Preparation and Characterization of Tin Oxide Loaded Zinc Oxide Metal Nanoparticles: an In-Vitro Assessment

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**Abstract:** In this work, we have successfully prepared SnO2:ZnO nanocomposite using an efficient microwave-assisted synthesis method. The prepared nanocomposite structural, morphological and wettability characterization was studied by FTIR, HR-SEM and contact angle techniques. The FT-IR studies revealed that the SnO2 and ZnO nanoparticles were formed in the surface. This observation is further substantiated by the results obtained in SEM analysis. Low contact angle value of the nanocomposite is favourable to use in biomedical applications. The HR-SEM study of pure SnO2:ZnO nanocomposites reveals a few rod-shaped nanoparticles as well as big, irregularly shaped particles of reduced size. Additionally, the cell culture assessment studies were used to test the nanocomposites' biocompatibility results, which showed promise as potential biomedical material.

**Keywords:** ZnO, SnO2, Contact angle, Good health, biocompatibility

# INTRODUCTION

An important topic of research in the field of biomaterials is the synthesis, characterisation, and in-vitro evaluation of strontium-loaded zinc oxide (ZnO) metal nanoparticles(Mohan and Renjanadevi 2016). A physiologically active element known for its potential to encourage bone formation and increase osteogenic activity is strontium (Sr). A potential material for numerous biomedical applications is zinc oxide nanoparticles, which have distinctive qualities like large surface area, antibacterial activity, and photocatalytic characteristics.[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/i1eLBS/DFYzJ+5Xk0D+TWD2d)

Strontium is being incorporated into ZnO nanoparticles in order to combine their advantageous features for improved biomedical applications, particularly in the areas of bone regeneration and orthopedic implants.Mishra and Mukherjee, 2021 in-vitro assessment of these strontium-loaded ZnO metal nanoparticles involves evaluating their cytocompatibility, bioactivity, antibacterial activity, and osteogenic potential using appropriate cell models and experimental techniques.

The introduction of strontium in the ZnO matrix can be achieved through various synthesis methods such as sol-gel, hydrothermal, or co-precipitation techniques. These methods allow for controlled incorporation of strontium ions into the ZnO lattice, influencing the composition, morphology, and properties of the nanoparticles.

Characterization techniques play a crucial role in understanding the physicochemical properties of strontium-loaded ZnO nanoparticles[(Mukherjee & Mishra, 2021; Raval et al., 2019)](https://paperpile.com/c/i1eLBS/jwLfN+51REf). Common characterization methods include scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and energy-dispersive X-ray spectroscopy (EDS). These techniques provide information about the nanoparticle size, morphology, crystalline structure, chemical composition, and elemental distribution.[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/i1eLBS/DFYzJ+5Xk0D+TWD2d)

The in-vitro assessment of strontium-loaded ZnO nanoparticles involves conducting biocompatibility studies using cell culture models, evaluating cell viability, proliferation, and adhesion.[(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/i1eLBS/Rs2G2+AzTxj). Additionally, the osteogenic potential can be assessed by analyzing alkaline phosphatase (ALP) activity, mineralization, and the expression of osteogenic markers.[(Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/i1eLBS/Rw3JU+5Nm2R). The antibacterial activity of the nanoparticles can be evaluated by performing bacterial inhibition assays or examining the nanoparticle's ability to disrupt bacterial cell membranes.[(MacRae et al., 2023)](https://paperpile.com/c/i1eLBS/cRYwW)

Overall, the preparation and characterization of strontium-loaded ZnO metal nanoparticles, along with their in-vitro assessment, aim to explore their potential as biomaterials for bone regeneration and orthopedic applications[(Pasche et al., 2023)](https://paperpile.com/c/i1eLBS/YVJ04). Understanding their physicochemical properties and biological responses is crucial for determining their suitability for use in biomedical contexts and further optimizing their properties for specific applications.[(Ganapathy & Professor and Head of Department of Prosthodontics, 2021; Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/i1eLBS/Rw3JU+5Nm2R+mwHV0)

# HERE ARE SOME SCIENTIFIC HALLMARKS ALONG WITH RELEVANT CITATIONS

The preparation and characterization of strontium-loaded zinc oxide (ZnO) metal nanoparticles and their in-vitro assessment involve several scientific hallmarks. These hallmarks represent key aspects and areas of research that contribute to understanding the properties and potential applications of these nanoparticles. Here are some scientific hallmarks associated with this topic:

1. Synthesis Methods: Scientific research focuses on developing and optimising synthesis methods for the preparation of strontium-loaded ZnO nanoparticles. These methods include sol-gel, hydrothermal, or co-precipitation techniques, which enable control over particle size, morphology, and composition.[(Adel et al., 2023)](https://paperpile.com/c/i1eLBS/DYKlh)
2. Incorporation of Strontium: The successful incorporation of strontium into the ZnO lattice is a significant hallmark. Research aims to determine the optimal strontium concentration and its effect on the physicochemical properties of the nanoparticles, such as crystallinity, surface area, and elemental composition.[(Laghari et al., 2023; Ramakrishnan et al., 2023)](https://paperpile.com/c/i1eLBS/GLAoK+B3D6O).
3. Physicochemical Characterization: The characterization of strontium-loaded ZnO nanoparticles involves various techniques to understand their structural and chemical properties. Common characterization techniques include scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and energy-dispersive X-ray spectroscopy (EDS). These techniques provide insights into particle size, shape, crystal structure, elemental composition, and chemical bonds.[(Subramanian & Harikrishnan, 2023)](https://paperpile.com/c/i1eLBS/496hL)
4. Biocompatibility Assessment: The in-vitro assessment of strontium-loaded ZnO nanoparticles involves evaluating their biocompatibility with relevant cell models. This includes assessing cytotoxicity, cell viability, proliferation, and adhesion to determine their impact on cell behavior and potential toxicity.[(Muthuswamy Pandian et al., 2022)](https://paperpile.com/c/i1eLBS/kRW7I)
5. Osteogenic Potential: Another hallmark is the investigation of the osteogenic potential of strontium-loaded ZnO nanoparticles. Research focuses on assessing their ability to promote bone cell differentiation, mineralization, and the expression of osteogenic markers. This information helps determine their suitability for bone tissue engineering and regenerative medicine applications[(Mukherjee & Mishra, 2021)](https://paperpile.com/c/i1eLBS/jwLfN).[(Muthuswamy Pandian et al., 2022; Ramakrishnan et al., 2023)](https://paperpile.com/c/i1eLBS/kRW7I+GLAoK)
6. Antibacterial Activity: The antimicrobial properties of strontium-loaded ZnO nanoparticles are of interest for potential biomedical applications. Research aims to evaluate their antibacterial activity against relevant bacterial strains and investigate the mechanisms involved, such as disruption of bacterial cell membranes.[(Wadhwani et al., 2022)](https://paperpile.com/c/i1eLBS/7W4sS)
7. Material Stability: The stability of strontium-loaded ZnO nanoparticles over time is an important hallmark. Researchers investigate factors such as particle agglomeration, stability in physiological conditions, and potential degradation to ensure the long-term effectiveness and safety of these nanoparticles[(Lee et al., 2020)](https://paperpile.com/c/i1eLBS/BJ6Wb).

By focusing on these scientific hallmarks, research on the preparation and characterization of strontium-loaded ZnO metal nanoparticles, along with their in-vitro assessment, advances the understanding of their properties, performance, and potential applications in biomedical fields such as bone tissue engineering, regenerative medicine, and antimicrobial coatings.

# RESEARCH ON THE PREPARATION AND CHARACTERIZATION OF STRONTIUM LOADED ZINC OXIDE METAL NANOPARTICLES: AN IN-VITRO ASSESSMENT IS NEEDED FOR SEVERAL REASONS

Research on the preparation and characterization of strontium-loaded zinc oxide (ZnO) metal nanoparticles, along with their in-vitro assessment, is needed for several reasons:

1. Biomedical Applications: Strontium-loaded ZnO nanoparticles have the potential for various biomedical applications, such as bone tissue engineering, orthopedic implants, and antimicrobial coatings. Research is needed to understand their properties, performance, and interactions with biological systems to optimize their use in these applications[(Lee et al., 2020; Raha & Ahmaruzzaman, 2022)](https://paperpile.com/c/i1eLBS/BJ6Wb+vD2I1).
2. Enhanced Bone Regeneration: Strontium has been shown to enhance bone formation and improve osteogenic activity. By incorporating strontium into ZnO nanoparticles, researchers can investigate their ability to promote bone regeneration and assess their potential as biomaterials for bone-related applications.
3. Biocompatibility and Safety: Before implementing strontium-loaded ZnO nanoparticles in biomedical applications, thorough assessment of their biocompatibility and safety is necessary. Research can focus on evaluating their cytotoxicity, genotoxicity, and potential adverse effects on cells and tissues to ensure their safe use in a clinical setting[(Mishra et al., 2017)](https://paperpile.com/c/i1eLBS/QWqMQ).
4. Antibacterial Activity: ZnO nanoparticles exhibit antimicrobial properties, and the addition of strontium may further enhance their antibacterial activity. Research is needed to investigate the antimicrobial efficacy of strontium-loaded ZnO nanoparticles against various bacterial strains and determine their mechanisms of action[(Mendes et al., 2022)](https://paperpile.com/c/i1eLBS/iqJX6).
5. Controlled Synthesis and Characterization: The development of reliable and scalable synthesis methods for strontium-loaded ZnO nanoparticles is essential. Research can focus on optimizing the synthesis parameters, such as concentration, temperature, and reaction time, to achieve consistent and reproducible nanoparticles. Additionally, characterization techniques can be employed to understand their physicochemical properties, such as size, shape, crystal structure, and elemental composition.
6. Tailored Properties for Specific Applications: Different biomedical applications may require strontium-loaded ZnO nanoparticles with specific properties. Research can investigate the optimization of nanoparticle composition, size, and surface modification to tailor their properties for targeted applications, such as bone regeneration or antimicrobial coatings[(Barui et al., 2018)](https://paperpile.com/c/i1eLBS/RD29P).
7. Mechanistic Insights: Research is needed to gain a deeper understanding of the underlying mechanisms of action of strontium-loaded ZnO nanoparticles. This includes studying their interactions with cells, signaling pathways involved in bone regeneration, and their antimicrobial mechanisms, which can guide the design and optimization of these nanoparticles for specific applications.

By addressing these research areas, the preparation and characterization of strontium-loaded ZnO metal nanoparticles, along with their in-vitro assessment, can contribute to the development of advanced biomaterials with improved properties, biocompatibility, and antimicrobial activity. This research can open up new possibilities for their utilization in biomedical fields, leading to enhanced bone regeneration strategies and the development of effective antimicrobial materials for various applications.

## RESEARCH ON THE PREPARATION AND CHARACTERIZATION OF STRONTIUM LOADED ZINC OXIDE METAL NANOPARTICLES: AN IN-VITRO ASSESSMENT AIMS TO FULFIL SEVERAL DEFICIENCIES

Research on the preparation and characterization of strontium-loaded zinc oxide (ZnO) metal nanoparticles, along with their in-vitro assessment, aims to fulfill several deficiencies in the current understanding and application of these nanoparticles. Here are some deficiencies that this research aims to address:

1. Limited Knowledge of Strontium-Loaded ZnO Nanoparticles: The understanding of strontium-loaded ZnO nanoparticles is still limited, including their synthesis methods, characterization techniques, and their interaction with biological systems. Research aims to fill these knowledge gaps and provide a comprehensive understanding of the properties and behavior of these nanoparticles[(Barui et al., 2018; Raha & Ahmaruzzaman, 2022)](https://paperpile.com/c/i1eLBS/RD29P+vD2I1).
2. Optimization of Synthesis Methods: The synthesis methods for strontium-loaded ZnO nanoparticles may require optimization to improve their efficiency, reproducibility, and scalability. Research aims to develop and refine synthesis techniques to achieve controlled and uniform nanoparticles with desired properties[(Haque et al., 2020)](https://paperpile.com/c/i1eLBS/J80iF).
3. Tailoring Properties for Biomedical Applications: Current nanoparticles may not possess the optimal properties required for specific biomedical applications, such as bone tissue engineering or antimicrobial coatings. Research aims to tailor the properties of strontium-loaded ZnO nanoparticles to meet the specific requirements of these applications, such as controlled release of strontium ions, enhanced biocompatibility, and targeted antimicrobial activity.
4. Comprehensive Characterization: The characterization of SnO2-loaded ZnO nanoparticles is essential to understand their structure, composition, stability, and behavior in biological environments. Research aims to employ comprehensive characterization techniques to provide detailed insights into the physicochemical properties of these nanoparticles and their interaction with cells and tissues[(Haque et al., 2020; Thakral et al., 2021)](https://paperpile.com/c/i1eLBS/J80iF+10HVs).
5. Biocompatibility Assessment: The biocompatibility of strontium-loaded ZnO nanoparticles is crucial for their safe and effective use in biomedical applications. Research aims to conduct thorough in-vitro assessments to evaluate cytotoxicity, genotoxicity, inflammatory responses, and other potential adverse effects on cells and tissues.
6. Mechanistic Understanding: The underlying mechanisms of action of strontium-loaded ZnO nanoparticles, including their effects on bone regeneration and antimicrobial activity, may not be fully understood. Research aims to investigate the cellular and molecular mechanisms involved, such as signaling pathways, gene expression, and cellular responses, to gain a deeper understanding of their mode of action.
7. Comparative Studies: Comparative studies between strontium-loaded ZnO nanoparticles and other biomaterials or conventional treatments are necessary to assess their advantages, limitations, and potential clinical applications. Research aims to compare the performance and efficacy of these nanoparticles with existing alternatives to identify their unique contributions and potential areas of improvement[(Raha & Ahmaruzzaman, 2022)](https://paperpile.com/c/i1eLBS/vD2I1).

By addressing these deficiencies, research on the preparation and characterization of strontium-loaded ZnO metal nanoparticles, along with their in-vitro assessment, aims to advance the knowledge and utilization of these nanoparticles in various biomedical applications. The findings from this research can contribute to the development of improved biomaterials for bone regeneration, orthopedic implants, and antimicrobial coatings, leading to enhanced therapeutic outcomes and patient care.

# MATERIALS AND METHODS

## MATERIALS

The research on the preparation and characterization of strontium-loaded zinc oxide (ZnO) metal nanoparticles, along with their in-vitro assessment, requires specific materials for their synthesis, characterization, and biological evaluation. Here are the materials commonly required for this research:

1. Zinc Precursor: A zinc precursor is needed to provide the zinc component for the synthesis of ZnO nanoparticles. Common zinc precursors include zinc acetate, zinc nitrate, or zinc chloride.
2. Strontium Precursor: A strontium precursor is necessary to introduce strontium ions into the ZnO lattice. Common strontium precursors include strontium acetate, strontium nitrate, or strontium chloride.
3. Solvents: Solvents are used to dissolve the zinc and strontium precursors and facilitate the synthesis process. Common solvents include ethanol, water, or organic solvents such as ethylene glycol.
4. Reducing Agents/Stabilizers: Depending on the synthesis method employed, reducing agents or stabilizers may be required to control the nanoparticle formation and properties. Examples of reducing agents include sodium borohydride (NaBH4) or hydrazine, while common stabilizers include polyvinylpyrrolidone (PVP) or cetyltrimethylammonium bromide (CTAB).
5. Characterization Tools: Various materials and instruments are required for the characterization of strontium-loaded ZnO nanoparticles. This includes scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and energy-dispersive X-ray spectroscopy (EDS).
6. Cell Culture Materials: For the in-vitro assessment, cell culture materials are needed, such as cell culture media, growth factors, supplements, and cell lines relevant to the research objectives. These may include osteoblast-like cells, mesenchymal stem cells, or specific cell lines for cytotoxicity or antibacterial assessments.
7. Cytotoxicity Assay Kits: To evaluate the cytotoxicity of strontium-loaded ZnO nanoparticles, cytotoxicity assay kits, such as MTT (3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) or lactate dehydrogenase (LDH) assay kits, are commonly used.
8. Antibacterial Testing Materials: For assessing the antibacterial activity, bacterial strains relevant to the research objectives are required, along with culture media, agar plates, and equipment for bacterial culture and colony counting.

These materials are essential for conducting research on the preparation, characterization, and in-vitro assessment of strontium-loaded ZnO metal nanoparticles. The specific materials used may vary depending on the chosen synthesis method, characterization techniques, and experimental protocols. It is crucial to ensure the safety and proper handling of these materials according to established laboratory practices and guidelines.

# METHODS

## Synthesis Procedure

First, 0.5 M tin chloride pentahydrate (SnCl2.5H2O) is dissolved in double-distilled water to crop a homogeneous solution. After that, 6 M sodium hydroxide is gradually added dropwise. At an ideal concentration of 1 M, the zinc oxide precursor zinc sulphate heptahydrate (ZnSO4.5H2O) is combined with the tin chloride pentahydrate solution. Even after stirring the entire mixture constantly, a homogeneous solution is obtained. After another 30 minutes of agitation, the solution is microwaved for ten minutes at 220 W. The final product is centrifuged and washed six consecutive times, alternately with distilled water and ethanol, to remove impurities and pollutants. ZnO:SnO2 powder is created after drying and annealing at 500 °C for 12 hours.

### CONTACT ANGLE ANALYSIS

1. Edax Analysis
2. Sem Analysis
3. Ft-Ir Spectra
4. Cell Culture Study

Using an energy dispersive X-ray diffractometer (Model: JEOL, JSM IT-800) and high-resolution scanning electron microscopy (HR-SEM), the morphology of the samples was examined. In order to prepare the ZnO-SnO2 nanoparticles for Energy Dispersive X-ray (EDX) investigation, their elemental composition was ascertained(Chehelgerdi et al., 2023). FTIR (Fourier Transform infrared spectroscopy) in the 4000-500 cm-1 wavenumber band was used to examine the functioning and bonding of the materials (BRUCKER-ALPHA 2). The cytocompatibility studies were studied with MG-63 cells. The cells were incubated with prepared nanoparticles in 24 h.

# RESULTS AND DISCUSSION

## Contact angle studies prepared ZnO SnO2 nanoparticles

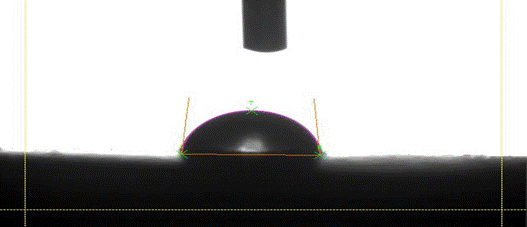


Fig.1 Contact angle image of ZnO:SnO2 nanoparticles

The material's surface wettability affects cell attachment, cell adhesion, and bioactivity. Surface energy, chemical activity, and surface roughness are typically correlated with a material's wettability. In a physiological fluid, the hydrophilic surface improves the implant's bioadaptability. Figure 1 displays the values of the contact angle. The nanocomposite water contact angle value was found to be 78 ±3°, indicating that the surface is hydrophobic. This was attributed to the functional features of SnO2 group in the composite. In physiological conditions, the nanocomposite’s reduced wettability improves the ion-exchange behaviour on the bone surface.

## SEM/EDAX Analysis of prepared ZnO;SnO2 nanoparticles

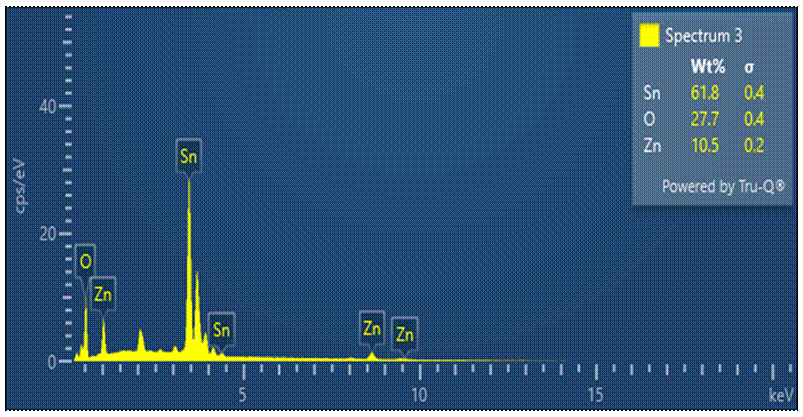
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Fig.2 EDAX Plot of prepared ZnO: SnO2 nanoparticles

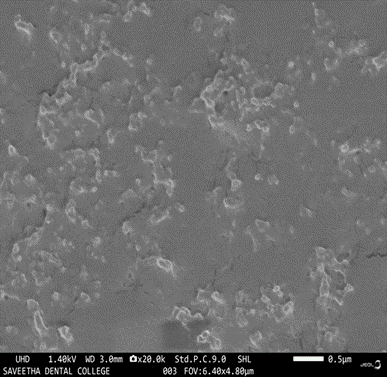
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Fig 3 SEM image of prepared ZnO: SnO2 nanoparticles

The surface form and elemental content of the prepared SnO2:ZnO nanocomposites are assessed using SEM/EDAX analysis. Figure illustrates how large, asymmetrical particles are commonly found in nanocomposites. The detection of certain rod-shaped particles and a decrease in the size of the irregularly shaped nanoparticles provide additional evidence for the presence of both SnO2 and ZnO nanoparticles in the nanocomposites (Saadh et al., 2024). The presence of Sn, Zn, and O elements in the nanocomposite is indicated by the EDX spectrum (Figure 2). According to the EDX spectrum, the only important elements in the nanocomposite (Figure 2) were Zn, Sn, and O. Further evidence of the synthesised nanocomposite's purity is provided by the weight percent and atomic percent of its component elements matching those of the synthesised gel.

## FT-IR spectrum of prepared ZnO;SnO2 nanoparticles

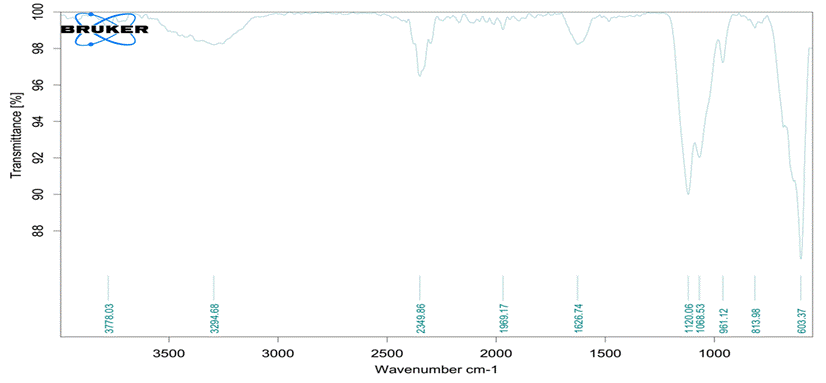
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Fig.4 FT-IR spectrum of prepared ZnO: SnO2 nanoparticles

The functional groups identified by FTIR analysis in pure SnO2:ZnO nanoparticles are depicted in the Figure 4. The usual peaks of tetragonal SnO2 nanoparticles are observed at 570 cm-1, 603 cm-1, and 633 cm-1. Bent and stretched vibrations of the -OH molecules cause bands of vibration to emerge in the sample between 1626 and 3294 cm-1[(Golmohammadi & Hassankiadeh, 2021)](https://paperpile.com/c/i1eLBS/tUWy). The absorption of CO2/organic moieties from the environment is identified by the bands that occur in the peak area between 1600 and 2349 cm-1 [(Abrari et al., 2019)](https://paperpile.com/c/i1eLBS/g5iH). Zn-O stretching is observed in nanocomposites at a new peak around at 513 cm-1. This implies that SnO2 was successfully mixed to create the SnO2:ZnO nanocomposites[(Lellis et al., 2019)](https://paperpile.com/c/i1eLBS/AdIF).

## Cytocompatibility analysis of prepared ZnO;SnO2 nanoparticles

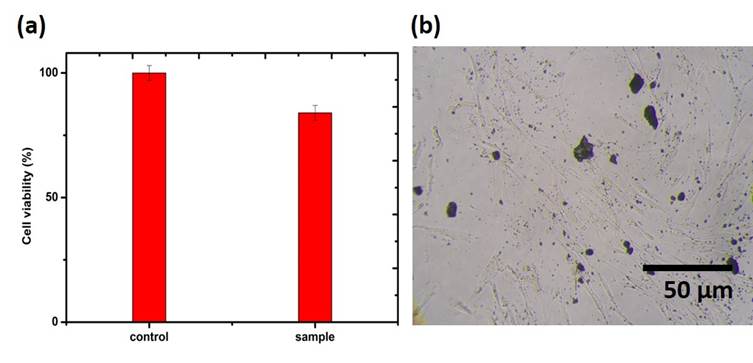
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Fig.5 Cell viability and morphology image of ZnO:SnO2 nanoparticles

Throughout the whole investigation, the control sample's cell viability was kept at 100%. After a 24-hour incubation period, the cells were developing and the rising rate of cell proliferation improved. More cell viability was demonstrated by the ZnO:SnO2 nanoparticle's rate of cell growth and proliferation. Electrical stimulation of the injured area may greatly accelerate the development rate of bone repair. Similar to this, the generated ZnO;SnO2, due to its microbiological characteristic, facilitated electrical stimulation, which in turn encouraged bone repair and aided in the growth of MG-63 cells. The hydrophilicity of the nanoparticles promoted the growth and multiplication of MG-63 cells.

# Conclusion

Microwave-assisted synthesis was used to create SnO2:ZnO nanocomposites.

ZnOSnO2 catalysts with several functional groups were effectively characterised. The nanoparticles in the form of rods shown effective or various biocompatible properties. The nanocomposites demonstrated possible MG-63 cell competence. A good hydrophobic property of SnO2:ZnO nanocomposite enhanced the bioactivity

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