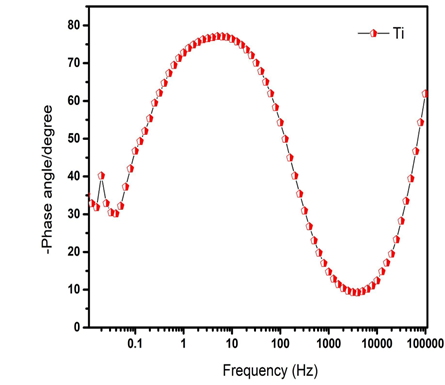
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**Fig 5&6** Impedance Spectroscopy of uncoated and cerium oxide coated Ti implants

## Phase angle of uncoated and cerium oxide coated Ti implants

The cup phase angle of uncoated Ti implant (Fig.5,6) initially increases to ~ 60 degrees and then decreases below 40 degrees indicating weak capacitive behavior that turns to resistive behavior at higher frequencies. This indicates that the protective action is limited in corrosive conditions. On the other hand, the Ti implant with CeO₂ coating (Fig. 6) has initial phase angle about 70 degree and is higher over a broader frequency range compared to its neighbours, before it drops. This high phase angle, which is consistently maintained over time, shows that good capacitive behavior is achieved with a very effective barrier or protection against corrosion by the CeO₂ coating. It inhibits corrosion and prolongs the life of Ti implants. CeO₂-coated Ti implants show better electrochemical stability and better corrosion resistance, which are better suited for biomedical applications.



**Fig 7 & 8** Phase angle of uncoated and cerium oxide coated TI implants

The results of these studies emphasized that both the synthesis and coating processes played a critical role in the herd immunity effect. The stabilization effect of polyvinylpyrrolidone (PVP), as well as the introduction of sodium hydroxide (NaOH) during the synthesis process, were decisive in obtaining the appropriate nanoparticles properties[(Koczkur et al., 2015)](https://paperpile.com/c/sj7M9N/2LkW4). The polymeric stabilizer, PVP, was also exploited to tune their growth and surface attachment to guarantee their systematic distribution and coating on the titanium alloys. The Biuret method was more controlled in terms of reaction conditions for forming quality CeO₂ nanoparticles. But such methodological consideration is key to producing reliable findings, and this needs to be specifically designed for high-throughput generation[(Pandey et al., 2023)](https://paperpile.com/c/sj7M9N/Rjv0a)[(Muthuswamy Pandian et al., 2022; Ramakrishnan et al., 2023)](https://paperpile.com/c/sj7M9N/xioV5+RR91G), [(Merchant et al., 2022)](https://paperpile.com/c/sj7M9N/iLVqV), [(Sreevarun et al., 2023)](https://paperpile.com/c/sj7M9N/ZVZf9).Furthermore, exploring the advances in above-synthesized properties of CeO₂ nanoparticles and further application on titanium alloys will be interesting future studies through optimization of synthesis and coating parameters. Further characterisation of the long-term stability and in vivo biocompatibility of these coatings will therefore be essential for deployment of these observations into clinical use. General coating performance can also be enhanced by other stabilizing agents and various deposition techniques[(Amirtharaj Mosas et al., 2022)](https://paperpile.com/c/sj7M9N/TpuWh). Overall, this study establishes a foundation for the development of better materials for dental implants, which may lead to an improvement in the longevity of implants and the outcome for patients.

# Conclusion

CeO₂-Coated Ti Alloys in Dental Implants and the Study of Their Corrosion Resistance XRD and FTIR confirmed the successful deposition of CeO₂, and Impedance spectroscopy and phase angle measurements showed enhanced corrosion resistance of the coated specimens. SAED patterns showed sharp spots reflecting that the CeO₂ coating is in highly crystalline nature. The results demonstrate that although an untreated titanium alloy was susceptible to corrosion and fracture, CeO₂ coatings markedly improve the corrosion protection and structural stability of titanium dental implants.

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