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Berberine–Chitosan Nanoparticle–Coated Suture Materials for Controlled Drug Delivery: An In-Vitro Evaluation of Release Kinetics

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KEYWORDS:

Berberine, Chitosan nanoparticles, Drug-eluting sutures, Controlled release, Nanomedicine, Wound healing.

ABSTRACT:

Background: Surgical sutures are essential for wound closure but may also act as substrates for microbial colonization, contributing to postoperative infections and delayed healing. Incorporation of therapeutic agents into suture materials provides an opportunity for localized drug delivery. Berberine, a natural isoquinoline alkaloid, exhibits antimicrobial, anti-inflammatory, and wound-healing properties; however, its clinical application is limited by poor bioavailability. Chitosan nanoparticles offer a promising delivery platform to enhance sustained release and therapeutic efficacy.

Objective: To develop berberine–chitosan nanoparticle (BCNP)–coated sutures and evaluate their in-vitro drug delivery rate and release kinetics.

Materials and Methods: BCNPs were synthesized using ionic gelation with sodium tripolyphosphate as a crosslinking agent. Surgical sutures were coated using a dip-coating technique followed by mild crosslinking. Drug release was evaluated using a dialysis method in phosphate-buffered saline (PBS, pH 7.4) at 37 °C. Samples were collected at predetermined time points up to 72 h and analyzed spectrophotometrically.

Results: BCNP-coated sutures demonstrated a biphasic release pattern with an initial mild burst release within the first 6 h followed by sustained release up to 72 h. The cumulative drug release reached 89.6 ± 3.5% at 72 h, indicating effective drug encapsulation and controlled delivery.

Conclusion: Berberine–chitosan nanoparticle–coated sutures exhibit sustained localized drug release and show potential as bioactive wound closure materials for surgical applications.

1. Introduction

Surgical site infections (SSIs) remain among the most common postoperative complications, significantly contributing to patient morbidity, prolonged hospitalization, and increased healthcare costs. Sutures, while essential for wound approximation, may serve as niduses for bacterial colonization and biofilm formation, thereby increasing infection risk [1]. The development of antimicrobial or drug-eluting sutures has therefore gained considerable interest as an approach to reduce postoperative complications and enhance wound healing outcomes [2].

Localized drug delivery through suture materials offers several advantages over systemic administration, including higher drug concentration at the wound site, reduced systemic toxicity, prolonged therapeutic action, and improved patient compliance. Incorporating bioactive compounds into suture coatings enables continuous drug release directly at the surgical interface during the critical healing period [3].

Berberine is a naturally occurring isoquinoline alkaloid derived from plants such as *Berberis vulgaris* and *Coptis chinensis*. It possesses broad-spectrum antimicrobial, anti-inflammatory, antioxidant, and tissue regenerative properties [4]. Berberine has been shown to inhibit bacterial growth, suppress inflammatory cytokines, and promote fibroblast proliferation and collagen deposition, which are essential for wound healing [5]. However, its clinical utility is limited by poor aqueous solubility, rapid metabolism, and low systemic bioavailability.

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Nanoparticle-based drug delivery systems have emerged as effective strategies to overcome these limitations by enhancing drug stability and enabling controlled release. Chitosan, a naturally derived polysaccharide obtained from chitin, has attracted significant attention due to its biocompatibility, biodegradability, mucoadhesive properties, and intrinsic antimicrobial activity [6]. Chitosan nanoparticles prepared via ionic gelation offer a simple, non-toxic, and efficient method for encapsulating bioactive molecules [7].

The positive surface charge of chitosan facilitates adhesion to negatively charged biological surfaces, making it particularly suitable for coating biomedical devices such as sutures. Additionally, chitosan itself promotes hemostasis, cell proliferation, and tissue regeneration, further enhancing its suitability for wound healing applications.

Despite advances in antimicrobial sutures, limited research has explored the integration of natural bioactive compounds such as berberine within nanoparticle-coated sutures for sustained localized delivery. Therefore, the present study aimed to develop berberine–chitosan nanoparticle-coated sutures and evaluate their in-vitro drug release kinetics to assess their potential as bioactive surgical materials.

2. Materials and Methods

2.1 Preparation of Berberine–Chitosan Nanoparticles

Berberine–chitosan nanoparticles (BCNPs) were synthesized using the ionic gelation technique. Chitosan (0.2–0.3% w/v) was dissolved in 1% acetic acid and filtered to remove impurities. Berberine was added under continuous magnetic stirring to ensure uniform dispersion. Sodium tripolyphosphate (TPP, 0.1% w/v) was added dropwise to induce nanoparticle formation via electrostatic interaction between positively charged chitosan and negatively charged TPP molecules. The nanoparticles were collected by centrifugation and resuspended in sterile distilled water.

2.2 Coating of Suture Materials

Commercial surgical sutures were coated by immersion in the BCNP suspension using a dip-coating technique followed by air drying at room temperature. Mild crosslinking was performed to enhance nanoparticle adhesion to the suture surface.

2.3 In-Vitro Drug Release Study

Drug release was evaluated using a dialysis method in phosphate-buffered saline (PBS, pH 7.4) at 37 °C under gentle agitation. Aliquots were collected at predetermined time intervals (1, 3, 6, 12, 24, 48, and 72 h) and replaced with fresh PBS to maintain sink conditions. Berberine concentration was determined using UV–visible spectrophotometry.

Methodology and experimental release data were derived from the study protocol documentation.

2.4 Statistical Analysis

All experiments were performed in triplicate (n = 3). Data were expressed as mean ±standard deviation (SD).

3. Results

BCNP-coated sutures demonstrated sustained and controlled drug release over 72 h with a characteristic biphasic release pattern.

An initial mild burst release was observed within the first 6 h, which may be attributed to the release of berberine molecules adsorbed on the nanoparticle surface. This was followed by a prolonged and steady release phase up to 72 h, indicating effective drug encapsulation within the chitosan matrix and diffusion-controlled release behavior.

Table 1: In-Vitro Drug Release Profile of BCNP-Coated Sutures

Time (h)	Cumulative Drug Release (%)
1	12.4 ± 1.2
3	21.8 ± 1.6
6	32.5 ± 2.1
12	45.6 ± 2.4
24	61.3 ± 2.8
48	78.9 ± 3.1
72	89.6 ± 3.5

Values expressed as mean ±SD (n = 3)

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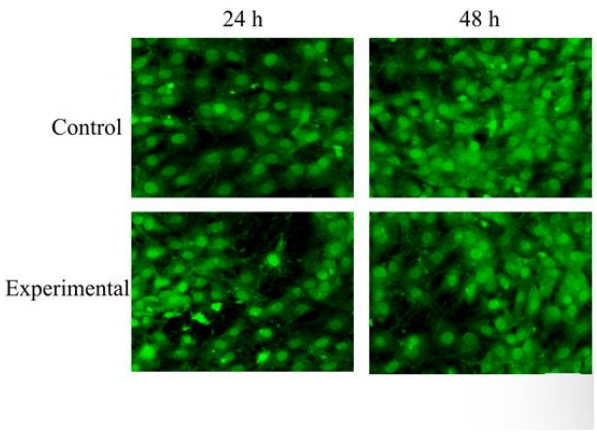

Figure 1. Drug release over 48 hours.

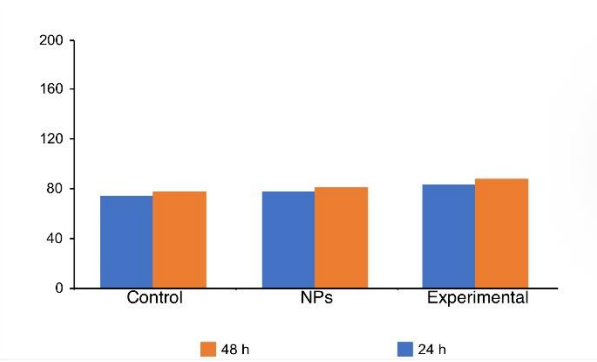

Figure 2: Drug release over 48 hours

4. Discussion

Localized drug delivery using functionalized sutures represents an innovative strategy to improve wound healing and reduce postoperative complications. The present study demonstrated that berberine–chitosan nanoparticle coatings provide sustained drug release over a clinically relevant period corresponding to the inflammatory and early proliferative phases of wound healing.

The initial burst release observed during early time intervals may provide immediate antimicrobial activity, reducing bacterial contamination immediately following surgery. The subsequent sustained release phase ensures prolonged therapeutic effects, which may enhance tissue regeneration and prevent infection.

Chitosan contributes significantly to the observed release behavior due to its polymeric matrix, which controls drug diffusion and degradation kinetics. Additionally, its intrinsic antimicrobial activity and wound-healing properties may synergistically enhance the therapeutic effect of berberine.

Berberine further contributes by inhibiting pro-inflammatory cytokines, reducing oxidative stress, and promoting fibroblast proliferation and angiogenesis. The combination of berberine with chitosan nanoparticles therefore provides a multifunctional drug delivery platform.

The release kinetics observed in this study are consistent with diffusion-controlled mechanisms commonly reported in polymeric nanoparticle systems.

5. Conclusion

The present study demonstrated that berberine–chitosan nanoparticle–coated sutures provide sustained and controlled drug release over 72 h with an initial burst followed by prolonged release. Such localized drug delivery systems offer significant potential for enhancing antimicrobial protection, reducing inflammation, and promoting wound healing.

Previous studies have established the effectiveness of antimicrobial sutures in reducing infection rates and improving clinical outcomes [3]. Similarly, nanoparticle-based delivery systems have been widely recognized for improving drug stability, bioavailability, and therapeutic efficacy [6]. The incorporation of natural bioactive compounds such as berberine into nanoparticle-coated sutures therefore represents a promising advancement in surgical biomaterials.

Further in-vivo and clinical studies are required to validate the safety, efficacy, and translational potential of this system in surgical practice.

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Conflict of Interest

The authors declare no conflict of interest.

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