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Original Research Article

Evaluation of the Antimicrobial Efficacy of Silver Nanoparticle Coated Sutures Versus Uncoated Silk Sutures Material: An In Vitro Study

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Abstract

Introduction: *Surgical site infections (SSIs) are a frequent postoperative complication that can delay wound healing and increase patient morbidity. Braided silk sutures, despite their favorable handling characteristics, lack intrinsic antimicrobial activity and are prone to bacterial colonization. Incorporating antimicrobial agents such as silver nanoparticles into suture materials may help reduce microbial contamination and improve surgical wound healing.*

Aim: *To evaluate and compare the antimicrobial effectiveness of silver nanoparticle (AgNP)-coated silk sutures and conventional uncoated silk sutures against Streptococcus pyogenes, Staphylococcus aureus, and Escherichia coli.*

Materials and Methods: *Antimicrobial activity was evaluated using a modified Kirby–Bauer agar diffusion method. Standardized 1-cm segments of 2-0 silk sutures were coated with stabilized silver nanoparticles (AgNPs) by dip-coating. Zones of inhibition (ZOI) were measured on Mueller–Hinton agar inoculated with Streptococcus pyogenes, Staphylococcus aureus*, and *Escherichia coli. Sustained antimicrobial activity was assessed using a 14-day serial transfer method, with the same suture segments transferred periodically to freshly inoculated agar plates. ZOI measurements were recorded on Days 7, 10, and 14.*

Results*: Uncoated silk sutures did not inhibit microbial growth. In contrast, AgNP-coated sutures showed marked antimicrobial activity against all tested microorganisms, with the largest mean zone of inhibition observed against Escherichia coli (14.2 ± 0.7 mm).*

Conclusion: *Silver nanoparticle-coated silk sutures demonstrated prolonged antimicrobial activity against microorganisms commonly associated with SSIs, indicating their potential utility in minimizing postoperative infections and enhancing surgical outcomes.*

Keywords: *Surgical site infections, silver nanoparticles, antimicrobial activity, zone of inhibition, silk sutures.*

Introduction

Surgical site infections remain a major clinical challenge, largely driven by bacterial adhesion and biofilm formation on surgical sutures. Surgical site infections (SSIs) may occur following a surgical procedure and can involve the skin, subcutaneous tissues, deep soft tissues, and organs. As the second leading cause of healthcare-associated infections, surgical site infections contribute substantially to patient morbidity and mortality, while increasing healthcare expenditures. (Mellinghoff SC et al., and Liston J, Bayles A., 2023). The incidence of surgical site infections ranges from 0.5% to 3% among patients undergoing surgery. Patients affected by these infections typically experience hospital stays that are 7–11 days longer than those of uninfected patients (Seidelman et al.,2023), Consequently, patients often require more extensive antibiotic therapy, resulting in increased medical costs (Mara¸s and Sürme, 2023). According to the CDC 2018 guidelines, several factors can influence the risk of developing a surgical site infection. These factors may be related to the patient, the nature of the surgical procedure, or perioperative practices, including preoperative, intraoperative, and postoperative care (Mara¸s, G.and Sürme, Y 2023). The likelihood of infection is affected by the patient's immune status, appropriate use of prophylactic antibiotics, extent of microbial contamination at the surgical site, and presence of implanted or foreign materials (Seidelman et al.,2023). Surgical site infections arise from complex interactions between patient characteristics, operative factors, and perioperative care practices. (Yang, Y, Zhou, Z et al 2024 and Dhom J, Bloes DA et al.,2017).

Once placed at the surgical site, suture materials are rapidly coated with host-derived proteins such as fibrinogen, fibronectin, and collagen. These proteins promote bacterial adhesion and colonization. Adherent microorganisms can form biofilms enclosed within a protective extracellular matrix, enhancing their resistance to antimicrobial agents and host immune defenses (Dhom J, Bloes DA et al.,2017 and Hrynyshyn A, Simões M et al.,2022) Consequently, biofilm-associated surgical site infections are difficult to treat, particularly in the presence of multidrug-resistant bacteria, and remain a major challenge in postoperative wound management (Hrynyshyn A, Simões M et al.,2022).

Biofilm formation on surgical sutures is influenced by both the suture material and its surface characteristics(Dhom J, Bloes DA et al.,2017, Li, H.; Wang, Z.; Robledo-Lara, J.Aet al.,2021 and Asher, R.; Chacartchi, T et al.,2019) Braided sutures are generally more susceptible to bacterial colonization than monofilament sutures because their multifilament structure provides niches that facilitate bacterial retention and growth(Dhom et al.,2017 and Wang et al., Z.; Robledo-Lara, J.Aet al.,2021).To reduce bacterial contamination, particularly in braided sutures, triclosan has been used as an antimicrobial coating because of its broad-spectrum activity against various microorganisms, including antibiotic-resistant strains(Yang, Y.; Zhou, Z et al 2024, Dhom J, Bloes DA et al.,2017 and He, P.; Liu, Z et al., 2023).

Common pathogens associated with surgical site infections include Staphylococcus aureus, coagulase-negative staphylococci, Enterococcus spp. and Escherichia coli. Exogenous contamination may originate from the operating environment, healthcare personnel, and surgical instruments.

Silver nanoparticle-coated sutures have been shown to reduce bacterial adhesion and biofilm formation, making them a promising strategy for preventing biofilm-associated surgical site infections (Paladini F, Panico A, et al 2025).

Aim

To compare the antimicrobial efficacy of silver nanoparticle coated suture material and uncoated silk suture material using an in-vitro model.

Materials and methods

The present in vitro study was conducted at PERIOBIOLOGICS LLP, Tilak Nagar, New Nallakunta, Hyderabad, Telangana, India. The study was approved by the Institutional Ethics Committee of the Panineeya Institute of Dental Sciences and Research Centre, IEC NO: PMVIDS & RC/IEC/PERIO/PR/649-25 Hyderabad, Telangana.

Methodology

Preparation of Suture Material

Commercially available sterile 2-0 braided silk sutures were aseptically cut into standardized 1-cm segments using sterile scissors and forceps. The sutures were divided into two groups:

Group A: Plain silk sutures (control)

Group B: Silver nanoparticle (AgNP)-coated silk sutures (test)

Preparation and Coating with Silver Nanoparticles

Test sutures were coated with stabilized silver nanoparticles (approximately 80 nm) using a dip-coating technique. Each suture segment was immersed in a 25 mL AgNP suspension for 30 minutes, removed with sterile forceps, and dried under sterile conditions to facilitate nanoparticle adherence. Control sutures remained uncoated.

Preparation of Bacterial Inoculum

The antimicrobial activity was evaluated against three bacterial strains commonly associated with surgical site infections:

- *Streptococcus pyogenes* (ATCC 19615)
- *Staphylococcus aureus* (ATCC 6538)
- *Escherichia coli* (ATCC 25922)

Pure cultures were grown in Tryptic Soy Broth and adjusted to a 0.5 McFarland standard (approximately 1.5×10^8 CFU/mL).

Preparation of Agar Plates

Sterile Mueller–Hinton Agar (MHA) plates were inoculated with the standardized bacterial suspension using sterile cotton swabs to produce a uniform bacterial lawn. The inoculated plates were allowed to dry briefly before suture placement.

Placement of Suture Segments

Control and AgNP-coated suture segments were aseptically placed on the inoculated MHA plates using sterile forceps, ensuring adequate spacing between samples. Separate plates were prepared for each bacterial strain.

Incubation Procedure

The plates were incubated aerobically at 37°C for 24 hours. This allowed bacterial growth and diffusion of silver ions from the coated sutures into the surrounding agar.

Assessment of Antimicrobial Activity

Following incubation, antimicrobial activity was assessed by measuring the Zone of Inhibition (ZOI) around each suture using a digital Vernier caliper. Larger inhibition zones indicated greater antimicrobial efficacy. Each experiment was performed in triplicate to ensure reproducibility.

Fig. 1. Measurement of the Zone of Inhibition using a digital Vernier caliper

Serial Transfer Method

Sustained antimicrobial activity was evaluated using a 14-day serial transfer method. The same AgNP-coated suture segments were transferred aseptically every 48 hours onto freshly inoculated MHA plates containing standardized cultures of *S. pyogenes*, *S. aureus*, and *E. coli*. After each transfer, plates were incubated at 37°C for 24 hours, and the Zone of Inhibition was measured. Progressive reduction in the ZOI indicated gradual depletion of antimicrobial activity. Strict aseptic techniques were maintained throughout the experiment to prevent contamination and ensure reliability.

Results

The antimicrobial efficacy of silver nanoparticle (AgNP)-coated silk sutures was evaluated against Streptococcus pyogenes, Staphylococcus aureus, and Escherichia coli using a modified Kirby–Bauer disc diffusion method. The results demonstrated a marked difference between the antimicrobial activities of uncoated and AgNP-coated silk sutures.

Statistical analysis demonstrated significantly greater antimicrobial activity for AgNP-coated sutures than for uncoated silk sutures against all tested bacterial strains (Welch's t-test, $p < 0.001$). The uncoated sutures showed no measurable antimicrobial activity, whereas AgNP-coated sutures produced mean zones of inhibition of 12.4 ± 0.5 mm against

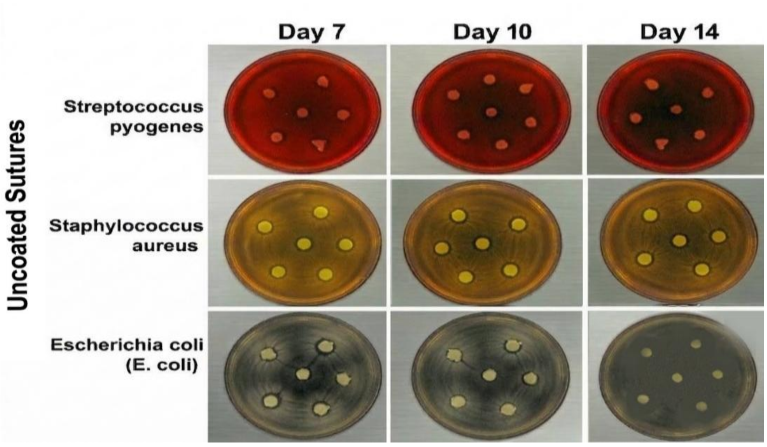
Streptococcus pyogenes, 10.8 ± 0.3 mm against *Staphylococcus aureus*, and 14.2 ± 0.7 mm against *Escherichia coli*. One-way ANOVA demonstrated a significant decline in antimicrobial activity over the 14-day study period; however, measurable inhibition zones persisted until Day 14, indicating sustained antimicrobial efficacy.

The uncoated silk sutures showed no detectable antimicrobial activity against any of the tested bacterial strains, with a Zone of Inhibition (ZOI) of 0 mm in all samples. Bacterial growth extended directly to the edge of the suture material, indicating the absence of inhibitory effects. These findings confirm that conventional silk sutures lack inherent antimicrobial properties. Furthermore, owing to their braided protein-based structure, silk sutures may facilitate bacterial adherence and "wicking," thereby increasing the potential risk of surgical site infections (SSIs).

Table 1. Experimental Results

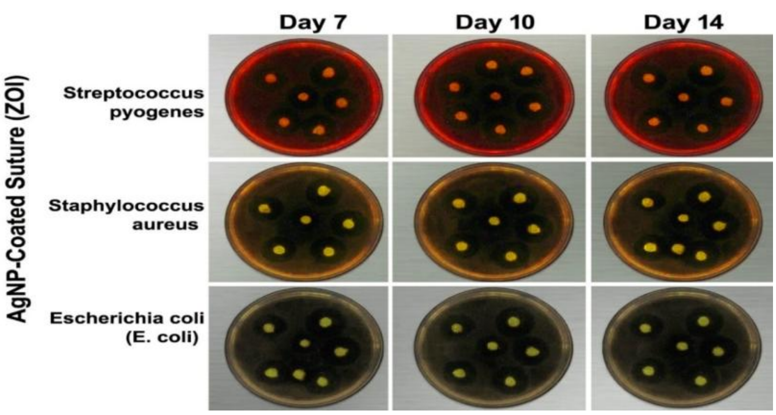
Day	Suture type	*S. pyogenes*	*S. aureus*	*E. coli*
Day 7	AgNP-Coated	12.4 ± 0.5 mm	10.8 ± 0.3 mm	14.2 ± 0.7 mm
	Uncoated Silk	0 mm	0 mm	0 mm
Day 10	AgNP-Coated	11.1 mm	9.2 mm	12.5 mm
	Uncoated Silk	0 mm	0 mm	0 mm
Day 14	AgNP-Coated	8.5 mm	6.4 mm	9.8 mm
	Uncoated Silk	0 mm	0 mm	0 mm

Fig 2 Picture demonstrating zone of inhibition of uncoated silk sutures



AgNP-coated silk sutures demonstrated significant antimicrobial activity against all tested microorganisms by producing distinct zones of inhibition, primarily through the sustained release of silver ions (Ag^+), which disrupt bacterial cell membranes and induce bacterial cell death.

Fig 3 Picture demonstrating zone of inhibition of silver nanoparticle coated silk sutures



Among the tested microorganisms, *Escherichia coli* showed the greatest susceptibility to AgNP-coated sutures (14.2 ± 0.7 mm), followed by *Streptococcus pyogenes* (12.4 ± 0.5 mm) and *Staphylococcus aureus* (10.8 ± 0.3 mm). The greater antimicrobial activity against *E. coli* may be attributed to its thinner cell wall, which facilitates silver ion penetration, whereas the thicker peptidoglycan layer of *S. aureus* may reduce silver ion diffusion and susceptibility.

Fig 4: Bar graph showing the antimicrobial activity of AgNP-coated and uncoated silk sutures. AgNP-coated sutures produced significant zones of inhibition against all tested microorganisms, with E. coli showing the greatest susceptibility, followed by S. pyogenes and S. aureus.

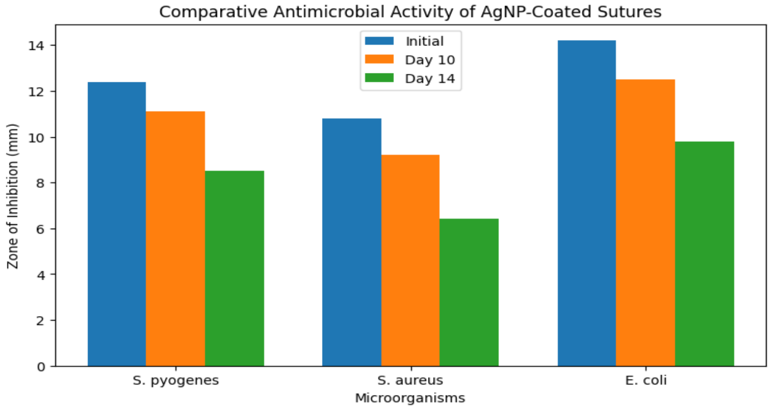


Table 2 Intergroup Comparison (Uncoated Silk vs AgNP-Coated Suture)

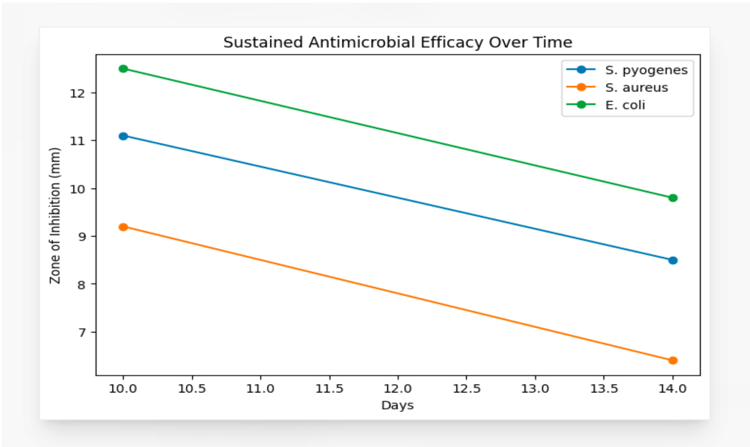
Bacterial Strain	Uncoated Silk (Mean ± SD)	AgNP-Coated Suture (Mean ± SD)	Mean Difference	p-value*	Significance
Streptococcus pyogenes	0.0 ± 0.0	12.4 ± 0.5	12.4	<0.001	Highly Significant
Staphylococcus aureus	0.0 ± 0.0	10.8 ± 0.3	10.8	<0.001	Highly Significant
Escherichia coli	0.0 ± 0.0	14.2 ± 0.7	14.2	<0.001	Highly Significant

Approximate p-values were calculated from the reported mean ± SD, assuming n = 3 per group.

Table 3: Intragroup Comparison within AgNP-Coated Suture Group

Comparison	Mean Difference (mm)	Interpretation
E. coli vs S. pyogenes	1.8	E. coli showed greater inhibition
E. coli vs S. aureus	3.4	E. coli showed greatest inhibition
S. pyogenes vs S. aureus	1.6	S. pyogenes showed greater inhibition

Fig 5: The line graph shows a gradual decrease in the antimicrobial activity of AgNP-coated sutures from Day 10 to Day 14. Despite this reduction, sustained antibacterial efficacy was maintained throughout the study period against all the tested organisms.



Overall, the findings indicate that coating silk sutures with silver nanoparticles significantly enhances their antimicrobial properties and may contribute to reducing bacterial colonization and postoperative wound infection.

Discussion

In this study, the prolonged antimicrobial efficacy of silver nanoparticle (AgNP)-coated silk sutures was evaluated against Streptococcus pyogenes, Staphylococcus aureus, and Escherichia coli over a 14-day period using a modified Kirby–Bauer disc diffusion method. The results demonstrated that AgNP-coated sutures exhibited significant antimicrobial activity throughout the experimental period, whereas uncoated silk sutures showed no measurable zones of inhibition. The antimicrobial effect was greatest against E. coli, followed by S. pyogenes and S. aureus, respectively. Although the zones of inhibition decreased slightly from day 10 to day 14, sustained antibacterial activity was still observed, indicating a prolonged release of silver ions from the coated sutures.

De Simone et al. and Gallo et al. similarly demonstrated the successful coating of silk and polyglactin 910 sutures with silver through a photochemical silver reduction process (De Simone et al., 2014; Gallo et al., 2016). Ravindra et al. demonstrated that AgNP-impregnated cotton fibers exhibited improved mechanical strength due to interactions with cellulose hydroxyl groups (Ravindra S, Murali Mohan Y et al., 2010). AgNPs exert antimicrobial effects by generating reactive oxygen species, disrupting cell membranes, interfering with proteins, and inhibiting DNA replication (Ramani SA, Senthil SU et al.,2023, Patil MP and Kim GD 2017, Patra JK and Baek KH 2016, Manivasagan P, Venkatesan J et al.,2014). Zhang et al. and Baygar et al. demonstrated that silk sutures coated with silver nanoparticles exhibited potent antimicrobial activity against Candida albicans, Escherichia coli, and Staphylococcus aureus, findings that are consistent with the present study (Zhang S, Liu X et al., 2014; Baygar T, Sarac N et al., 2019). Similarly, Ghafoor et al. reported that biodegradable polymeric films containing natural antimicrobial compounds effectively inhibited the growth of Escherichia coli and Pseudomonas aeruginosa (Ghafoor B, Ali MN et al 2016)

In periodontal and oral surgical procedures, where sutures remain exposed to a highly contaminated oral environment, AgNP-coated sutures may help minimize postoperative infections, reduce inflammation, and improve wound healing. However, because this was an in vitro study, the results may not fully replicate the complex conditions of the oral cavity. Further in vivo and clinical studies are necessary to evaluate the long-term biocompatibility, safety, and effectiveness of AgNP-coated sutures in routine periodontal and implant surgeries.

Limitations

The present in vitro study could not completely simulate the complex oral environment, including saliva, blood contamination, host immune response, and polymicrobial biofilm interaction. In addition, the study evaluated only a limited number of bacterial strains and focused primarily on antimicrobial efficacy without assessing the cytotoxicity, mechanical properties, and clinical performance of AgNP-coated sutures.

Conclusion

The integration of silver nanoparticles transforms a passive mechanical device (i.e., silk) into an active antimicrobial barrier. While uncoated silk provides a scaffold for bacterial colonization, AgNP-coated sutures actively create a "sterile zone" around the wound closure site, potentially reducing the microbial load of both Gram-positive and Gram-negative bacteria.

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