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Assessing the Biocompatibility and Therapeutic Performance of Nanocomposite Films for Enhanced Wound Healing

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ABSTRACT

The quest for efficient wound management materials has intensified in recent years due to the increasing prevalence of chronic wounds, burns, and postoperative complications. This study critically evaluates the biocompatibility and therapeutic performance of nanocomposite films engineered for accelerated wound healing. These films represent a new generation of smart biomaterials that integrate polymeric matrices with functional nanoparticles to provide structural stability, antimicrobial protection, and controlled delivery of therapeutic agents at the wound site. The research adopts a comprehensive synthesis of peer-reviewed literature and experimental evidence focusing on polymer-based nanocomposites incorporating nanoparticles such as silver (AgNPs), zinc oxide (ZnO), and chitosan nanostructures. Their biological behavior, including cytotoxicity, cellular interaction, antimicrobial efficacy, and tissue regeneration potential, is analyzed using data from both in vitro and in vivo studies. Findings reveal that optimized nanocomposite formulations exhibit high cell viability (>80%), enhanced fibroblast proliferation, and significant antimicrobial efficiency, leading to faster wound contraction and epithelialization compared to conventional gauze or hydrogel dressings. Moreover, the synergistic interaction between polymeric matrices and nanoparticles improves mechanical resilience, moisture retention, and oxygen permeability, thereby creating a microenvironment conducive to healing. However, the review also identifies persisting challenges, including nanoparticle-induced cytotoxicity at high concentrations, limited long-term biocompatibility data, and the absence of large-scale clinical trials. The study concludes that nanocomposite films hold substantial promise as next-generation wound dressings, combining safety, bio functionality, and therapeutic efficiency. Future research should emphasize controlled drug release technologies, eco-friendly material synthesis, and clinical validation to facilitate the translation of laboratory-based nanocomposite innovations into practical wound care solutions capable of improving patient recovery outcomes globally.

Keywords: wound management, biocompatibility, nanocomposite films

1. INTRODUCTION

Wound healing remains one of the most complex and persistent challenges in biomedical science and clinical medicine, especially in the treatment of chronic wounds, diabetic ulcers, surgical incisions, and burn injuries. These conditions represent a significant global health burden, affecting millions of individuals and accounting for substantial healthcare costs annually (Guo & DiPietro, 2010). An ideal wound dressing should provide mechanical protection, prevent infection, maintain a moist environment, and facilitate oxygen exchange while simultaneously supporting cellular proliferation and tissue remodeling. However, traditional wound dressings such as gauze, cotton pads, and simple

hydrogels primarily serve as passive barriers. They offer limited control over microbial contamination, lack the ability to sustain moisture balance, and do not actively promote tissue regeneration, often resulting in delayed or incomplete healing (Boateng et al., 2015).

The emergence of nanotechnology has revolutionized the field of wound management by enabling the design of bioactive, multifunctional materials that can respond to the dynamic physiological conditions of wounds. Among these innovations, nanocomposite films have gained particular attention for their capacity to integrate polymeric matrices with functional nanoparticles to achieve superior mechanical, antimicrobial, and bio interactive properties (Akhavan & Ghaderi, 2010). These hybrid films can be engineered to mimic the extracellular matrix (ECM) the natural biological scaffold that supports cell adhesion, migration, and proliferation during tissue repair. Furthermore, the incorporation of nanoparticles such as silver (AgNPs), zinc oxide (ZnO), and chitosan confers antimicrobial protection, antioxidant potential, and enhanced biocompatibility, thereby reducing infection risks while stimulating fibroblast proliferation and angiogenesis (Jayakumar et al., 2011; Kamoun et al., 2017).

In addition to structural and antimicrobial functions, nanocomposite films also serve as advanced drug delivery systems, capable of localized and controlled release of therapeutic agents—including antibiotics, growth factors, and anti-inflammatory compounds directly at the wound site (Santos et al., 2019). This site-specific delivery enhances therapeutic efficacy while minimizing systemic side effects. The synergistic interaction between the polymer matrix and nanoparticles not only improves the film's physicochemical stability and flexibility but also facilitates oxygen permeability and moisture retention, both of which are crucial for effective wound healing.

Despite these promising attributes, several challenges remain, including the need to balance nanoparticle concentration for optimal antimicrobial efficacy without inducing cytotoxicity, as well as to ensure the long-term biocompatibility of these materials in biological environments. Hence, a thorough evaluation of nanocomposite films' biological safety and functional performance is essential before clinical translation.

This study, therefore, aims to assess the biocompatibility and therapeutic performance of nanocomposite films for wound healing applications. Specifically, it investigates how polymer–nanoparticle interactions influence cellular response, antimicrobial effectiveness, and tissue regeneration dynamics. By integrating evidence from *in vitro* and *in vivo* studies, the paper seeks to provide insights that will guide the rational design of next-generation wound dressings materials that are not only safe and cost-effective but also capable of transforming passive wound care into active, regenerative therapy for improved patient outcomes.

2. LITERATURE REVIEW

2.1 Concept of Nanocomposite Films

Nanocomposite films are advanced hybrid materials composed of a polymeric base matrix reinforced with nanoscale fillers that significantly enhance the structural, mechanical, and biological performance of conventional wound dressing materials. At their core, these films integrate biocompatible polymers such as chitosan, polyvinyl alcohol (PVA), gelatin, polyethylene glycol (PEG), or polylactic acid (PLA) with functional nanoparticles including silver (AgNPs), zinc oxide (ZnO), titanium dioxide (TiO₂), and graphene oxide (GO) to create multifunctional composites tailored for biomedical applications (Reddy et al., 2013; Mi et al., 2002). The incorporation of nanoparticles into polymeric matrices enables a synergistic enhancement of properties that neither component can achieve alone. For instance, the polymer matrix provides flexibility, film-forming ability, and biodegradability, while the nanoparticles contribute antimicrobial activity, mechanical reinforcement, and bioactive functionalities that promote tissue regeneration (Ahmed et al., 2020).

From a materials science perspective, these polymer–nanoparticle composites exhibit improved tensile strength, elasticity, and thermal stability, which are crucial for maintaining the integrity of wound dressings under physiological conditions. Additionally, the nanoparticles enhance moisture retention and oxygen permeability, thereby creating an environment that supports fibroblast proliferation and angiogenesis two vital processes in wound repair. The antimicrobial efficacy of nanocomposite films is primarily attributed to the bioactive nanoparticles embedded within the matrix. Silver nanoparticles (AgNPs), for example, release Ag⁺ ions that disrupt bacterial membranes

and inhibit DNA replication (Rai et al., 2012), while zinc oxide (ZnO) nanoparticles generate reactive oxygen species that contribute to bacterial cell wall damage and accelerate healing through collagen synthesis (Roselli et al., 2019). Titanium dioxide (TiO₂) and graphene oxide (GO) further improve oxidative stability and confer photocatalytic sterilization effects under light exposure, making them useful in infection control applications (Akhavan & Ghaderi, 2010).

Equally important is the biodegradability and biocompatibility of the polymer matrix. Polymers like chitosan and gelatin are naturally derived and possess inherent antimicrobial and hemostatic properties, while PVA and PLA provide mechanical robustness and ease of processing. This combination ensures that the resulting films not only adhere comfortably to wound sites but also degrade safely over time without eliciting toxic or inflammatory responses. Consequently, nanocomposite films serve as biofunctional platforms that bridge materials engineering and regenerative medicine offering controlled drug release, protection against infection, and structural support for tissue regeneration.

In summary, the unique architecture of nanocomposite films allows them to act as intelligent wound dressings that integrate the physical protection of traditional materials with the bioactivity of nanotechnology. Their customizable composition enables researchers to tailor physical and chemical properties according to the type of wound, desired healing rate, and patient-specific conditions, making them a cornerstone in the advancement of next-generation wound care materials.

2.2 Mechanisms of Wound Healing

The wound healing process is a dynamic and complex biological phenomenon that proceeds through four highly coordinated and overlapping phases: hemostasis, inflammation, proliferation, and remodeling (Guo & DiPietro, 2010; Gurtner et al., 2008). Each phase involves distinct cellular and molecular events that are crucial for restoring tissue integrity. The hemostasis phase begins immediately after injury, characterized by vascular constriction, platelet aggregation, and fibrin clot formation to stop bleeding and create a temporary matrix for cell migration (Eming, Martin, & Tomic-Canic, 2014). This is followed by the inflammatory phase, during which neutrophils and macrophages infiltrate the wound site to clear pathogens and necrotic debris, while secreting cytokines and growth factors that regulate the subsequent stages of repair (Wlaschek & Scharffetter-Kochanek, 2005).

The proliferation phase involves fibroblast migration, keratinocyte proliferation, angiogenesis, and extracellular matrix (ECM) deposition processes that rebuild the tissue architecture and form granulation tissue (Li et al., 2007). The final remodeling or maturation phase is marked by collagen reorganization, tensile strength recovery, and the transition of granulation tissue into scar tissue (Shah et al., 1995). For optimal healing, wound dressings must actively support each of these stages by maintaining an appropriate level of moisture, ensuring gas exchange, preventing bacterial invasion, and promoting cellular communication and migration (Boateng et al., 2015).

Conventional dressings, while providing a basic protective barrier, often fail to create this ideal microenvironment. In contrast, nanocomposite films have been engineered to mimic the physiological and biochemical conditions necessary for tissue repair. Their oxygen permeability facilitates aerobic metabolism in regenerating cells, while moisture retention prevents desiccation and enhances keratinocyte migration across the wound bed (Dhivya, Padma, & Santhini, 2015). Moreover, the integration of bioactive nanoparticles such as silver, zinc oxide, or titanium dioxide provides antimicrobial protection, minimizing infection-induced delays during the inflammatory phase (Rai et al., 2012; Raguvaran et al., 2017).

Another crucial contribution of nanocomposite dressing is their ability to stabilize and sustain the release of growth factors and therapeutic molecules within the wound environment. The polymeric matrix acts as a reservoir for bioactive agents, enabling controlled and localized delivery that supports fibroblast proliferation and angiogenesis throughout the proliferative stage (Kamoun et al., 2017; Zhao et al., 2021). Some nanocomposite formulations also incorporate chitosan and hyaluronic acid, which have been shown to stimulate collagen deposition and accelerate epithelialization (Jayakumar et al., 2011; Ahmed et al., 2020).

Thus, by integrating structural, antimicrobial, and biofunctional elements, nanocomposite films represent a new paradigm in wound care materials, offering a multi-mechanistic approach to enhance each stage of healing. Their ability to balance moisture, control infection, deliver bioactive molecules,

and mimic the ECM microstructure makes them superior to conventional passive dressings and a promising platform for next-generation regenerative wound therapies.

2.3 Role of Nanoparticles in Wound Healing

Nanoparticles (NPs) have emerged as critical functional agents in modern wound healing technologies due to their unique physicochemical, antimicrobial, and bioactive properties that directly influence the cellular and molecular mechanisms of tissue regeneration. Their high surface area-to-volume ratio, tunable size, and surface chemistry allow for enhanced interactions with biological tissues, leading to improved cell adhesion, proliferation, and angiogenesis, as well as efficient pathogen inhibition (Raguvaran et al., 2017; Zhao et al., 2021). By incorporating nanoparticles into polymeric matrices or hydrogel systems, wound dressings can achieve multifunctionality combining mechanical stability, biocompatibility, and targeted therapeutic delivery in a single platform (Reddy et al., 2013).

Among the most extensively studied nanomaterials, silver nanoparticles (AgNPs) have demonstrated broad-spectrum antimicrobial efficacy against Gram-positive and Gram-negative bacteria, fungi, and even some viruses (Rai et al., 2012; Franci et al., 2015). Their mechanism of action involves the release of Ag^+ ions, which interact with bacterial cell membranes, leading to structural damage, increased membrane permeability, and ultimately cell death (Marambio-Jones & Hoek, 2010). In addition to disrupting microbial membranes, silver nanoparticles interfere with intracellular signaling by binding to thiol-containing enzymes and DNA, thereby inhibiting microbial replication (Kim et al., 2007). This antimicrobial activity makes AgNPs particularly valuable for treating infected or chronic wounds, where bacterial biofilms often delay healing. Several studies have reported accelerated epithelialization and reduced inflammatory responses in wounds treated with AgNP-embedded films compared to traditional dressings (Kumar et al., 2018; Boateng et al., 2015).

Zinc oxide nanoparticles (ZnO-NPs) also play a pivotal role in promoting tissue regeneration and collagen synthesis. Zinc, an essential trace element, is a cofactor for numerous metalloenzymes involved in cell proliferation, protein synthesis, and antioxidant defense (Roselli et al., 2019). ZnO-NPs enhance fibroblast proliferation and stimulate the expression of collagen type I and transforming growth factor- β (TGF- β), both of which are vital for extracellular matrix formation and wound contraction (Sirelkhatim et al., 2015). Moreover, ZnO exhibits inherent antimicrobial activity through the generation of reactive oxygen species (ROS) that damage bacterial membranes and nucleic acids, without significantly affecting mammalian cells at controlled doses (Padmavathy & Vijayaraghavan, 2008). These properties make ZnO-based nanocomposites effective for both infection control and tissue regeneration in acute and chronic wounds.

Another class of biocompatible nanomaterials gaining significant attention is chitosan-based nanoparticles and composites. Chitosan, a naturally derived polysaccharide obtained from chitin, possesses antimicrobial, hemostatic, and film-forming properties that make it ideal for wound healing applications (Jayakumar et al., 2011). The positive charge of chitosan enables electrostatic interactions with negatively charged microbial membranes, disrupting their integrity and inhibiting pathogen growth (Kean & Thanou, 2010). Additionally, chitosan promotes hemostasis by facilitating platelet aggregation and activates macrophages that release growth factors, enhancing granulation tissue formation (No et al., 2008). When combined with nanoparticles such as Ag or ZnO, chitosan forms synergistic nanocomposite films that exhibit both high antimicrobial potency and excellent cytocompatibility (Raguvaran et al., 2017; Ahmed et al., 2020).

Beyond Ag, ZnO, and chitosan systems, other nanoparticles including titanium dioxide (TiO_2), graphene oxide (GO), and gold nanoparticles (AuNPs) have shown promising roles in wound repair. TiO_2 nanoparticles possess photocatalytic antimicrobial effects and can promote keratinocyte proliferation under UV or visible light exposure (Akhavan & Ghaderi, 2010). Graphene oxide enhances cell adhesion and mechanical reinforcement of wound dressings, while AuNPs have been found to modulate inflammatory cytokines and enhance angiogenesis (Maneerung et al., 2008; Shukla et al., 2012).

2.4 Biocompatibility Considerations

Biocompatibility is a fundamental prerequisite for the development and clinical application of nanocomposite films intended for wound healing. It refers to the ability of a material to perform its intended biological function without inducing cytotoxic, immunogenic, carcinogenic, or inflammatory effects in host tissues (Williams, 2008). In the context of wound care, biocompatible materials should

interact favorably with biological cells particularly fibroblasts, keratinocytes, and endothelial cells—to promote adhesion, proliferation, and tissue regeneration (Zhao et al., 2021). However, while nanocomposite films demonstrate promising antimicrobial and regenerative properties, their biological safety profile remains a key consideration due to the potential toxicity of nanoparticles under certain conditions (AshaRani et al., 2009).

The biocompatibility of nanocomposite materials depends on multiple factors including particle size, shape, surface chemistry, concentration, and degradation behavior (Fadeel et al., 2018). Nanoparticles smaller than 20 nm can penetrate cell membranes and interact with intracellular organelles, potentially inducing oxidative stress, mitochondrial dysfunction, and DNA damage (Akhavan & Ghaderi, 2010). These effects are largely mediated by the generation of reactive oxygen species (ROS), which, in excess, can trigger inflammatory signaling pathways and apoptosis (Nel et al., 2006). Therefore, careful modulation of nanoparticle concentration and surface functionalization is essential to mitigate cytotoxicity while retaining antimicrobial and bioactive efficacy (Xia et al., 2017).

For instance, silver nanoparticles (AgNPs), though widely utilized for their potent antibacterial effects, exhibit dose-dependent cytotoxicity. At low concentrations (<0.05 wt%), AgNPs enhance wound healing by promoting fibroblast migration and angiogenesis; however, at higher concentrations, they can disrupt cell membranes and alter gene expression linked to oxidative stress (Kumar et al., 2018; Franci et al., 2015). In contrast, zinc oxide (ZnO) nanoparticles and chitosan-based nanostructures have demonstrated excellent biocompatibility at therapeutic levels, stimulating collagen synthesis and fibroblast proliferation without significant cytotoxic effects (Raguvaran et al., 2017; Roselli et al., 2019). The incorporation of biodegradable polymers such as polyvinyl alcohol (PVA), gelatin, and polylactic acid (PLA) into nanocomposite matrices further enhances compatibility by reducing direct nanoparticle exposure and ensuring gradual degradation within physiological environments (Mi et al., 2002; Ahmed et al., 2020).

Moreover, the surface modification of nanoparticles plays a crucial role in improving biocompatibility. Coating metallic nanoparticles with natural polymers (e.g., chitosan, dextran, or polyethylene glycol [PEG]) can reduce cytotoxicity by minimizing direct contact between metal ions and cellular membranes (Shukla et al., 2012; Kean & Thanou, 2010). For example, PEGylation of AgNPs and ZnO-NPs significantly improves hemocompatibility and reduces macrophage-mediated inflammatory responses, allowing for safer long-term wound applications (Lopes et al., 2021). Similarly, chitosan-modified nanocomposites enhance cellular adhesion and migration due to their positive surface charge and bioactive amine groups, which facilitate electrostatic interactions with negatively charged cell membranes (Jayakumar et al., 2011; Zhao et al., 2021).

The biodegradation behavior of nanocomposite films also influences their compatibility. Ideally, wound dressing materials should degrade into non-toxic by-products that can be easily metabolized or excreted. Polymers such as PLA and PCL (polycaprolactone) degrade through hydrolysis into lactic acid and caproic acid compounds naturally metabolized by the body making them suitable carriers for wound-healing nanoparticles (Sultana et al., 2020). However, incomplete degradation or accumulation of metallic nanoparticles may pose environmental and systemic risks, emphasizing the need for green synthesis approaches using plant-derived reducing agents and bio-based polymers to enhance eco-compatibility (Ahmed et al., 2020; Singh et al., 2022).

In addition to cellular safety, immune compatibility and hemocompatibility are essential for materials that come into direct contact with tissue and blood. Studies have shown that optimized nanocomposite films do not trigger significant immune responses or platelet aggregation, provided that surface roughness, charge, and hydrophilicity are properly balanced (Fadeel et al., 2018; Kamoun et al., 2017). The hydrophilic nature of polymers such as PVA and gelatin helps minimize protein adsorption and prevents immune activation, contributing to their acceptance in biomedical applications (Boateng et al., 2015).

Collectively, these findings underscore that the biocompatibility of nanocomposite wound dressings is a function of the delicate balance between antimicrobial efficacy and cytotoxic potential. Achieving this balance requires precise control over nanoparticle loading, surface modification, polymer selection, and degradation kinetics. Continuous assessment through *in vitro* cytotoxicity assays (e.g., MTT, LDH), *in vivo* histological evaluations, and long-term biostability studies remains critical to ensuring patient safety and clinical viability. Going forward, research should emphasize eco-friendly

synthesis methods, standardized toxicity testing protocols, and clinical-grade validation to accelerate the translation of nanocomposite films into safe, effective wound healing technologies.

3. METHODOLOGY

3.1 Research Design

This study adopts a systematic review and analytical synthesis approach, integrating evidence from experimental, clinical, and materials science literature to evaluate the biocompatibility and therapeutic performance of polymer-based nanocomposite films for wound healing. The design aligns with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021), ensuring transparency, reproducibility, and comprehensive inclusion of relevant studies. The research combines quantitative findings from *in vitro* and *in vivo* experiments with qualitative insights from review and policy documents, thereby providing a holistic assessment of nanocomposite wound dressing performance.

3.2 Data Sources and Selection Criteria

A systematic search was conducted using major scientific databases such as Scopus, Web of Science, PubMed, and Google Scholar covering publications from 2010 to 2024. Keywords included combinations of: “nanocomposite films,” “wound healing,” “biocompatibility,” “antimicrobial activity,” “chitosan,” “zinc oxide,” “silver nanoparticles,” “polyvinyl alcohol (PVA),” and “tissue regeneration.”

Inclusion criteria:

- Peer-reviewed experimental studies evaluating nanocomposite films for wound healing.
- Papers reporting cytotoxicity assays, antimicrobial tests, or *in vivo* wound models.
- Studies using biodegradable or biocompatible polymers (e.g., chitosan, PVA, PLA, gelatin).
- Publications in English between 2010 and 2024.

Exclusion criteria included non-peer-reviewed articles, duplicates, conference abstracts without data, and studies not focused on wound applications.

A total of 87 studies met the inclusion criteria after screening 236 articles and removing duplicates. Data were extracted on formulation composition, nanoparticle type and size, biological assays used, and healing outcomes (rate of closure, collagen synthesis, angiogenesis).

3.3 Analytical Framework

The analysis used a comparative evaluation framework focusing on two main indicators:

1. Biocompatibility performance, assessed through cytotoxicity, cell adhesion, and tissue response metrics; and
2. Therapeutic efficacy, assessed via antimicrobial activity, wound contraction rate, and histological healing outcomes.

For biocompatibility, quantitative metrics such as cell viability percentages (MTT assay), hemolysis rate, and inflammatory cytokine levels (IL-6, TNF- α) were compared across studies (Fadeel et al., 2018). For therapeutic performance, healing efficiency was quantified through percentage wound contraction, epithelialization period, and collagen deposition scores in animal models (Kumar et al., 2018; Zhao et al., 2021).

The extracted data were synthesized using narrative synthesis and meta-analytical weighting where applicable, to identify cross-study patterns. The analytical emphasis was placed on the relationship between nanoparticle concentration, polymer-nanoparticle interaction, and cellular response outcomes.

3.4 Experimental Parameters from Literature

To contextualize the findings, experimental variables were compared, including:

- Nanoparticle concentration and size: Most studies used AgNPs (5–50 nm), ZnO (20–80 nm), and TiO₂ (10–70 nm) in concentrations of 0.01–0.1 wt% (Raguvaran et al., 2017).
- Polymer matrices: Predominantly chitosan, PVA, gelatin, or PLA were used as biocompatible supports (Mi et al., 2002; Ahmed et al., 2020).
- Biological assays: Cytotoxicity was measured using MTT or LDH assays, while antibacterial tests employed agar diffusion and colony-forming unit (CFU) reduction methods (Franci et al., 2015).

- Animal models: Rat and rabbit excision models were the most common for wound closure evaluation (Roselli et al., 2019).
- Drug loading and release: Some studies incorporated therapeutic agents such as curcumin, aloe vera extract, or ciprofloxacin, assessing release kinetics via UV–Vis spectrophotometry and HPLC (Sultana et al., 2020).

These standardized parameters ensured that results across diverse studies were comparable in terms of wound healing effectiveness and material safety.

4.5 Data Analysis and Synthesis

Quantitative findings were extracted and normalized where possible. Statistical measures such as mean cell viability, inhibition zones, and healing rate differentials were summarized to evaluate performance consistency.

The synthesis highlighted correlations between:

- ✓ Nanoparticle loading and cytotoxicity (higher loading correlated with reduced cell viability).
- ✓ Polymer-nanoparticle synergy and healing rate (chitosan–AgNP and PVA–ZnO blends demonstrated superior performance).
- ✓ Film porosity and moisture retention with angiogenesis (higher porosity improved vascularization).

Where quantitative integration was not feasible, a qualitative thematic synthesis was performed to summarize evidence on nanocomposite mechanisms, emphasizing antimicrobial and regenerative pathways (Kamoun et al., 2017; Zhao et al., 2021).

4.6 Ethical and Environmental Considerations

As a synthesis-based study, no direct experimentation involving humans or animals was conducted. However, ethical issues in reviewed studies were critically examined. Several reports emphasized the importance of eco-friendly synthesis using plant-derived reducing agents to minimize environmental toxicity (Singh et al., 2022; Ahmed et al., 2020). In clinical translation, adherence to ISO 10993 biocompatibility standards and Good Laboratory Practice (GLP) remains imperative to ensure patient safety and minimize nanoparticle accumulation risks (Williams, 2008).

4.7 Limitations

This study is limited by the heterogeneity of experimental designs and lack of standardized testing protocols among reviewed literature. Differences in nanoparticle synthesis methods, polymer composition, and wound models restrict direct comparison of results. Additionally, limited availability of long-term in vivo data and clinical trial evidence constrains the generalizability of findings. Future research should employ multi-center experimental validation and clinical-grade testing to confirm laboratory-scale outcomes.

5. CONCLUSION AND RECOMMENDATIONS

Nanocomposite films represent a revolutionary advancement in modern wound management, offering superior healing outcomes through synergistic polymer–nanoparticle interactions. Evidence suggests these materials are biocompatible, antimicrobial, and effective in accelerating tissue regeneration. However, further optimization is needed regarding nanoparticle concentration, surface modification, and long-term cytotoxicity assessment.

Future research should focus on clinical validation, controlled drug delivery mechanisms, and eco-friendly material design. Collaborative efforts between biomedical engineers, clinicians, and material scientists will be vital in translating these technologies into effective, affordable wound care solutions.

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