Evaluation of Antibacterial and Antioxidant Properties of Tin Oxide Nanoparticles Loaded Ciprofloxacin Against Dental Implant Infections

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**Abstract:** This study investigates the properties of tin oxide (SnO₂) nanoparticles and Ciprofloxacin-loaded SnO₂ NPs for potential biomedical applications. Dental infections are often caused by bacterial infiltration into the pulp, but these can be mitigated using drug-loaded nanoparticles. Antimicrobial activity of Ciprofloxacin-loaded SnO₂ NPs was assessed through inhibition zone measurements, showing equal or greater inhibition than Streptomycin. Bare SnO₂ exhibited moderate antimicrobial effects. Antioxidant testing revealed a slight decrease in scavenging activity for Ciprofloxacin-loaded SnO₂ NPs (IC₅₀ of 30.649 mg/mL compared to 26.554 mg/mL for the control). FT-IR analysis confirmed the presence of functional groups, while biomineralization studies indicated promising bioactivity. Overall, Ciprofloxacin-loaded SnO₂ NPs exhibit enhanced antimicrobial and bioactive properties, positioning them as effective candidates for biomedical applications, particularly in treating infections.

**Keywords**: Tin Oxide, Ciprofloxacin, dental infection

# Introduction

Dental implants are the most widely considered treatment choice for the replacement of misplaced teeth [(Warreth et al., 2017)](https://paperpile.com/c/0x0fO5/E1OH)[(Ajay, Rakshagan, et al., 2022)](https://paperpile.com/c/0x0fO5/uDadu). The most widely used materials for the fabrication of dental implants are titanium and its alloys, which have high biocompatibility, resistance to corrosion, mechanical strength, etc [(Froes & Qian, 2018)](https://paperpile.com/c/0x0fO5/AD3m). The major source of the failure of dental implants is bacterial infections following surgery [(Graf et al., 2023)](https://paperpile.com/c/0x0fO5/sldSV). Bacterial adhesion on the implant surfaces leads to decreased bone formation due to the biofilm formation by the bacteria [(Doymus et al., 2021)](https://paperpile.com/c/0x0fO5/tUYs). Additionally, the biofilm on the implant prevents the implant from integrating with the surrounding tissue, which increases the risk of implant failure [(Asadi et al., 2022)](https://paperpile.com/c/0x0fO5/uuu6g). To overcome this problem to introduce the nanoparticles [(Biju et al., 2024)](https://paperpile.com/c/0x0fO5/e6sVP) [(Ajay, Suma, et al., 2022)](https://paperpile.com/c/0x0fO5/HTtUI).

Nanoparticles are extra fine particles that are in the range of 10-9 m in diameter. It improves and enhances the properties of its bulk material by several times [(Biju et al., 2024; Calixto et al., 2014)](https://paperpile.com/c/0x0fO5/e6sVP+94vwo)[(Dharman et al., 2021)](https://paperpile.com/c/0x0fO5/GQqXS). To enhance soft tissue integration and boost dental implant success rates, nanoparticles are applied as particle coatings on the surface of the implants [(Samiei et al., 2016)](https://paperpile.com/c/0x0fO5/vCYJC). Nanoparticles from various metals possess bactericidal effects against a variety of bacteria, thermal resistance that is essential for fixation and the least cytotoxicity when stabilized on the surfaces [(Abdulkareem et al., 2015)](https://paperpile.com/c/0x0fO5/RM6qH). This effective antimicrobial property of metallic nanoparticles is attributed due its insignificant size and high surface-to-volume ratio [(Allaker & Memarzadeh, 2014)](https://paperpile.com/c/0x0fO5/AZcp0). However, to make the utmost use of such antimicrobial capability, proper coating techniques and approaches are required [(Xu et al., 2020)](https://paperpile.com/c/0x0fO5/1Oe48).

The most common bacteria causing dental implant-related diseases such as Osteomyelitis is Staphylococcus aureus and it is widely treated by the systemic administration of antibiotics like gentamicin and ciprofloxacin [(Grayson et al., 2017)](https://paperpile.com/c/0x0fO5/lJvVk). Ciprofloxacin belongs to a class of antibiotics called quinolones [(Tiwari & Jain, 2023)](https://paperpile.com/c/0x0fO5/UJsw5). It acts against the majority of gram-positive and gram-negative organisms by inhibiting bacterial topoisomerase IV and DNA gyrase [(Chin & Neu, 1984)](https://paperpile.com/c/0x0fO5/4aom6). Ciprofloxacin is absorbed rapidly when administered orally and has an extended half-life [(Neha et al., 2021)](https://paperpile.com/c/0x0fO5/ANKaI)[(Maliael et al., 2021)](https://paperpile.com/c/0x0fO5/6VIVy)[(Lakshmi, 2021)](https://paperpile.com/c/0x0fO5/4ZN6z). It is highly tolerated for a longer duration following its administration [(Crump et al., 1983)](https://paperpile.com/c/0x0fO5/JizNg). Hence, Ciprofloxacin is the most promising drug used in the treatment of dental infections like osteomyelitis [(Gentry & Rodriguez, 1990)](https://paperpile.com/c/0x0fO5/K6wcg). Due to the alteration in the success rate of a Ti-based implant due to bacterial attachment, surface modification of titanium by metal nanoparticles coated with antibiotics is necessary to decrease the number of bacteria and to produce more beneficial medical treatment outcomes [(A S et al., 2023)](https://paperpile.com/c/0x0fO5/1ULYc). Therefore, the present study aims to evaluate the antimicrobial properties of tin oxide nanoparticles loaded with ciprofloxacin against dental implant infections.

# Materials and methods

## Preparation of Tin Oxide solution

The synthesis of SnO was conducted in the following manner: 100 mg of anhydrous tin chloride (SnCl2) was dissolved in 10 ml of acetone of analytical grade and subjected to probe sonication for 20 minutes. The resultant solution was incubated at room temperature for seven days, and opto-morphological changes in the structure were periodically recorded. The reaction was considered complete after 7 days, at which point the solution exhibited a dark red color when observed under ambient light. Then the sample was incorporated with a ciprofloxacin drug loaded with 100 mg and then dried at room temperature. Further, the sample was analyzed as characterization studies [(A S et al., 2023)](https://paperpile.com/c/0x0fO5/1ULYc).

## Surface characterization studies

The surface topography analysis of the ciprofloxacin-loaded tin oxide was analyzed using the FE-SEM IT800 Nano SEM Model with Energy dispersive X-ray analysis (EDX) (A.s. et al., 2023). The functional group sample was confirmed by the FT-IR spectra of were examined by the Alpha II Bruker Model with the wavenumber range from 4000 to 500 cm-1

## In-Vitro biomineralization studies

In order to evaluate the biomineralization studies of ciprofloxacin loaded tin oxide, whether it can nucleate the calcium and phosphate group for initial assessment 7 days immersion Simulated Body Fluid (SBF) solution. The process has been confirmed by the surface morphology analysis and FT-IR studies to find out the functional group.

## Antioxidant activity

The antioxidant activity of the ciprofloxacin-loaded Tin oxide was assessed through a 1,1-diphenyl-2-picryl hydrazyl (DPPH) method. To create the stock solution, 24 milligrams of DPPH were dissolved in 100 mL of methanol. Methanol was used to filter the stock solution, producing a combination that was suitable for use at 517 nm with an absorbance of roughly 0.973. 100 µL of the sample solution and 3 mL of the workable DPPH solution were mixed in a test tube. As a standard, 3 mL of a solution containing DPPH in 100 µL of methanol was also prepared. Then, the tubes were kept in a dark room for 30 minutes, and the absorbance at 517 nm [(Binadi et al., 2025)](https://paperpile.com/c/0x0fO5/tY1Hw). The percentage of antioxidants or Radical Scavenging Activity (RSA) was calculated using the following formula.

% of antioxidant activity= [(Ac−As) ÷Ac] × 100

where: Ac—Control reaction absorbance; As—Testing specimen absorbance.

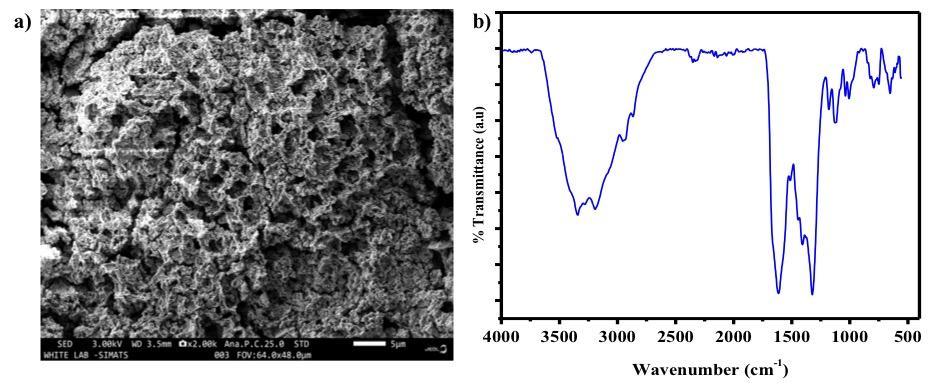
# Statistical analysis

Statistical analysis was conducted using Anova one way software. When comparing the groups with the control, one-way analysis of variance was used, and p-values ≤0.05 were regarded as statistically significant.

# Results

## Surface topography

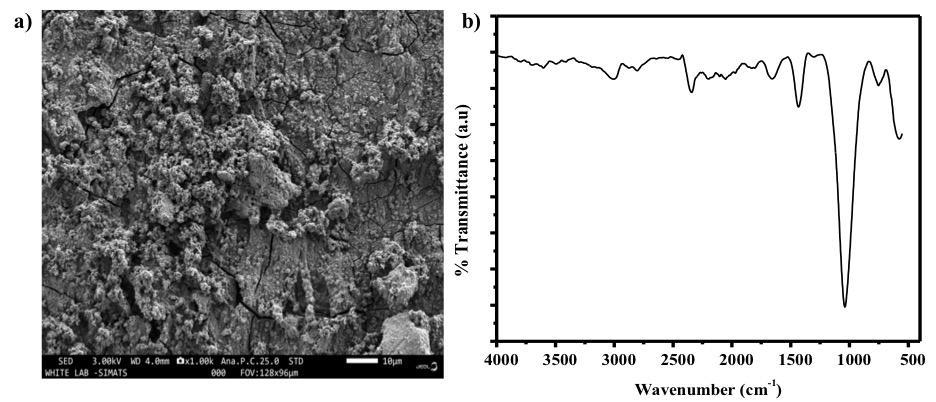
The physical features of surface properties and functional group analysis of ciprofloxacin loaded tin oxide material are displayed in Figure 1. Figure 1a shows the surface structure of the porous morphology of the material was observed. The formation of porous morphology can be engineered to control the release of the drug rate and its sustained or controlled delivery over time. The large surface area of the porous structure allows for a higher drug-loading capacity material. In the context of biomaterials, these pores' structures play a significant role in determining the material's properties and performance, especially in applications like tissue engineering and drug delivery. Figure 1b. FT-IR spectra of broad bands appeared at water molecules with a wave number of 3600 to 3200 cm-1. The vibration band assigned at CH2 is 1628 cm‑1 presence of drug molecules. The stretching vibration of Sn-O and O-Sn-O was revealed to be 632 and 1025 cm-1 respectively. The occurrence of an amine group and Sn-O present in the 1280 and 560 cm-1.



**Figure 1.** a) SEM image and b) FT-IR spectra of tin oxide loaded ciprofloxacin images

## In-vitro biomineralization

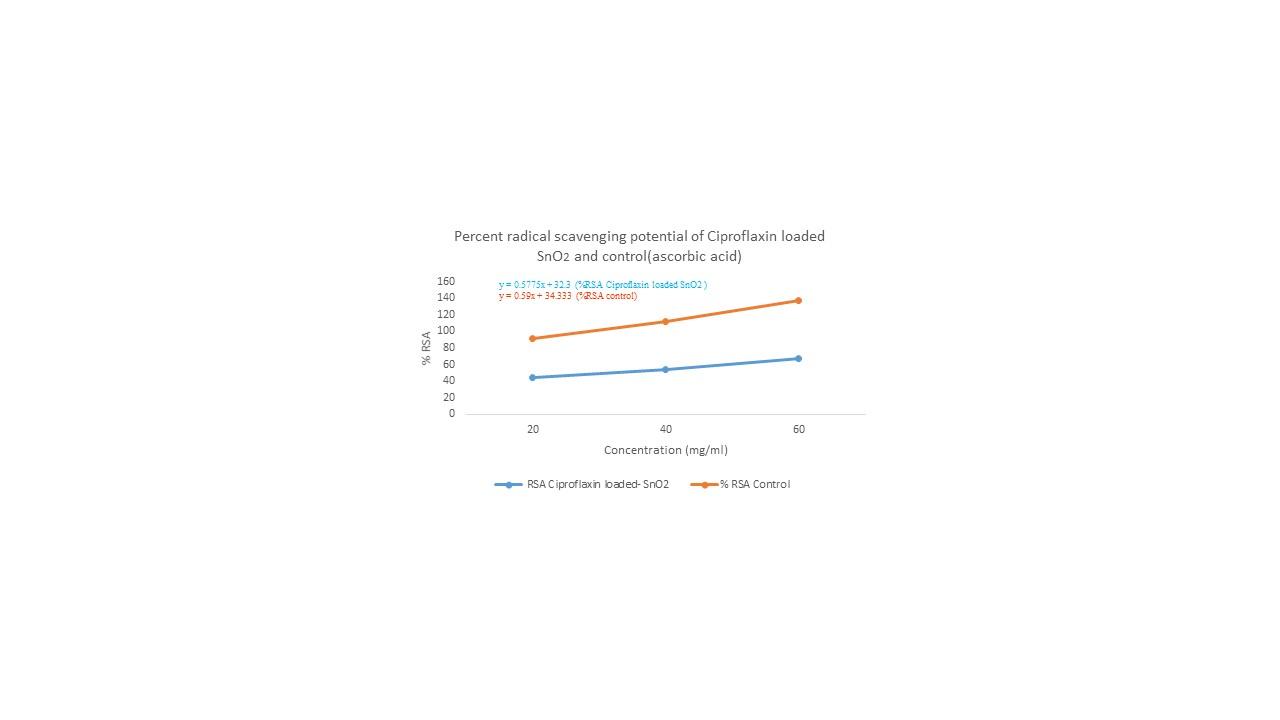
In-vitro, biomineralization is a process where living organisms or their components are used to facilitate the formation of minerals on the ciprofloxacin loaded tin oxide in their biological environment. This process often involves the nucleation and growth of minerals. Here the material was immersed in 7 days of SBF solution, which forms the nucleation surface shown in Figure 2a SEM image. The surface formation of agglomerate structures with small cracks was revealed on the surface. The nucleation process takes the recruitment of calcium and phosphate deposited over the surface. Figure 2b. FT-IR spectra of the calcium carbonate and phosphate peaks were observed in the immersion sample. The presence of a high-intensity and sharp peak was assigned at 1040 cm-1. The stretching vibration of carbonate peaks appeared at 1450 cm-1. Overall, the calcium and phosphate were confirmed by the in-vitro biomineralization studies.



**Figure 2.** a) SEM image and b) FT-IR spectra of 7 days immersion in SBF solution Tin oxide loaded ciprofloxacin

## Antioxidant activity

The antioxidant activity of ciprofloxacin-loaded tin oxide material was evaluated in the different concentrations shown in Figure 3. The concentration of 20, 40 and 60 mg of sample demonstrates the increasing percentage of inhibition rate. In contrast to the DPPH, the free radicals (ROS) searched by protons transferred from ciprofloxacin-loaded SnO2. Ascorbic acid had been used as a reference, and the produced Ciproflaxin loaded SnO2 was tested for its antioxidant activity in a dose-dependent manner [(Dauthal & Mukhopadhyay, 2012)](https://paperpile.com/c/0x0fO5/xL69u). Figure 3 shows the results observed for antioxidant activity assay(Rafi et al., 2024). The IC50 values (Table 1) have also been interpreted using the line equation. The Ciproflaxin loaded SnO2 exhibited radical scavenging potential of 44.4%, 54.3% and 67.5% while the control exhibited radical scavenging potential of 46.5%, 57.2% and 70.1% for 20 mg/ml, 40 mg/ml and 60 mg/ml. The IC50 value for control and Ciproflaxin loaded SnO2 was 26.554 and 30.649 respectively.



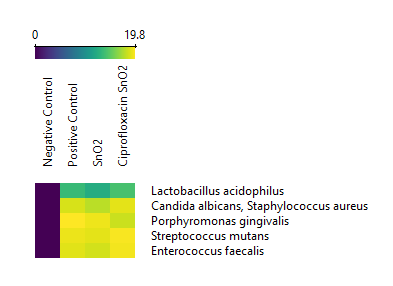
**Figure 3.** Antioxidant properties of tin oxide loaded drug and evaluated in different concentrations

**Table 1.** IC50 Value forCiproflaxin loaded SnO2 and Control

|  |  |
| --- | --- |
| **Content** | **IC50 value** |
| Control (Ascorbic acid) | 26.554 |
| Ciproflaxin loaded SnO2 | 30.649 |

## Antibacterial activity

The antimicrobial activity of SnO₂ and ciprofloxacin-coated SnO₂ was evaluated by measuring inhibition zones (mm) against *Lactobacillus acidophilus*, *Candida albicans*, *Staphylococcus aureus*, *Porphyromonas gingivalis*, *Streptococcus mutans* and *Enterococcus faecalis* with streptomycin as a positive control and ethanol as a negative control [(Kamaraj et al., 2014)](https://paperpile.com/c/0x0fO5/ZbOQT). The heatmap analysis of antimicrobial activity of SnO₂ and Ciprofloxacin-loaded SnO₂ against various microorganisms is depicted in Figure 4.



**Figure 4.** The heatmap analysis of antimicrobial activity of SnO₂ and Ciprofloxacin-loaded SnO₂

# Discussion

The antimicrobial activity of SnO₂ and Ciprofloxacin-loaded SnO₂ against various micro organisms results shows that the negative control (ethyl alcohol) showed no inhibition, confirming that antimicrobial effects were due to active agents. The positive control (Streptomycin) exhibited strong activity, serving as a benchmark. Ciprofloxacin-loaded SnO₂ showed inhibition zones comparable to or greater than the positive control, suggesting enhanced efficacy, while bare SnO₂ demonstrated moderate activity, indicating its intrinsic antimicrobial properties[(Katyal et al., 2021)](https://paperpile.com/c/0x0fO5/u0kqd) [(Harsha & Subramanian, 2022)](https://paperpile.com/c/0x0fO5/DBeVJ)

. Differences in inhibition zones highlight varying microbial susceptibility, with Porphyromonas gingivalis being more sensitive and Lactobacillus acidophilus more resistant [(Solanki et al., 2022)](https://paperpile.com/c/0x0fO5/sZiFA). The heatmap clustering reflects these susceptibility patterns, emphasizing the potential of Ciprofloxacin-loaded SnO₂ as an effective antimicrobial agent, warranting further investigation into its mechanism, cytotoxicity, and clinical applications [(Chidambaram et al., 2022)](https://paperpile.com/c/0x0fO5/5WEdT).

From the results of the current study, it was found that tin oxide nanoparticles loaded with ciprofloxacin showed significant antioxidant activity with IC50 value 30.649. The radical scavenging potential of Ciprofloxacin-loaded SnO₂ nanoparticles was evaluated at different concentrations (20 mg/mL, 40 mg/mL, and 60 mg/mL) and compared to the control [(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/0x0fO5/lwg6v). The results showed that the control exhibited a slightly higher radical scavenging activity than the Ciprofloxacin-loaded SnO₂ across all tested concentrations (Tuluwengjiang et al., 2024). This indicates that the introduction of Ciprofloxacin into the SnO₂ nanoparticles led to a minor reduction in antioxidant activity[(Ajay, Sasikala, et al., 2022)](https://paperpile.com/c/0x0fO5/VIbT9)[(Deepika et al., 2022)](https://paperpile.com/c/0x0fO5/up217).

A key parameter for evaluating antioxidant efficiency is the IC₅₀ value, which represents the concentration required to inhibit 50% of radical activity. The IC₅₀ value for the control was found to be 26.554 mg/mL, while the Ciprofloxacin-loaded SnO₂ had a higher IC₅₀ value of 30.649 [(Balaji Ganesh S & Sugumar, 2021)](https://paperpile.com/c/0x0fO5/dPmbN). The control sample was more effective at scavenging free radicals compared to the Ciprofloxacin-loaded SnO₂.

Despite the observed reduction in antioxidant activity, Ciprofloxacin-loaded SnO₂ still exhibited considerable radical scavenging potential [(Jabin et al., 2021)](https://paperpile.com/c/0x0fO5/WWm62). This suggests that while its antioxidant properties may not be as high as the control, the material could still be useful in biomedical applications.

Bacterial accumulation after an implant placement leads to inflammation of the periodontal tissues and unstable osseointegration which would eventually result in implant failure, a very serious complication post-implant placement [(Dutta et al., 2020)](https://paperpile.com/c/0x0fO5/dceIl). The advantages of SnO2 nanoparticles include lesser cost, harmlessness, abundant availability, and improved biocompatibility [(Orlandi, 2019)](https://paperpile.com/c/0x0fO5/AvVLL). From the results of previous studies, it is also evident that SnO2 nanoparticles exhibit properties of broad-spectrum antibacterial activity [(Rehman et al., 2019)](https://paperpile.com/c/0x0fO5/a5vHT). From the results of Parnia F et al., it was found that modification of the surface of titanium using metal nanoparticles with antibacterial properties decreases the number of bacteria and can provide beneficial clinical treatment outcomes [(Sabarathinam & Madhulaxmi, 2021)](https://paperpile.com/c/0x0fO5/W8GuW)[(Sushanthi et al., 2021)](https://paperpile.com/c/0x0fO5/qL618)[(Harsha et al., 2022)](https://paperpile.com/c/0x0fO5/xXTDj). It was also found to improve bone formation and soft tissue integration leading to better fixation of implants within the none [(Parnia et al., 2017)](https://paperpile.com/c/0x0fO5/BWjW5).

In another study conducted by Asadi S et al., it was found that ciprofloxacin (CIP) loaded titanium nanotube coated with biopolymer which was used to decrease the side effects related with the systemic direction of CIP exhibited a significant antibacterial effect on both Gram-positive and negative bacteria [(Asadi et al., 2022)](https://paperpile.com/c/0x0fO5/uuu6g). Similarly, Doymus et al. evaluated the antimicrobial properties of drug-loaded chitosan microspheres and nano-hydroxyapatite on titanium implants which showed significant results of antibacterial activity against S. aureus and also enhanced the surface bioactivity of the implants by promoting hydroxyapatite crystal growth [(Doymus et al., 2021)](https://paperpile.com/c/0x0fO5/tUYs).

Similarly in another study conducted by Yang Bai et al., It was found that Zinc and magnesium alloy-coated Ti implants inhibited oxidative stress resulting in improved antioxidant properties. It also facilitated the proliferation of HGFs and promoted osteoblast differentiation which increases the stability of implants [(Bai et al., 2022)](https://paperpile.com/c/0x0fO5/IxSFW).

# Conclusion

In conclusion, the study demonstrates that Ciprofloxacin-loaded SnO₂ nanoparticles exhibit enhanced antimicrobial and bioactive properties compared to bare SnO₂, making them a promising candidate for biomedical applications, particularly in the treatment of dental infections. The Ciprofloxacin-loaded SnO₂ NPs showed comparable or superior antimicrobial effectiveness to Streptomycin, indicating their potential as effective therapeutic agents. Although a slight reduction in antioxidant activity was observed, the overall bioactivity, confirmed by FT-IR analysis and biomineralization studies, underscores their suitability for use in medical applications. These findings support the continued exploration of SnO₂-based nanomaterials for improving therapeutic outcomes in various biomedical fields.

Future studies should focus on optimizing the synthesis methods of SnO₂ nanoparticles to improve their bioactivity and stability. Investigating the long-term biocompatibility and toxicity profiles of Ciprofloxacin-loaded SnO₂ NPs in vivo will be crucial for ensuring their safety for clinical use.

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