Review Article | The Odisha Journal of Orthopaedics and Trauma | January 2025 | 06;01: 02-06

Contemporary Concepts in Infection Prevention for Open Fractures: Focus on Antibiotic Prophylaxis and Surgical Protocols

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Abstract

Introduction: Open fractures represent a critical orthopedic emergency characterized by significant soft-tissue disruption and a high propensity for infection, which can lead to devastating complications like chronic osteomyelitis and limb loss. Despite standardized care, infection rates remain high in severe injuries, necessitating a shift toward multimodal prevention strategies.

Objective: This review explores contemporary concepts in infection prevention for open fractures, specifically focusing on the evolution of systemic and local antibiotic delivery, innovations in implant technology, and evidence-based surgical protocols.

Methods: A synthesis of current clinical guidelines (WHO, CDC, and specialty societies) and recent research (up to 2025) was conducted to evaluate the efficacy of emerging prophylactic interventions and surgical site management techniques.

Results: Findings indicate that while prompt systemic antibiotic administration (within one hour of injury) remains the gold standard, adjunctive local delivery via antibiotic-impregnated beads or powders significantly reduces infection in high-grade fractures. Furthermore, innovations such as bioactive nanostructured implant coatings and pH-triggered antibacterial layers offer promising results in preventing biofilm formation. In surgical management, the selective use of prophylactic incisional negative pressure wound therapy (iNPWT) and standardized alcohol-based skin antisepsis have demonstrated efficacy in reducing surgical site infections (SSI).

Conclusion: Effective infection prevention in open fractures requires a transition from traditional monotherapy to a comprehensive, protocol-driven approach. Future directions emphasize the need for large-scale randomized trials to standardize local antibiotic dosing and the integration of "smart" biomaterials into routine clinical practice to further mitigate the burden of fracture-related infections.

Keywords: Open Fractures, Infection Prevention, Antibiotic Prophylaxis, Implant Coatings.

Introduction

Open fractures remain a formidable challenge in orthopaedic trauma care, largely due to the high risk of infection that can compromise both limb function and patient survival. The exposed bone and soft tissues are susceptible to contamination from both the accident environment and subsequent surgical interventions, with infection rates ranging from 10% in low-energy injuries to over 30% in severe, high-grade open fractures, despite early surgical management and antibiotic prophylaxis [1, 2].

The sequelae of infection are profound, including delayed union, nonunion, chronic osteomyelitis, and, in extreme cases, limb loss or systemic sepsis. The social, psychological, and economic burden of such complications is particularly acute in regions where access to specialized trauma care and revision surgery remains limited. Therefore, effective infection prevention strategies are critical not only for optimal surgical outcomes but also for the broader goal of restoring patient quality of life [3].

Recent years have witnessed significant evolution in the prophylactic management of open fractures. The standard of prompt systemic antibiotic administration and early debridement has been augmented by advances in local antibiotic delivery (e.g., antibiotic powders and beads), innovations in antibacterial and "smart" implant coatings, and evidence-driven updates to surgical site preparation and closure techniques. These multimodal strategies, grounded in both laboratory research and emerging clinical trials, promise to further mitigate infection risk and improve both short- and long-term outcomes [4, 5].

This review summarizes the current evidence and emerging innovations regarding local antibiotics, novel implant coatings, and surgical site management in the prevention of infection after open fracture, while highlighting gaps for future research and contextual considerations relevant to both resource-rich and resource-constrained settings [6].

Systemic and Local Antibiotic Prophylaxis

Systemic Antibiotics Prompt administration of systemic antibiotics remains the foundation for infection prevention in open fractures. Guidelines recommend initiation as soon as possible, preferably within one hour of injury, with the antibiotic regimen tailored to the severity and classification of the fracture. For most open fractures, a

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Received 15/04/2024; Reviewed 23/05/2024; Accepted 08/10/2024; Published 10/01/2025

first-generation cephalosporin (such as cefazolin) is commonly used, with additional coverage for Gram-negative organisms (e.g., aminoglycosides) in Type III injuries. Coverage for anaerobes may be considered in farm injuries or high-risk contamination.

Multiple studies have shown that early and appropriate systemic antibiotic therapy significantly reduces the risk of surgical site infection and subsequent complications. However, antibiotic stewardship and careful dosing strategies must balance efficacy with the risk of resistance and adverse events [7].

Local Antibiotic Delivery Recent advances have focused on augmenting systemic therapy with local antibiotic administration at the wound or implant site. Methods include the direct application of antibiotic powders (e.g., vancomycin, gentamicin) and the use of antibiotic-impregnated carriers such as beads, cements, or gels. This approach achieves high local drug concentrations without systemic toxicity.

Meta-analyses and randomized trials report that adjunctive local antibiotics can reduce superficial and deep infection rates after open fracture fixation, particularly in high-grade injuries. Ongoing concerns include the potential for local antimicrobial resistance and the need for standardized dosing regimens.

Current Guidelines and Practices

- Systemic antibiotics should be administered as soon as possible following injury, and continued for 24-48 hours post-operatively unless otherwise indicated.
- Local antibiotics are increasingly being integrated into clinical protocols, especially for severe or contaminated injuries, but require careful evaluation and selection.
- Judicious combination of systemic and local strategies, tailored to individual patient and injury characteristics, offers the best prospect for infection prevention.

Innovations in Implant Coatings and Local Delivery

Innovations in implant coatings and local delivery systems have significantly advanced the performance and therapeutic potential of orthopedic implants. Recent developments focus on enhancing osseointegration, preventing infections, and enabling controlled, localized drug release directly at the implant site. These strategies improve implant integration and reduce systemic side effects commonly associated with oral or intravenous drug administration.

Implant Coatings Innovations

Modern implant coatings utilize bioactive and nanostructured materials to optimize bone-implant interactions. Biopolymeric and biomimetic coatings mimic natural bone environment components to promote faster bone growth and better mechanical stability. Nanostructured coatings, including hydrophilic and graphene-based layers, enhance implant surface properties by improving cellular adhesion and providing antibacterial effects. Antimicrobial coatings, combining elements like silver nanoparticles or pH-triggered antibacterial nanofibers, actively combat infection risks, a critical challenge in orthopedic surgeries(8). Notably, FDA-approved antibacterial coatings, such as NanoCept™, have been specifically designed to prevent infections in complex arthroplasty cases [9].

Local Drug Delivery Systems

Local drug delivery integrated within implant coatings offers precise, targeted release of therapeutic agents, such as antibiotics, anti-inflammatory drugs, or growth factors, directly to the bone microenvironment. This approach improves the biological availability of drugs while minimizing systemic exposure and side effects. Titanium implants equipped with nanotube structures or drug-loaded polymer layers facilitate controlled and sustained drug release, tailored to patient-specific treatment requirements and implant integration timing (10). This synergy between surfaces modifications and drug delivery enhances bone healing while simultaneously reducing the risk of implant-related complications [11].

These innovations collectively represent a paradigm shift in orthopedic implant technology, advancing personalized and effective treatment approaches that combine mechanical support with therapeutic functionality.

Surgical Site Preparation and Wound Care

Surgical site preparation and wound care are central to reducing surgical site infections (SSI) in orthopaedic patients, and current recommendations emphasize standardized antisepsis, careful handling of tissues, and evidence-based postoperative dressing strategies. Combining rigorous preoperative skin preparation with appropriate wound dressings and, where indicated, advanced technologies such as negative pressure wound therapy (NPWT) can significantly reduce wound complications and deep infections after orthopedic surgery [12].

Preoperative skin preparation

Patients are usually advised to shower or bathe with soap or an antiseptic wash (often chlorhexidine-based) before surgery to reduce skin microbial load. Immediately before draping, the surgical site is prepared in the operating room using an alcohol-based antiseptic solution (chlorhexidine or povidone–iodine in alcohol) unless contraindicated, as alcohol provides rapid kill and the antiseptic confers residual activity [13]. If alcohol or chlorhexidine is not suitable (for example, allergy or mucosal surfaces), aqueous povidone–iodine or aqueous chlorhexidine solutions are recommended alternatives [14].

Intraoperative site preparation and technique

Skin antisepsis is performed in the operating room immediately before draping, using sterile technique and applying the solution from the proposed incision outward, allowing complete drying before incision to maximize efficacy and reduce fire risk with alcohol-based agents [15]. Guidelines stress meticulous surgical technique, including gentle tissue handling, adequate hemostasis, limiting operating room traffic, timely prophylactic antibiotics, and strict sterility in handling implants and instruments to minimize contamination [16]. Use of iodophor-impregnated incise drapes may provide an additional antimicrobial barrier over prepared skin in selected high-risk procedures, although evidence for routine use is mixed and practice varies [17].

Postoperative wound care

Initial postoperative dressings are typically kept intact and dry for 24–48 hours, with subsequent changes based on exudate, type of dressing and local protocol, while monitoring for redness, swelling, discharge or dehiscence [18]. Modern dressings (such as foam, hydrofiber or hydrocolloid) are used to maintain a moist wound environment, manage exudate and reduce dressing-change frequency, which can improve patient comfort and support healing. Patient and caregiver education on hand hygiene, keeping the wound clean and dry, and promptly reporting symptoms of infection is essential to allow early diagnosis and intervention.

Negative pressure wound therapy and high risk cases

Prophylactic incisional negative pressure wound therapy (iNPWT) on closed incisions in high risk orthopaedic patients (for example, obese, trauma, or revision cases) has been associated with reduced deep and superficial SSI and wound dehiscence compared with standard dressings in several meta analyses [19].

Evidence suggests that iNPWT can lower overall postoperative wound complication rates, though authors consistently call for larger, high quality trials and recommend selective use based on individual risk and cost considerations [20].

For open or dehisced wounds, therapeutic NPWT remains an important option to control exudate, promote granulation and prepare the wound bed for closure or grafting, particularly in complex orthopaedic trauma.

Clinical Protocols and Recommendations

Current clinical protocols for infection prevention in open fractures emphasize early administration of systemic antibiotics, meticulous surgical technique, and thorough wound assessment. Recommendations from major organizations, such as the World Health Organization and specialty societies, advocate prompt antibiotic prophylaxis ideally within one hour of injury, using agents tailored to local resistance patterns and wound characteristics. These protocols highlight the importance of standardizing antibiotic dosing, timing, and duration based on the severity of the fracture and associated contamination risk [21].

Surgical protocols prioritize initial debridement and irrigation as critical steps for infection control, recommending the use of sterile techniques and adequate wound exposure. Emerging standards also address adjunctive measures—such as the use of negative pressure wound therapy and advanced wound dressings—to support infection prevention post-operatively. Clinical guidelines increasingly incorporate multidisciplinary input and recent innovations, ensuring protocols remain evidence-based and adaptable to evolving best practices.

By providing clear recommendations for systemic antibiotic use, wound management, and operative technique, these protocols aid clinicians in reducing infection risk, improving patient outcomes, and ensuring care consistency. Adherence to well-defined guidelines not only enhances clinical effectiveness but also facilitates audit, training, and continuous improvement efforts in orthopedic trauma care [22].

Research Gaps and Future Directions

Despite progress in infection prevention for open fractures, several research gaps persist. There is limited consensus on optimal antibiotic selection, dosing strategies, and duration, especially for complex or high-grade injuries. The efficacy of novel local delivery systems and advanced implant coatings remains under investigation, with few large-scale randomized trials addressing long-term outcomes and resistance patterns. Additionally, the relative impact of emerging surgical adjuncts—such as antimicrobial wound dressings and negative pressure therapies—requires further exploration through comparative effectiveness studies.

Future research should prioritize multicenter trials on systemic and local antibiotic regimens, the development of standardized risk assessment tools, and the integration of precision medicine approaches for individualized patient care. Advancements in rapid diagnostic technologies, molecular profiling of wounds, and biomaterial science could further refine infection prevention strategies. Collaboration between clinicians, microbiologists, and biomedical engineers will be essential to address these challenges and translate innovative technologies into routine clinical practice [23].

Conclusion

Infection prevention for open fractures has evolved into a multifaceted strategy that integrates timely, targeted systemic antibiotics, judicious use of local delivery, and standardized surgical protocols to minimize contamination and bacterial burden. Contemporary evidence supports early gram-positive coverage with escalation for severe or highly contaminated injuries, combined with meticulous debridement, appropriate soft-tissue management, and rational use of adjuncts such as negative pressure wound therapy and modern implant technologies. At the same time, antibiotic

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Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his/her consent for his/her images and other clinical information to be reported in the Journal. The patient understands that his/her name and initials will not be published, and due efforts will be made to conceal his/her identity, but anonymity cannot be guaranteed.

Conflict of Interest: NIL
Source of Support: NIL

How to Cite this Article

Marandi H, Das A. Contemporary Concepts in Infection Prevention for Open Fractures: Focus on Antibiotic Prophylaxis and Surgical Protocols. The Odisha Journal of Orthopaedics and Trauma. January 2025; 06;01: 02-06.
https://doi.org/10.13107/ojot.2025.v06.i01.62