



Antimicrobial Activity of Berberine–Chitosan Nanoparticle–Coated Sutures: An In-Vitro Evaluation

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ABSTRACT:

Background: Surgical sutures can act as substrates for bacterial colonization, leading to surgical site infections. Incorporating antimicrobial agents into sutures offers localized infection control. Berberine possesses broad-spectrum antimicrobial activity, while chitosan nanoparticles enable sustained drug delivery.

Objective: To evaluate the antimicrobial efficacy of berberine–chitosan nanoparticle (BCNP)–coated sutures against common pathogenic microorganisms.

Materials and Methods: Antimicrobial activity was assessed using the agar diffusion method against *Staphylococcus aureus*, *Enterococcus faecalis*, *Escherichia coli*, and *Pseudomonas aeruginosa*. Zones of inhibition produced by BCNP nanoparticles and BCNP-coated sutures were measured after 24 h incubation at 37 °C.

Results: BCNP nanoparticles demonstrated greater antimicrobial activity compared to coated sutures across all organisms. The highest zone of inhibition was observed against *Staphylococcus aureus* (38 mm for nanoparticles, 24 mm for coated sutures). Coated sutures exhibited significant antibacterial activity, confirming successful drug incorporation and release.

Conclusion: Berberine–chitosan nanoparticle-coated sutures exhibit broad-spectrum antimicrobial activity and may serve as promising bioactive surgical materials.

1. Introduction

Surgical site infections (SSIs) remain among the most common postoperative complications worldwide, contributing significantly to patient morbidity, prolonged hospitalization, increased healthcare costs, and delayed wound healing outcomes [1]. Despite advances in aseptic techniques and antibiotic prophylaxis, the presence of foreign materials such as sutures continues to represent a major risk factor for infection development. Sutures can act as substrates for bacterial adhesion, colonization, and biofilm formation, thereby facilitating persistent infections that are often resistant to systemic antimicrobial therapy [2]. Biofilm-associated infections are particularly challenging to treat because microorganisms embedded within biofilms exhibit increased resistance to host immune responses and antimicrobial agents [2,3].

The development of antimicrobial-coated sutures has therefore emerged as an important strategy to reduce bacterial colonization and prevent postoperative infections. Previous studies have demonstrated that antimicrobial sutures significantly decrease microbial load and infection rates compared with conventional sutures [3,4]. However, currently available antimicrobial sutures often rely on synthetic agents such as triclosan, which may raise concerns regarding antimicrobial resistance, cytotoxicity, and long-term safety [4]. Consequently, there is growing interest in incorporating natural bioactive compounds with antimicrobial and wound-healing properties into suture materials.

Localized drug delivery through suture materials offers several advantages over systemic antibiotic administration. These include higher drug concentration at the surgical site, reduced systemic toxicity, prolonged therapeutic activity, improved patient compliance, and targeted antimicrobial effects during the critical phases



of wound healing [5]. Drug-eluting sutures can therefore serve as multifunctional biomaterials that provide both mechanical wound support and localized therapeutic effects.

Berberine is a naturally occurring isoquinoline alkaloid derived from medicinal plants such as *Berberis vulgaris*, *Coptis chinensis*, and *Hydrastis canadensis*. It has been extensively studied for its broad-spectrum antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties [6]. Berberine exhibits antimicrobial activity against Gram-positive and Gram-negative bacteria, fungi, and protozoa through multiple mechanisms, including disruption of bacterial cell membranes, inhibition of nucleic acid synthesis, interference with protein synthesis, and suppression of quorum sensing pathways involved in microbial virulence [6,7]. In addition, berberine has been shown to modulate inflammatory responses by inhibiting pro-inflammatory cytokines such as tumor necrosis factor- α (TNF- α) and interleukin-6 (IL-6), thereby promoting tissue repair and regeneration [7].

Beyond its antimicrobial activity, berberine plays a beneficial role in wound healing by enhancing fibroblast proliferation, collagen synthesis, angiogenesis, and epithelialization [7]. These biological effects make berberine a promising candidate for incorporation into biomedical devices aimed at improving wound healing outcomes. However, the clinical application of berberine is limited by poor aqueous solubility, rapid metabolism, and low bioavailability when administered systemically [6]. Therefore, the development of novel drug delivery systems capable of improving berberine stability and enabling sustained localized release is essential.

Nanoparticle-based drug delivery systems have gained considerable attention in recent years due to their ability to enhance drug stability, improve bioavailability, and provide controlled release profiles. Nanoparticles offer several advantages, including increased surface area, enhanced interaction with microbial membranes, improved penetration into biofilms, and prolonged therapeutic effects [8]. These properties make nanoparticle formulations particularly suitable for antimicrobial applications and localized drug delivery.

Chitosan, a naturally derived polysaccharide obtained from chitin, is widely used in biomedical applications due to its biocompatibility, biodegradability, low

toxicity, and intrinsic antimicrobial activity [9]. The antimicrobial effect of chitosan is primarily attributed to its positively charged amino groups, which interact with negatively charged bacterial cell membranes, leading to membrane disruption, leakage of intracellular components, and bacterial cell death [10]. In addition, chitosan promotes hemostasis, fibroblast proliferation, collagen deposition, and tissue regeneration, making it highly suitable for wound healing applications [18].

Chitosan nanoparticles prepared using ionic gelation methods provide an efficient platform for drug encapsulation and controlled release. The electrostatic interaction between chitosan and crosslinking agents such as sodium tripolyphosphate allows the formation of stable nanoparticles without the use of toxic solvents, thereby preserving the biological activity of encapsulated compounds [9]. Incorporation of berberine into chitosan nanoparticles can therefore enhance its stability, improve therapeutic efficacy, and enable sustained drug release.

The combination of berberine and chitosan nanoparticles offers potential synergistic antimicrobial effects due to the complementary mechanisms of action of both agents. While berberine disrupts bacterial metabolic pathways and nucleic acid synthesis, chitosan interferes with microbial cell membrane integrity and nutrient transport systems [10,11]. This synergistic interaction may enhance antimicrobial efficacy and reduce the likelihood of resistance development.

Although nanoparticle-based antimicrobial systems have been widely investigated, limited research has focused on the incorporation of natural bioactive nanoparticle formulations into suture materials for localized drug delivery. The development of berberine-chitosan nanoparticle-coated sutures may therefore represent an innovative approach to creating multifunctional surgical materials that combine mechanical wound closure with sustained antimicrobial and wound-healing activity.

Therefore, the present study aimed to evaluate the antimicrobial activity of berberine-chitosan nanoparticles and berberine-chitosan nanoparticle-coated sutures against clinically relevant microorganisms associated with surgical site infections. The findings of this study may contribute to the development of advanced bioactive sutures with potential applications in oral and maxillofacial surgery and other surgical disciplines.



2. Materials and Methods

2.1 Microorganisms

The antimicrobial activity was evaluated against:

- *Staphylococcus aureus*
- *Enterococcus faecalis*
- *Escherichia coli*
- *Pseudomonas aeruginosa*

These organisms are commonly implicated in surgical infections.

2.2 Antimicrobial Assay

The agar diffusion method was used. Mueller–Hinton agar plates were inoculated with standardized microbial suspensions. BCNP nanoparticles were introduced into wells, and BCNP-coated suture segments were placed on agar surfaces.

After incubation at 37 °C for 24 h, zones of inhibition were measured in millimeters.

3. Results

Both BCNP nanoparticles and BCNP-coated sutures demonstrated antimicrobial activity against all tested microorganisms.

Nanoparticles showed larger zones of inhibition compared to coated sutures due to greater direct diffusion into the surrounding medium. However, coated sutures demonstrated significant antibacterial activity, confirming effective drug release from the suture material.

The highest antimicrobial activity was observed against *Staphylococcus aureus*, while *Pseudomonas aeruginosa* exhibited the lowest sensitivity.

Table 1. Zone of Inhibition (mm)

S. No	Organism	Nanoparticle	Coated Suture
1	<i>Staphylococcus aureus</i>	38	24
2	<i>Escherichia coli</i>	34	18
3	<i>Enterococcus faecalis</i>	26	14

4	<i>Pseudomonas aeruginosa</i>	16	12
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4. Representative Culture Plate Images



Enterococcus faecalis

Figure 1. Antimicrobial Activity Against *Enterococcus faecalis*

Figure Legend: Agar diffusion assay demonstrating zone of inhibition produced by berberine–chitosan nanoparticle formulation and coated suture against *Enterococcus faecalis* after 24 h incubation.



Staphylococcus aureus

Figure 2. Antimicrobial Activity Against *Staphylococcus aureus*



Figure Legend: Representative culture plate showing antimicrobial activity of BCNP nanoparticles and coated suture against *Staphylococcus aureus*.



Escherichia Coli

Figure 3. Antimicrobial Activity Against *Pseudomonas aeruginosa* and *Escherichia coli*

Figure Legend: Zones of inhibition observed against Gram-negative organisms *Pseudomonas aeruginosa* and *Escherichia coli*.

5. Discussion

The present study demonstrated that berberine–chitosan nanoparticles and BCNP-coated sutures exhibit broad-spectrum antimicrobial activity against both Gram-positive and Gram-negative microorganisms commonly associated with surgical site infections. The results showed that nanoparticles produced larger zones of inhibition compared to coated sutures, which may be attributed to greater drug diffusion and direct interaction between nanoparticles and bacterial cells. Nevertheless, the coated sutures exhibited clinically relevant antimicrobial activity, confirming successful incorporation of berberine into the chitosan nanoparticle coating and its sustained release from the suture surface.

The highest antimicrobial activity observed against *Staphylococcus aureus* is particularly significant because this organism is one of the most prevalent pathogens involved in postoperative infections, including oral and maxillofacial surgical procedures [10]. The substantial inhibition against *Escherichia coli* and *Enterococcus faecalis* further supports the broad-spectrum

antibacterial potential of the formulation. The comparatively lower activity observed against *Pseudomonas aeruginosa* may be explained by its intrinsic resistance mechanisms, including efflux pumps, reduced membrane permeability, and biofilm-forming capacity [11].

The antimicrobial activity observed in this study can be attributed to the synergistic effects of berberine and chitosan nanoparticles. Berberine disrupts bacterial cell membranes, inhibits protein synthesis, interferes with DNA replication, and suppresses quorum sensing pathways that regulate bacterial virulence [6,12]. Chitosan contributes through electrostatic interaction with negatively charged bacterial cell walls, leading to membrane destabilization and leakage of intracellular components [8]. Additionally, chitosan has been shown to chelate essential metal ions required for microbial growth, further enhancing antibacterial activity [13].

Nanoparticle formulation enhances antimicrobial efficacy by increasing surface area, improving drug stability, and facilitating sustained release. The nanoscale size allows closer interaction with microbial membranes and enhances penetration into biofilms, which may improve antibacterial effectiveness compared with conventional drug formulations [14]. These properties explain the enhanced antimicrobial activity observed with BCNP nanoparticles in the present study.

The coated sutures demonstrated lower zones of inhibition compared to nanoparticles, which is expected because drug release from the suture surface occurs gradually rather than instantaneously. However, sustained release from coated sutures may provide prolonged antimicrobial protection at the surgical site, which is clinically advantageous for preventing postoperative infections during the early healing phase [15].

Previous studies have demonstrated that antimicrobial-coated sutures significantly reduce bacterial colonization and infection rates in surgical wounds [3,16]. The incorporation of natural bioactive compounds such as berberine offers additional advantages, including reduced risk of antimicrobial resistance and improved biocompatibility compared to synthetic antibiotics [17].

Furthermore, both berberine and chitosan possess anti-inflammatory and wound-healing properties, which may



contribute synergistically to improved tissue regeneration. Berberine has been shown to reduce pro-inflammatory cytokines such as TNF- α and IL-6, while chitosan promotes fibroblast proliferation and collagen deposition [7,18]. Therefore, BCNP-coated sutures may provide dual benefits of antimicrobial protection and enhanced wound healing.

Overall, the findings of this study support the potential of berberine–chitosan nanoparticle-coated sutures as advanced bioactive wound closure materials. However, further in-vivo studies are required to evaluate biocompatibility, mechanical strength, and clinical efficacy.

6. Conclusion

The present study demonstrated that berberine–chitosan nanoparticle-coated sutures exhibit significant antimicrobial activity against clinically relevant Gram-positive and Gram-negative microorganisms associated with surgical site infections. The coated sutures showed sustained antibacterial efficacy, confirming successful drug incorporation and controlled release from the nanoparticle coating.

The synergistic antimicrobial mechanisms of berberine and chitosan nanoparticles, combined with sustained drug delivery, make this system a promising candidate for bioactive surgical sutures aimed at infection prevention. Compared with conventional antimicrobial sutures, the use of natural bioactive compounds may reduce the risk of antimicrobial resistance while providing additional anti-inflammatory and wound-healing benefits [17].

These findings highlight the potential clinical application of BCNP-coated sutures in surgical disciplines, including oral and maxillofacial surgery, general surgery, and orthopedics. Future research should focus on in-vivo evaluation, cytocompatibility assessment, mechanical property analysis, and clinical trials to validate translational applicability.

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