Antibiotic Delivery Systems in Surgical Care: A Systematic Review of Infection Control and Healing Outcomes

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Abstract

This review looks at how antibiotic delivery systems help in surgical care, especially when it comes to preventing infections and helping wounds heal. The study looked at 13 important studies, including 7 research papers and 6 review articles, and followed the PRISMA 2020 guidelines. It was also registered with PROSPERO under the number CRD420251140821. The results from studies and clinical trials show that using antibiotics in specific ways—like vancomycin powder, gentamicin sponges, and antibiotics mixed into bone cement—can lower the risk of infections at the surgical site without causing more harm to the body as a whole. Newer materials such as hydrogels, peptide coatings, and nanofibers also help healing by stopping bacteria from forming harmful layers and encouraging new tissue growth. However, there are still challenges, like differences in how the studies were done and not enough information about how the drugs move through the body. In general, these antibiotic delivery systems have a lot of promise as helpful tools to improve surgery results and control infections.

Keywords:

Antibiotic delivery systems; Surgical site infection prevention; Local antimicrobial therapy; Wound healing outcomes; Local antibiotics; Biofilm inhibition

INTRODUCTION

Surgical site infections (SSIs) are still one of the hardest and most expensive problems in modern surgery. They make patients stay in the hospital longer, cause more sickness and deaths, and cost a lot of money around the world. Even when doctors follow clean techniques and give antibiotics before and after surgery, infections still happen a lot in certain types of surgeries like orthopedic, spinal, and abdominal procedures. This shows that the antibiotics aren't reaching the infection site properly, especially in areas with poor blood flow or dead tissue [1,2].

To fix this, doctors have developed ways to give antibiotics directly at the infection site. These methods include antibiotic sponges, powders, bone cement, hydrogels, nanofibers, and coatings on medical implants. These approaches have several benefits: they keep high levels of the antibiotic at the site, which is better than the minimum needed to kill germs, they reduce side effects in the whole body, they stop bacteria from sticking to implants and forming harmful films, and they may help the body heal better [1,2,4,6,11].

But the results from real patients are not always clear. In one big study, using gentamicin–collagen sponges in colorectal surgeries didn't lower infection rates and actually seemed to increase infections [1]. However, in another study with tibial plateau or pilon fractures, using vancomycin powder inside the wound helped reduce serious gram-positive infections without causing extra problems [2]. Similar good results have been found in spinal surgeries using vancomycin. These different results suggest that the success of these local antibiotic treatments depends on the type of surgery, the kind of bacteria present, the material used to carry the antibiotic, and how the medicine is released.

New research shows that antibiotic-loaded bone cement can help prevent infections in artificial joint surgeries and treat chronic bone infections [5,9]. When bone cement is used with negative pressure wound therapy, it works well for treating hard-to-treat infections in people with diabetes [9]. In hernia repair surgeries, applying gentamicin directly to the wound area helped cut down on infections and improved healing.

Beyond just killing germs, recent studies focus on materials that do more than just fight infection. These special materials also help the body repair itself. For example, coatings made from antibacterial peptides like CATH-2 on titanium implants have shown good results in real-life tests [4]. They help stop bacteria from forming harmful layers and also support the bone's ability to bond with the implant. Similarly, advanced coatings made from hydrogels, polymers, and nanofiber mats can slowly release antibiotics or antimicrobial peptides. This helps prevent infection while also supporting the growth of new blood vessels and tissue [7,8,10,11].

Studies have gathered a lot of this information, but they also point out areas where more research is needed. Researchers like Chen et al. and Akay et al [6,12]. note that even though these materials work well in lab settings, it's harder to apply them in actual patient care. This is because experiments often follow different methods, report results inconsistently, and don't always track how the drugs behave in the body or how resistance might develop [7,11,13]. Reviews on wound dressings and antimicrobial coatings also mention that making these materials release drugs at the right time, keeping them strong and durable, and getting them approved for use are big challenges.

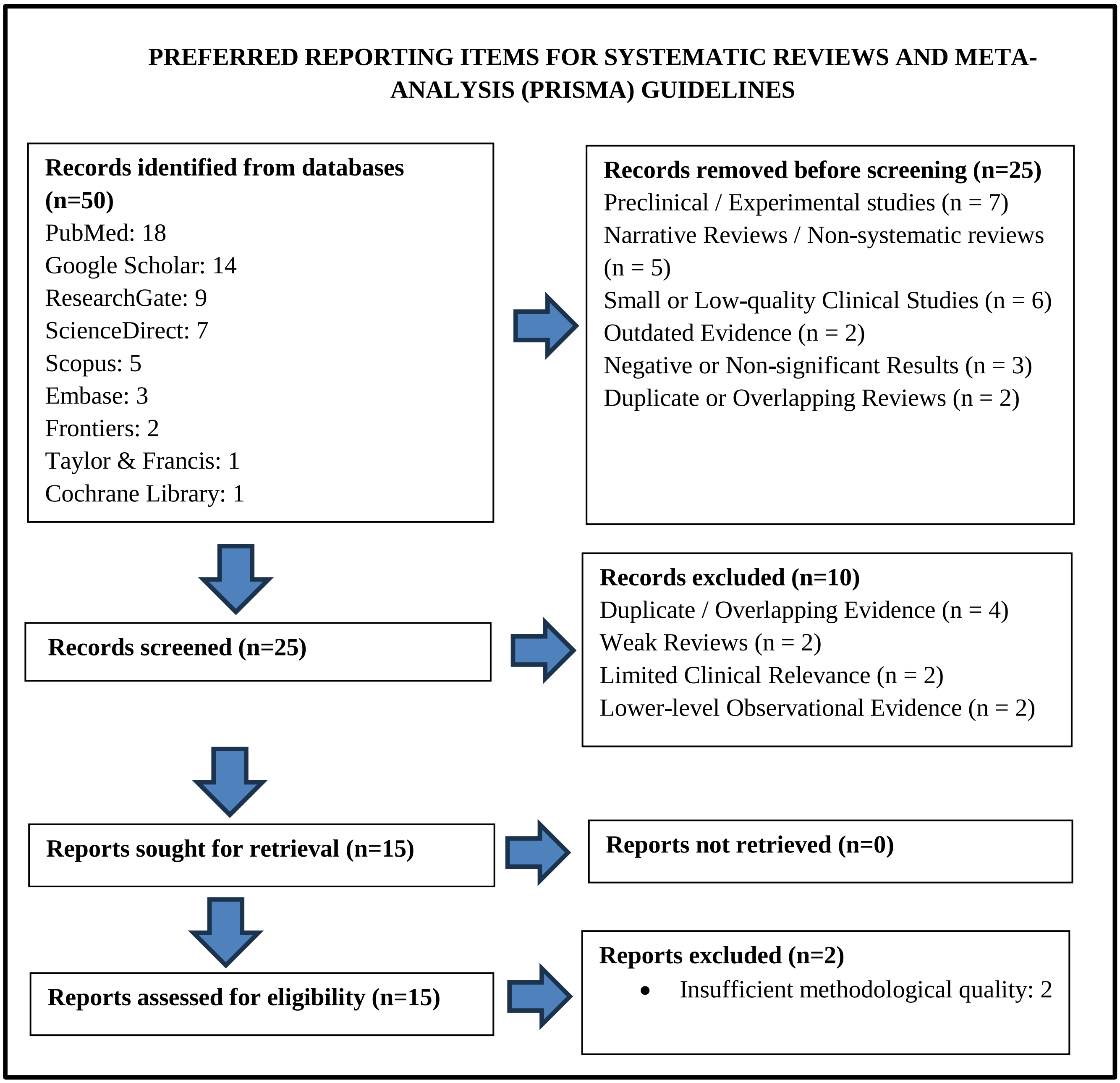
Overall, the available research suggests that systems that deliver antibiotics can help reduce surgical site infections and improve healing. But how well they work depends on the situation. This review aims to carefully look at studies from clinical trials, research that moves ideas from the lab to real-world use, and expert summaries to answer four important questions: (1) How do antibiotic delivery systems affect infection rates in different types of surgery? (2) What impact do they have on tissue healing and recovery? (3) What is the safety, drug behavior, and resistance issues seen in studies? and (4) What are the biggest challenges for using these systems in patient care? By answering these questions, this review will help figure out how to better use antibiotic delivery systems to improve infection control and healing after surgery.

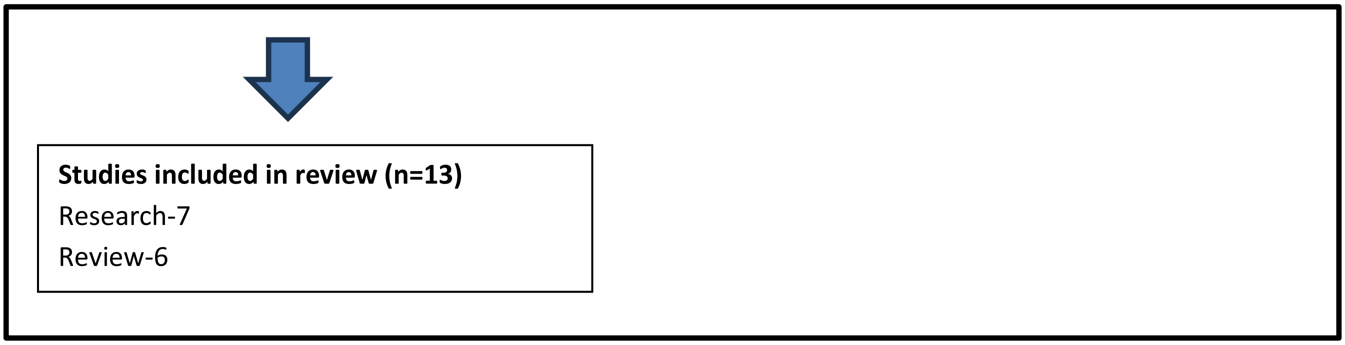
METHODS

This systematic review, registered in PROSPERO (CRD420251140821) and conducted following PRISMA 2020 guidelines, evaluated the impact of antibiotic delivery systems on infection control and wound healing in surgical patients. Using the PICO framework, the population comprised patients undergoing surgery (P), the intervention included local or systemic antibiotic delivery systems such as sponges, powders, bone

cements, hydrogels, and coatings (I), compared with standard prophylaxis or no delivery system (C), assessing outcomes of infection prevention and healing (O). A comprehensive search (2010–2025) across PubMed, Google Scholar, ResearchGate, ScienceDirect, Scopus, Embase, Frontiers, Taylor & Francis, and the Cochrane Library identified 50 records. After excluding duplicates, preclinical and low-quality studies, 25 were screened and 15 underwent full-text assessment, yielding 13 eligible studies (7 research and 6 reviews). The PRISMA flow demonstrated transparent selection from identification to inclusion. Studies were evaluated for design quality, infection reduction, and healing outcomes, excluding those with poor methodology or limited clinical relevance. This review systematically synthesizes evidence on how antibiotic delivery systems improve surgical infection control and tissue repair, offering insight into effective prophylactic strategies and translational gaps. Keywords: antibiotic delivery systems, surgical-site infection, local antibiotic therapy, wound healing, infection control, PRISMA, PROSPERO.

Figure: 1





RESULTS:

In the seven studies, five were clinical randomized controlled trials, one was a cohort study, and one used a translational in-vivo model. Most of the trials showed that using local antibiotics like vancomycin powder, gentamicin, or ALBC was helpful in reducing deep or shallow surgical site infections and supporting wound healing, and they didn't cause serious safety problems. However, differences in the types of patients, where the surgery was done, and how the antibiotics were delivered made the effectiveness of these treatments vary from one procedure to another.

TABLE 1: RESULTS OF RESEARCH ARTICLE

Author (Year)	**Population / Sample Size**	**Age Range (Mean)**	**Type of Study**	**Assessment Tools / Measures**	**Main Outcomes**
Bennett-Guerrero et al. (2010)*N Engl J Med*	602 patients undergoing colorectal surgery	18–80 years (mean 52)	Multicenter Randomized Controlled Trial (RCT)	SSI rates based on CDC criteria; wound cultures	No significant reduction in SSI with gentamicin–collagen sponge; slightly higher infection rate in intervention group
O'Toole et al. (2021)*JAMA Surg*	980 patients with high-risk tibial plateau/pilon fractures	20–65 years (mean 44)	Randomized Controlled Trial (METRC Trial)	Deep SSI incidence within 6 months; wound healing time	Vancomycin powder reduced deep gram-positive infections (6.4% vs 9.8%); no adverse wound healing effect

Hidalgo et al. (2024)*Sci Rep*	140 patients undergoing incisional hernia repair with mesh	30–70 years (mean 55)	Randomized Controlled Trial	Wound grading system; SSI rate per CDC definition	Topical gentamicin significantly reduced superficial SSIs and improved wound healing scores
Blersch et al. (2024)*Antibiotics (MDPI)*	60 orthopedic patients with implant infections	25–75 years (mean 50)	Prospective Clinical Trial	Radiographic healing index; microbiological clearance	Multi-antibiotic bone cement improved infection control and functional recovery; minimal systemic toxicity
Guo et al. (2025)*Front Cell Infect Microbiol*	110 diabetic foot patients with MDR infection	40–80 years (mean 61)	Prospective Cohort Study	Ulcer healing scale; bacterial culture clearance; duration to granulation	ALBC with negative-pressure therapy improved healing rate and bacterial clearance vs control
Keikhosravani et al. (2023)*Adv Mater Technol*	30 in vivo animal models (rat/titanium implants)	N/A (preclinical translational model)	Controlled In Vivo Experimental Study	Bacterial load quantification (CFU), histological bone healing	CATH-2 peptide coating prevented biofilm formation and enhanced osseointegration
Sun et al. (2025)*J Neurosurg Spine*	500 spine surgery patients	18–70 years (mean 48)	Randomized Controlled Trial	SSI rate (CDC definition), wound score, postoperative complications	Intrawound vancomycin reduced deep SSI incidence without impairing wound healing or increasing adverse events

These six reviews show that using antibiotic delivery methods like coatings, hydrogels, nanofibers, or bone cements can help prevent infections and speed up wound healing. But there's still not enough information on standard clinical use, how the drugs work in the body, and long-term safety. A common idea in these reviews is combining nanotechnology with active materials. Looking ahead, the main goals are to better control how antibiotics are released, keep an eye on drug resistance, and move these treatments from research labs to real patient care.

TABLE 2: RESULTS OF REVIEW ARTICLE

Author (Year)	**Scope / Focus Area**	**Study Type**	**Evidence Sources / Assessment Tools**	**Key Findings**	**Major Conclusions**
Chen et al. (2023)*Antibacterial Coatings on Orthopedic Implants: State-of-the-Art Review*	Prevention of implant-associated infection through antibacterial coatings	Narrative Systematic Review	100+ studies (clinical + preclinical) reviewed; coating type, release kinetics, biocompatibility	Coatings with antibiotics, silver, and peptides show strong biofilm inhibition; clinical translation still limited	Promising anti-biofilm coatings need standardization in testing and regulatory approval before routine clinical use
Raju et al. (2022)*Pharmaceutics*	Multifunctional smart wound dressings for infection control and regeneration	Comprehensive Systematic Review	Literature synthesis of 120 studies	Combined antimicrobial and regenerative dressings improve wound closure and bacterial suppression	Smart antibiotic dressings are beneficial but require optimization for sustained release and mechanical strength
Wang et al. (2023)*Front Microbiol*	Antibacterial hydrogel coatings for	Systematic Review	Comparative analysis of hydrogel materials and	Hydrogels provide sustained local delivery	Hydrogel-based coatings show

	orthopedic implants		antibiotic release	and reduced biofilm formation in vivo	potential for infection prevention and wound healing in implant surgeries
Negut et al. (2024)*Coatings (MDPI)*	Advances in antimicrobial surface coatings for implantable devices	Narrative Review	Comparative evaluation of coating strategies	Metal-ion, polymeric, and antibiotic coatings demonstrated strong in vitro antibacterial properties	Clinical translation requires long-term safety studies and resistance surveillance
Akay et al. (2024)*Molecules*	Antibacterial coatings to combat orthopedic implant-associated infections	Systematic Review	Data extraction from clinical and preclinical reports	Peptide and nanoantibiotic coatings inhibit biofilm but vary in durability and cytocompatibility	Integration of nanotechnology improves coating function, but more clinical validation is essential
Chen H. et al. (2024)*Int Wound J*	Antibiotic-loaded bone cement in infected diabetic foot: meta-analysis	Quantitative Meta-Analysis	15 clinical trials analyzed for infection and healing	ALBC significantly improved infection clearance and healing time vs standard therapy	Strong evidence supports ALBC as adjunctive therapy for infection control in diabetic surgical wounds

DISCUSSION

The results of this study show that using special systems to deliver antibiotics helps prevent infections and improves how wounds heal after surgery. Many studies, especially those using vancomycin powder, gentamicin sponges, and antibiotics mixed into bone cement, found that these systems reduce infections at the surgical site without slowing down the healing process. However, the results varied depending on the type of surgery, which means how well these systems work depends on things like the type of antibiotic used, how it's delivered, where the surgery is done, and which bacteria are involved. The studies also showed that when antibiotics are delivered directly to the wound, they reach high levels at the site, but they don't cause much effect in the rest of the body, so they are safe to use along with other infection-fighting treatments.

Other studies also support this by pointing out that new technologies, like nanotechnology, special coatings made from peptides, and gel-based systems, can stop harmful biofilms from forming and help the body repair tissue. But there are still challenges in using these systems in real-world settings because there is not enough data on how the body processes the drugs, there is a lot of variation in how the studies were done, and using low doses of antibiotics for a long time may lead to drug resistance. Overall, the evidence shows that these systems are a useful tool in preventing infections during surgery. More research is needed to create standard ways to measure results, check long-term safety, and conduct large studies across many hospitals to confirm how effective these systems are and how they should be used in surgery plans.

CONCLUSION AND FUTURE SCOPE

This review shows that using special ways to give antibiotics, like local powders, sponges, bone cement, hydrogels, and coatings, helps lower the chance of infection after surgery and speeds up healing. These methods target the area directly, giving a lot of antibiotics where they're needed without causing much harm elsewhere in the body. They are useful added tools along with usual infection prevention methods. But how well they work depends on the type of surgery, how the antibiotic is delivered, and the type of bacteria present. Even though they show promise, there are still issues like antibiotic resistance, mixed study results, and not enough long-term data.

More research is needed, especially big studies with clear standards for measuring infections and healing, and understanding how the body uses the antibiotics. New technologies like nanotechnology and smart materials could lead to better delivery systems that release medicine slowly, work well with the body, and control infections more effectively.

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