Facile Synthesis Of Ti₃C₂–Co₃O₄ Nanocomposite and its Antimicrobial and Anticancer Activities

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**ABSTRACT:** The Ti₃C₂–Co₃O₄ nanocomposite has emerged as a promising material due to the synergistic properties of MXenes and transition metal oxides, making it suitable for various biomedical applications. In this study, a facile synthesis route was adopted to prepare a Ti₃C₂–Co₃O₄ nanocomposite via a two-step process. Initially, Ti₃C₂ MXene was synthesized by selectively etching aluminum from Ti₃AlC₂ using hydrofluoric acid, followed by ultrasonication to obtain few-layered MXene nanosheets. Subsequently, Co₃O₄ nanoparticles were grown in situ on the surface of Ti₃C₂ via a hydrothermal method using cobalt nitrate as a precursor, ensuring uniform distribution and strong interfacial interaction between the two components. The morphology and surface characteristics of the nanocomposite were examined by scanning electron microscopy (SEM), which revealed a layered structure of MXene sheets decorated with uniformly dispersed Co₃O₄ nanoparticles. The anticancer potential of the nanocomposite was evaluated against human cancer cell lines, demonstrating significant cytotoxicity and inhibition of cancer cell proliferation, thereby confirming its therapeutic potential. Furthermore, the antimicrobial efficacy of the Ti₃C₂–Co₃O₄ nanocomposite was assessed against bacterial strains *Enterococcus faecalis* and *Streptococcus mutans*, as well as fungal strains *Candida albicans* and *Candida parapsilosis*. The results revealed pronounced antimicrobial activity, particularly due to the generation of reactive oxygen species and disruption of microbial cell membranes. The combination of high surface area, enhanced conductivity, and strong redox properties of the nanocomposite contributed to its excellent biological performance. This study highlights the potential of Ti₃C₂–Co₃O₄ nanocomposites as effective agents for dual applications in cancer therapy and antimicrobial treatments, offering a novel and multifunctional platform for future biomedical innovations.

**Keywords:** Co₃O₄ nanoparticles, Anticancer activity, Antimicrobial activity, Reactive oxygen species, Ti₃C₂ MXene.

# INTRODUCION

The advancement of nanomaterials has opened new frontiers in the field of biomedicine, particularly in the development of novel agents with potent antimicrobial and anticancer activities [(Ajay et al., 2023; Chokkattu et al., 2023; Padarthi et al., 2023)](https://paperpile.com/c/pnwdvO/d8RJj+zrSi6+E4OA2). Among the diverse classes of nanostructured materials, two-dimensional (2D) transition metal carbides and nitrides, known as MXenes, have garnered considerable attention owing to their exceptional physicochemical properties, such as high electrical conductivity, large surface area, tunable surface chemistry, and excellent mechanical strength[(Dadashi Firouzjaei et al., 2022)](https://paperpile.com/c/pnwdvO/CA8w). Ti₃C₂, one of the most widely studied MXenes, is derived from the selective etching of the 'A' element (usually Al) from its MAX phase precursor Ti₃AlC₂[(Dharman et al., 2023; S. Sindhu et al., 2023; Sreenivasagan et al., 2023)](https://paperpile.com/c/pnwdvO/OUYe8+iD4KX+wwNbj). This delamination process exposes reactive surface terminations (–OH, –O, –F), which render Ti₃C₂ hydrophilic and highly functionalizable, making it an ideal platform for biomedical applications[(Gogotsi & Huang, 2021)](https://paperpile.com/c/pnwdvO/h3SW).Ti₃C₂ MXene has shown promising potential in drug delivery, photothermal therapy, and biosensing due to its unique layered structure and excellent biocompatibility[(Ramakrishnan et al., 2023; Shenoy & Maiti, 2023; J. S. Sindhu et al., 2023)](https://paperpile.com/c/pnwdvO/Qau6J+pvs15+qONF2). However, pristine Ti₃C₂ is often limited by oxidative degradation and insufficient intrinsic bioactivity, particularly in terms of antimicrobial and anticancer capabilities[(Rajasri et al., 2022)](https://paperpile.com/c/pnwdvO/zzWR). To overcome these challenges and further enhance its functional performance, the integration of Ti₃C₂ with metal or metal oxide nanoparticles has emerged as a promising strategy. In this regard, cobalt oxide (Co₃O₄), a well-known transition metal oxide, stands out due to its intrinsic redox properties, high catalytic activity, and capability to generate reactive oxygen species (ROS), which are critical for inducing cytotoxic effects in both microbial and cancer cells[(Anuradha & Jeyanthi, 2025)](https://paperpile.com/c/pnwdvO/0CbA).Co₃O₄ is a p-type semiconductor with a spinel structure composed of both Co²⁺ and Co³⁺ ions occupying tetrahedral and octahedral sites, respectively[(Kasabwala et al., 2021; Rajeshkumar & Lakshmi, 2021; Varghese et al., 2023)](https://paperpile.com/c/pnwdvO/iiAQp+XCoIg+Yzyql). This dual valency facilitates various redox reactions, enhancing its antimicrobial action through oxidative stress mechanisms[(Keerthana & Ramesh, 2021; Murugesan, 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/pnwdvO/4khPj+ui2Vt+E1dml)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Subramanian et al., 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/pnwdvO/4khPj+ui2Vt+E1dml+uTlpX). Furthermore, Co₃O₄ nanoparticles have been shown to interfere with mitochondrial function and DNA replication in cancer cells, thereby promoting apoptosis and suppressing tumor proliferation. Despite these beneficial properties, the clinical translation of Co₃O₄ has been limited by issues such as agglomeration, limited dispersion in biological media, and potential toxicity at higher concentrations. Thus, combining Co₃O₄ with a biocompatible and stable matrix like Ti₃C₂ MXene can synergistically mitigate these limitations while amplifying therapeutic efficacy[(C P et al., 2024)](https://paperpile.com/c/pnwdvO/ETxY).The Ti₃C₂–Co₃O₄ nanocomposite, therefore, represents a rational design approach to develop a multifunctional platform for dual antimicrobial and anticancer applications[(Pranati et al., 2021; Sakthi et al., 2021)](https://paperpile.com/c/pnwdvO/lDure+d4KNd). By anchoring Co₃O₄ nanoparticles onto the surface of Ti₃C₂ nanosheets, the resulting hybrid material benefits from the stability and high surface area of MXenes along with the biological reactivity of Co₃O₄[(G. & Ganapathy, 2022; Kumar & Ramesh, 2021)](https://paperpile.com/c/pnwdvO/zDVdj+f1W53)). This structural integration enhances interfacial electron transfer, increases ROS generation, and facilitates close interaction with microbial and cancer cell membranes. Additionally, the composite's layered morphology enables efficient cellular uptake and prolongs bioavailability, which are critical factors for therapeutic success.[(Lugun et al., 2022)](https://paperpile.com/c/pnwdvO/k4ud)Previous studies have demonstrated that such nanohybrids exhibit improved biological activities compared to their individual components. For instance, Ti₃C₂-based nanocomposites with metal oxides like ZnO, Fe₃O₄, and CuO have shown excellent bactericidal effects and cytotoxicity toward cancer cells through synergistic mechanisms. However, there is still a lack of comprehensive studies exploring the biological performance of Ti₃C₂–Co₃O₄ composites, especially against clinically relevant microbial pathogens and aggressive cancer cell lines[(Prakash et al., 2022)](https://paperpile.com/c/pnwdvO/3oXA).In this context, the present study focuses on the facile synthesis and characterization of a Ti₃C₂–Co₃O₄ nanocomposite using a hydrothermal method. The synthesis strategy was designed to ensure the uniform deposition of Co₃O₄ nanoparticles on Ti₃C₂ sheets, promoting intimate contact and strong interfacial bonding between the two components. Scanning electron microscopy (SEM) was employed to observe the surface morphology and confirm the structural features of the synthesized nanocomposite[(Cheng et al., 2023)](https://paperpile.com/c/pnwdvO/P5dR). The antimicrobial efficacy of the composite was evaluated against common pathogenic bacterial strains, including *Enterococcus faecalis* and *Streptococcus mutans*, and fungal strains such as *Candida albicans* and *Candida parapsilosis*. These microorganisms are known for their resistance to conventional antibiotics and their role in persistent infections, particularly in immunocompromised patients. The anticancer activity was assessed in vitro using established human cancer cell lines, with an emphasis on evaluating cell viability, ROS generation, and morphological changes induced by the nanocomposite[(Mubraiz et al., 2021)](https://paperpile.com/c/pnwdvO/cfxc).The main objective of this study is to develop a novel Ti₃C₂–Co₃O₄ nanocomposite with enhanced antimicrobial and anticancer properties, supported by detailed structural and biological analyses. By integrating the functional advantages of both MXenes and transition metal oxides, this research aims to provide a versatile nanoplatform for future biomedical applications, particularly in the fight against multidrug-resistant pathogens and cancer.

# MATERIALS AND METHODS

## Synthesis of Ti₃C₂NH₄Tₓ MXene

Ti₃C₂ MXene was synthesized from the Ti₃AlC₂ MAX phase through selective etching of the aluminum (Al) layer. Specifically, 0.5 g of Ti₃AlC₂ powder was gradually added to 30 mL of 2 M ammonium bifluoride (NH₄HF₂) solution under stirring. The etching reaction was conducted at room temperature for 24 hours. Upon completion, the resulting mixture was repeatedly washed with distilled water and ethanol via centrifugation until the pH of the supernatant reached neutrality. The neutralized slurry was then dried in a conventional oven at 80 °C for 12 hours. To achieve delamination and increase the interlayer spacing, 0.2 g of the dried Ti₃C₂NH₄Tₓ powder was dispersed in 30 mL of dimethyl sulfoxide (DMSO), and the mixture was stirred continuously for 24 hours. The intercalated material was subsequently dispersed in distilled water and subjected to ultrasonication in a nitrogen atmosphere for a few hours to prevent oxidation. This yielded exfoliated Ti₃C₂ MXene nanosheets suitable for composite formation.

## Synthesis of Co₃O₄

Co₃O₄ nanoparticles were synthesized via thermal decomposition of cobalt nitrate hexahydrate. A fixed quantity (1 g) of Co(NO₃)₂·6H₂O was placed in a ceramic crucible and annealed in a muffle furnace at 420 °C for 3 hours in air. This resulted in the formation of fine Co₃O₄ powder.

## Synthesis of Ti₃C₂–Co₃O₄ Nanocomposite

To fabricate the Ti₃C₂–Co₃O₄ composite, 0.6 g of Co(NO₃)₂·6H₂O and 0.6185 g of urea (in a molar ratio of 1:5) were dissolved in 70 mL of 25 M NaOH solution and stirred until a dark blue homogeneous solution was obtained. A measured amount (0.03 g) of exfoliated Ti₃C₂NH₄Tₓ nanosheets was added under an oxygen-free environment and stirred thoroughly. The resulting mixture was transferred into a Teflon-lined stainless steel autoclave after purging with nitrogen gas and subjected to hydrothermal treatment at 120 °C for 24 hours. The product was separated by centrifugation, washed rigorously, dried at 40 °C for 24 hours, and finally annealed at 280 °C for 3 hours in air to yield the Ti₃C₂–Co₃O₄ nanocomposite.

## Antimicrobial Activity

The antimicrobial activity of Ti₃C₂–Co₃O₄ nanoparticles was assessed through the disk diffusion method. For the preparation of the test sample, 50 mg of the nanoparticles were dissolved in 2.5 mL of ethanol and subsequently sterilized using a 0.22 µm Millipore filter. Sterile filter paper discs, each measuring 8 mm in diameter, were immersed in this solution to achieve a final concentration of 10 mg/mL. Mueller-Hinton agar (10 mL) was then poured into sterile Petri dishes to create the nutrient medium, onto which the treated discs were carefully positioned. Control discs containing 20 µg of ketoconazole (for fungal strains) and tetracycline (for bacterial strains) served as positive controls, while blank DMSO was utilized as the negative control. The plates were stored at 5°C for 2 hours to facilitate the diffusion of the nanoparticles into the agar, followed by incubation for 24 hours at 35°C for bacterial strains (*Enterococcus faecalis*, *Streptococcus mutans*) and at 25°C for fungal strains (*Candida albicans*, *Candida parapsilosi*s). The inhibition zones were measured using a Vernier caliper.

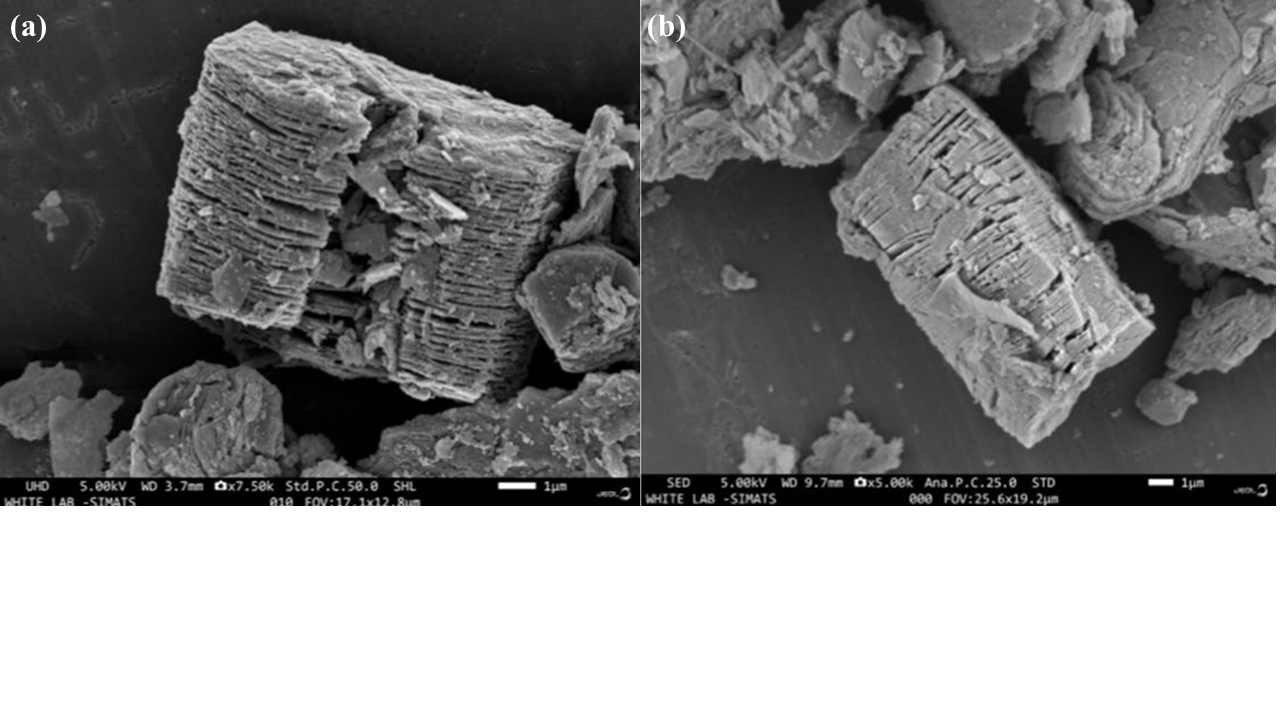
## Anticancer Activity

The anticancer activity of the Ti₃C₂–Co₃O₄ nanocomposite was assessed using the human colorectal adenocarcinoma cell line SW480. The cell line was procured from the National Centre for Cell Science (NCCS), Pune, India. SW480 cells were cultured in Dulbecco's Modified Eagle Medium (DMEM), supplemented with 10% fetal bovine serum (FBS) and 1% penicillin–streptomycin, and maintained in a humidified incubator at 37°C with 5% CO₂. Dimethyl sulfoxide (DMSO) was used as a solvent control at a concentration below 0.2%. For the cytotoxicity study, 1 × 10⁴ SW480 cells were seeded in 96-well plates and incubated overnight to ensure proper adhesion and proliferation. Cells were then treated with 50 µg/mL of the Ti₃C₂–Co₃O₄ nanocomposite for 24 hours in a CO₂ incubator. Post-treatment, the medium was discarded, and 25 µL of phosphate-buffered saline (PBS) containing 0.25 mg/mL of MTT reagent was added to each well. The cells were incubated again at 37°C under 5% CO₂ for an additional 24 hours to facilitate the formation of formazan crystals by mitochondrial dehydrogenases in viable cells. After incubation, the supernatant was removed, and the resulting formazan crystals were solubilized using DMSO. The absorbance was measured at 570 nm using a microplate reader to determine cell viability.

# RESULTS

## SEM Analysis

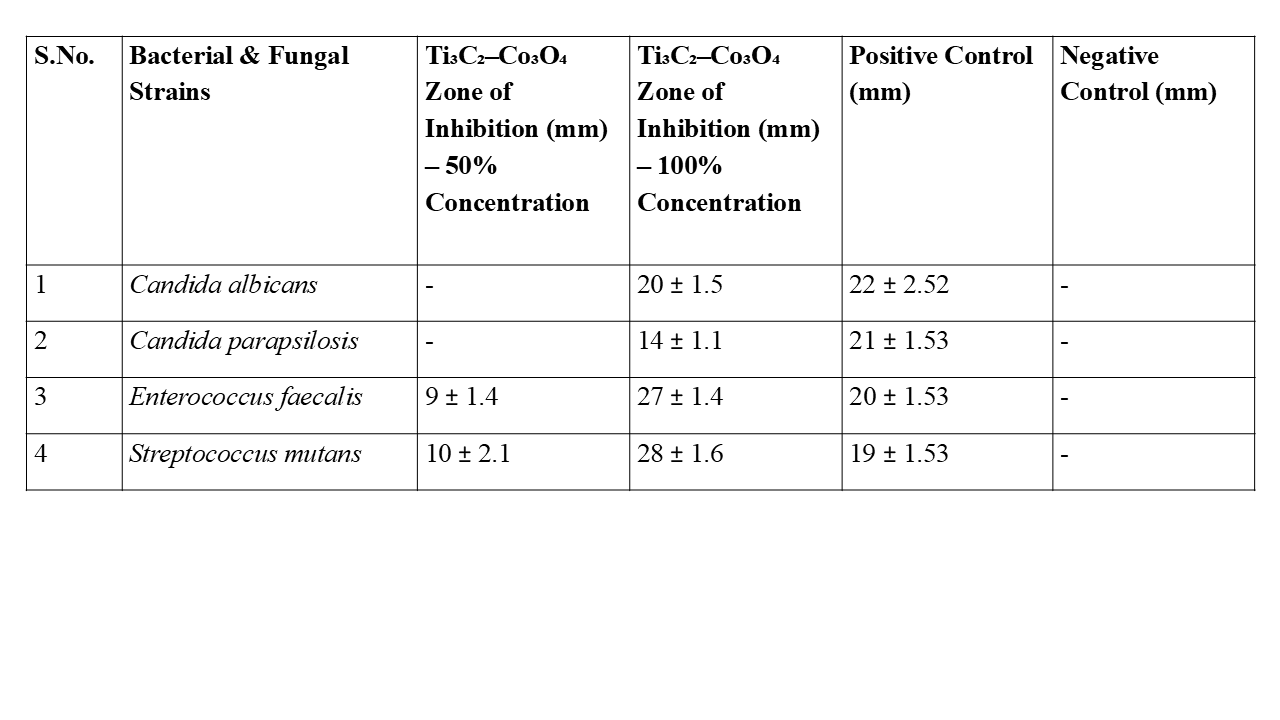
The surface morphology of the synthesized Ti₃C₂–Co₃O₄ nanocomposite was investigated using Scanning Electron Microscopy (SEM), and the obtained micrographs are presented in Figure 1(a), clearly exhibits the distinctive layered structure characteristic of Ti₃C₂ MXene, which appears as stacked, sheet-like morphologies with accordion-like folding. This morphology is indicative of successful etching and delamination of the Ti₃AlC₂ MAX phase to produce Ti₃C₂. The layered structure facilitates high surface area and active edge sites, which are advantageous for various applications, including catalytic and biomedical purposes. The SEM image further reveals that the exfoliated MXene layers have a rough texture with crumpled and fragmented edges, a feature that enhances interaction with other nanostructures and biomolecules.In Figure 1(b), the incorporation of Co₃O₄ nanoparticles onto the Ti₃C₂ surface is evident. The Co₃O₄ appears as uniformly dispersed granules and clusters embedded across the Ti₃C₂ layers. These particles exhibit a dense and slightly agglomerated appearance, suggesting strong interfacial contact with the MXene matrix. The surface texture in this image is noticeably rougher and more granular than in image (a), confirming the successful integration of Co₃O₄ into the layered Ti₃C₂ network. The formation of such a composite structure enhances the overall surface roughness, which is likely to contribute to improved catalytic and biological activity due to increased active site availability.The hybrid structure combines the electrical conductivity and large surface area of Ti₃C₂ MXene with the redox-active and semiconducting properties of Co₃O₄, making it a promising candidate for therapeutic applications. The intimate contact between the two components as observed in the SEM images also indicates strong interactions at the nanoscale, which are beneficial for stability and functionality in biological environments. Thus, the SEM analysis confirms the successful fabrication of a well-integrated Ti₃C₂–Co₃O₄ nanocomposite with a favorable architecture for anticancer and antimicrobial applications.



**Figure 1:** SEM Analysis of Ti₃C₂–Co₃O₄ nanocomposite

## Antimicrobial Activity

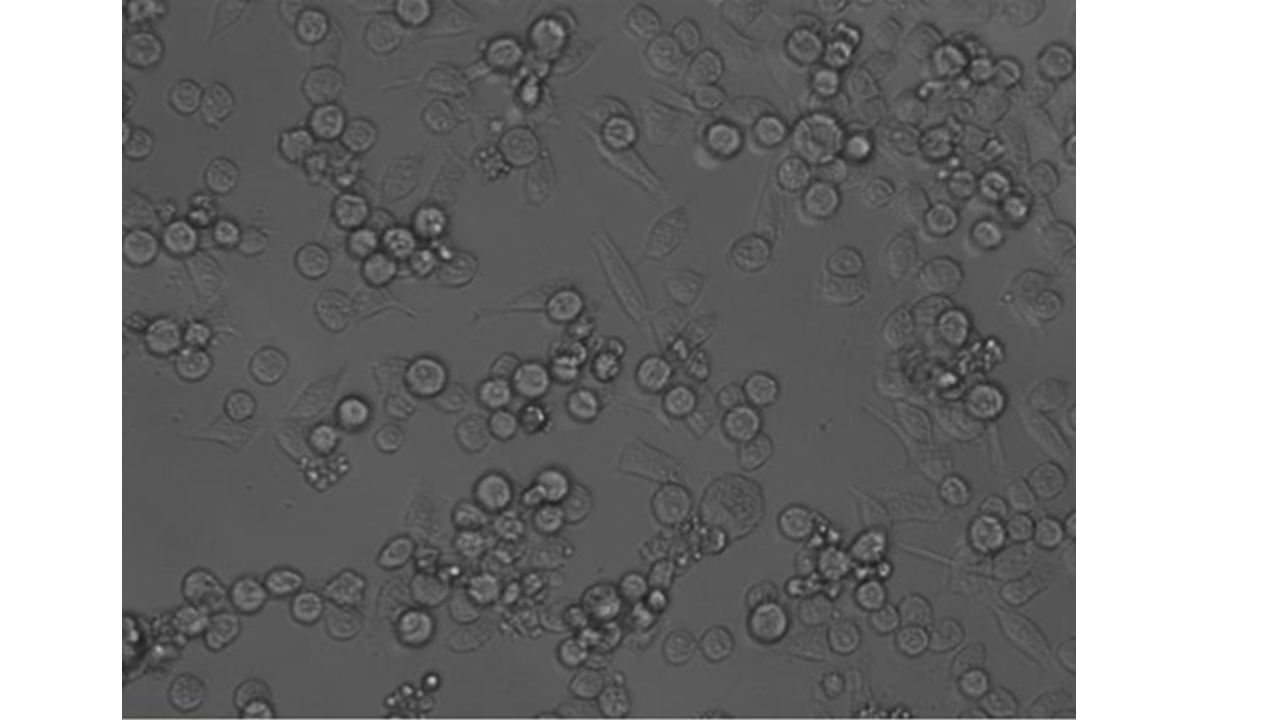
The antimicrobial activity of the Ti₃C₂–Co₃O₄ nanocomposite was evaluated against two bacterial strains (*Enterococcus faecalis* and *Streptococcus mutans*) and two fungal strains (*Candida albicans* and *Candida parapsilosis*) using the disk diffusion method. The results demonstrated a concentration-dependent inhibitory effect of the nanocomposite in Figure 2. At 50% concentration, the nanocomposite showed moderate antibacterial activity, with zones of inhibition of 9 ± 1.4 mm and 10 ± 2.1 mm for *E. faecalis* and *S. mutans*, respectively. However, no antifungal activity was observed at this concentration against *C. albicans* and *C. parapsilosis*, as indicated by the absence of measurable inhibition zones.When the concentration was increased to 100%, the Ti₃C₂–Co₃O₄ nanocomposite exhibited significantly enhanced antimicrobial effects. Against *E. faecalis* and *S. mutans*, inhibition zones increased to 27 ± 1.4 mm and 28 ± 1.6 mm, respectively, which were larger than those produced by the positive control (20 ± 1.53 mm and 19 ± 1.53 mm). This indicates that the nanocomposite is more effective at higher concentrations compared to standard antibiotics for these strains. Antifungal activity also became evident at 100% concentration, with *C. albicans* and *C. parapsilosis* showing inhibition zones of 20 ± 1.5 mm and 14 ± 1.1 mm, respectively. Although the activity against *C. parapsilosis* was slightly lower than the positive control (21 ± 1.53 mm), the result still demonstrates the composite's potential as an antifungal agent, especially since no inhibition was noted at lower concentrations.The overall results indicate that Ti₃C₂–Co₃O₄ nanocomposites possess strong antimicrobial properties, particularly against Gram-positive bacteria and to a lesser extent against fungal strains, with effectiveness improving significantly with increased concentration. The absence of zones in the negative control confirms the reliability of the observed inhibitory effects. These findings suggest that the composite could be a promising material for biomedical and antimicrobial applications.



**Figure 2:** Antimicrobial Activity of Ti₃C₂–Co₃O₄ nanocomposite was evaluated against two bacterial strains (*Enterococcus faecalis* and *Streptococcus mutans*) and two fungal strains (*Candida albicans* and *Candida parapsilosis*)

## Anticancer Activity

The anticancer activity of the Ti₃C₂–Co₃O₄ nanocomposite was evaluated using the SW480 human colorectal adenocarcinoma cell line in Figure 3. Morphological analysis using phase-contrast microscopy revealed substantial alterations in the treated cells compared to the untreated control group. The treated cells displayed significant loss of cellular integrity, detachment from the substrate, and extensive rounding, a typical sign of apoptotic induction. These observations suggest that the nanocomposite induces cytotoxic effects that compromise the viability of colorectal cancer cells.Further supporting evidence was obtained from the MTT assay, which quantitatively measures cell metabolic activity. Upon treatment with the Ti₃C₂–Co₃O₄ nanocomposite at a concentration of 50 µg/mL for 24 hours, a substantial reduction in cell viability was observed, indicating effective inhibition of cancer cell proliferation. The decrease in absorbance at 570 nm after MTT exposure signifies the diminished capacity of treated cells to reduce the MTT reagent to formazan crystals, reflecting impaired mitochondrial function and metabolic distress. This cytotoxic effect is consistent with the initiation of apoptosis or necrosis, both indicative of successful anticancer activity.The likely mechanism underlying this anticancer potential can be attributed to the unique physicochemical properties of the Ti₃C₂–Co₃O₄ nanocomposite (Nikalje et al., 2024). The MXene structure offers a high surface area and abundant active sites for interaction with cellular components, while cobalt oxide nanoparticles may generate reactive oxygen species (ROS), leading to oxidative stress, DNA damage, and activation of apoptotic pathways. The combination of these effects can disrupt essential cellular processes, ultimately resulting in cancer cell death(Chehelgerdi et al., 2023). The absence of toxicity in negative controls and the distinct morphological changes observed post-treatment confirm that the cytotoxicity is directly linked to the nanocomposite exposure. These findings highlight the Ti₃C₂–Co₃O₄ nanocomposite as a promising candidate for further development as a nanotherapeutic agent in colorectal cancer treatment strategies.



**Figure 3:** Anticancer Activity of Ti₃C₂–Co₃O₄ nanocomposite

# Discussion

The rapid advancement of nanotechnology has enabled the development of multifunctional nanomaterials with promising biomedical applications. Among them, MXene-based nanocomposites have garnered attention due to their unique structural, electrical, and chemical properties[(Linda et al., 2024)](https://paperpile.com/c/pnwdvO/Dhae). This study focuses on the facile synthesis of a Ti₃C₂–Co₃O₄ nanocomposite, aiming to explore its potential as an antimicrobial and anticancer agent. By integrating the high surface area and conductivity of Ti₃C₂ with the oxidative properties of Co₃O₄, the composite exhibits enhanced biological activity. The resulting material shows significant efficacy against pathogenic microbes and cancer cells, highlighting its potential for future therapeutic applications[(Spigoni et al., 2015)](https://paperpile.com/c/pnwdvO/kSVM). The surface morphology and microstructural features of the Ti₃C₂–Co₃O₄ nanocomposite were investigated using scanning electron microscopy (SEM), revealing critical insights into its layered architecture and interaction of constituent phases. The SEM images distinctly show that the Ti₃C₂ MXene retains its characteristic lamellar structure, indicating successful delamination and preservation of its two-dimensional morphology. This structural arrangement is vital for maximizing surface area, which is beneficial for applications such as catalysis, sensing, and biomedical interfaces[(Naguib et al., 2011)](https://paperpile.com/c/pnwdvO/3Zkl). The Co₃O₄ nanoparticles appear to be uniformly distributed across and partially embedded within the MXene sheets, suggesting a strong interfacial interaction between the oxide phase and the MXene matrix. This intimate contact potentially enhances the physicochemical stability and electron transport capability of the nanocomposite. Moreover, the rough surface texture and increased porosity observed are likely to facilitate cellular interaction, ion exchange, or drug adsorption, making the material suitable for biological and energy applications. The absence of agglomeration and the homogeneous distribution of Co₃O₄ particles further confirm the successful synthesis of a well-dispersed hybrid nanostructure. These morphological features corroborate the functional potential of the Ti₃C₂–Co₃O₄ nanocomposite in multifunctional applications, particularly where surface interaction plays a pivotal role[(Dubus et al., 2019)](https://paperpile.com/c/pnwdvO/EfhH).The Ti₃C₂–Co₃O₄ nanocomposite exhibits promising antibacterial activity, as evidenced by its significant inhibitory effects against both Gram-positive bacterial strains such as *Enterococcus faecalis* and *Streptococcus mutans*. The enhanced antibacterial performance can be attributed to the synergistic interaction between the conductive Ti₃C₂ MXene layers and the oxidative stress-inducing Co₃O₄ nanoparticles. Co₃O₄, a transition metal oxide, is known for generating reactive oxygen species (ROS) that disrupt bacterial cell walls, proteins, and nucleic acids, ultimately leading to cell death[(Italiano et al., 2018)](https://paperpile.com/c/pnwdvO/I4NS). Meanwhile, the MXene’s sharp, sheet-like morphology may physically pierce bacterial membranes, adding a mechanical bactericidal mechanism. The increased zone of inhibition observed at 100% concentration relative to 50% concentration demonstrates a dose-dependent antimicrobial effect, further confirming the composite’s potential as a broad-spectrum antibacterial agent. Notably, the Ti₃C₂–Co₃O₄ nanocomposite showed even higher antibacterial activity than standard antibiotics in certain strains, underscoring its capacity to overcome resistance mechanisms. The homogenous dispersion of Co₃O₄ on MXene ensures uniform ROS generation and enhances the interaction with bacterial cells. These findings suggest that Ti₃C₂–Co₃O₄ nanocomposites may serve as effective, multifunctional materials for biomedical coatings, wound dressings, or antimicrobial surfaces in clinical settings[(Rasool et al., 2016)](https://paperpile.com/c/pnwdvO/2O5I).The Ti₃C₂–Co₃O₄ nanocomposite demonstrates significant anticancer activity, highlighting its potential as a novel therapeutic agent. The observed cytotoxic effects against cancer cell lines can be attributed to the synergistic action between Ti₃C₂ MXene and Co₃O₄ nanoparticles. Co₃O₄ nanoparticles are known to induce apoptosis in cancer cells through the generation of reactive oxygen species (ROS), which disrupt mitochondrial membrane potential and activate caspase-dependent pathways[(Mohamed et al., 2025)](https://paperpile.com/c/pnwdvO/Avk1). The layered Ti₃C₂ structure offers a large surface area and sharp-edged morphology that may facilitate cellular uptake and membrane disruption, enhancing the composite's cytotoxic efficiency[(C et al., 2024)](https://paperpile.com/c/pnwdvO/92v4). Moreover, the conductive nature of MXene enables electron transfer, promoting redox cycling and further ROS generation, which intensifies oxidative stress within cancer cells. The microscopic analysis revealed morphological changes indicative of apoptosis, such as cell shrinkage, membrane blebbing, and nuclear condensation, confirming the anticancer mechanism. The dose-dependent response further reinforces the therapeutic relevance of this nanocomposite. These findings suggest that Ti₃C₂–Co₃O₄ nanocomposites may offer a multifunctional platform for targeted cancer therapy, combining oxidative stress-mediated apoptosis with efficient cellular interaction and internalization[(Huang et al., 2021)](https://paperpile.com/c/pnwdvO/bn85).

# CONCLUSION

This study presents the successful and facile synthesis of a Ti₃C₂–Co₃O₄ nanocomposite using a simple hydrothermal method, yielding a multifunctional material with notable antimicrobial and anticancer properties. SEM analysis revealed that the composite maintained the characteristic layered morphology of Ti₃C₂ MXene while displaying a uniform distribution of Co₃O₄ nanoparticles across its surface, confirming strong interfacial interaction and structural stability. The nanocomposite exhibited potent anticancer activity against SW480 colorectal cancer cells, significantly reducing cell viability through oxidative stress and apoptosis, as evidenced by characteristic morphological changes and dose-dependent cytotoxic effects. This therapeutic efficacy is attributed to the synergistic role of MXene's high conductivity and surface reactivity with the ROS-generating properties of Co₃O₄. In addition, the Ti₃C₂–Co₃O₄ nanocomposite demonstrated substantial antimicrobial effects against Gram-positive bacterial strains *Enterococcus faecalis* and *Streptococcus mutans*, as well as fungal strains *Candida albicans* and *Candida parapsilosis*, with larger zones of inhibition observed at higher concentrations. The antimicrobial mechanism is likely a combination of membrane disruption by MXene’s sharp edges and oxidative damage induced by Co₃O₄, resulting in effective inhibition of microbial growth. The overall findings underscore the potential of Ti₃C₂–Co₃O₄ nanocomposites as innovative and efficient agents for biomedical applications, particularly in targeted cancer therapy and infection control, providing a foundation for future translational research,

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