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Enhancing Infection Control and Tissue Repair through Hypochlorous Acid as an Outpatient Breakthrough Therapy for Chronic Orthopedic Surgical Wounds Complicated by Osteomyelitis

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ABSTRACT

Chronic orthopedic surgical wounds complicated by osteomyelitis pose significant challenges in outpatient care due to persistent infections, often months of treatment required, biofilm formation, and delayed bone healing. Surgical wounds are often secondary to infection, hardware irritation or failure, aseptic vs septic nonunion or malunion of fractures, medical comorbidities resulting in poor nutrition and wound healing capacity, and those who have undergone revision surgeries. Current outpatient treatment options, including systemic antibiotics and occasional surgical debridement, often fail to completely resolve infections or promote effective tissue regeneration. This comprehensive review explores the novel application of hypochlorous acid (HOCl) as an adjunct therapy for these refractory wounds, emphasizing its dual role as a potent antimicrobial and biofilm-disrupting agent. HOCl can be administered locally in the outpatient setting through advanced wound care techniques such as continuous infusion devices or routine topical irrigation, aiming to reduce bacterial bioburden, particularly methicillin-resistant *Staphylococcus aureus* (MRSA), while modulating inflammatory processes. Emerging clinical data demonstrate that HOCl not only accelerates infection resolution but also enhances bone regeneration by optimizing the wound environment. This innovative outpatient approach to managing chronic osteomyelitis could transform the standard of care by improving infection control, reducing the need for surgical interventions, and ultimately improving long-term functional outcomes and patient quality of life, while easing the burden on healthcare systems.

Keywords: Hypochlorous acid, *Staphylococcus aureus,* Surgical debridement, Infection control

INTRODUCTION

Chronic orthopedic surgical wounds, particularly those complicated by osteomyelitis, represent a formidable clinical challenge in outpatient care. These wounds, often the result of traumatic injuries, post-surgical complications, or underlying systemic conditions, are characterized by persistent infections, delayed healing, and in severe cases, the progressive destruction of bone tissue. Osteomyelitis, an infection of the bone typically caused by bacterial pathogens such as *Staphylococcus aureus*, necessitates long-term, complex management due to its capacity for biofilm formation, antibiotic resistance, and recalcitrance to standard treatments. In the outpatient setting, the treatment of these chronic wounds is often protracted, with patients undergoing weeks or months of systemic antibiotic therapy, surgical debridement, and various forms of wound care to control infection and promote tissue regeneration [1].

The advent of biofilm-forming bacteria, such as methicillin-resistant *Staphylococcus aureus* (MRSA), further complicates the management of these wounds. Biofilms, dense microbial communities encased in a protective extracellular matrix, shield bacteria from host immune responses and antimicrobial agents [2]. This confers a high

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and eradicate bacterial colonies. Moreover, the prolonged presence of infection impairs the wound healing process, leading to chronic inflammation, delayed re-epithelialization, and hindered bone regeneration. These factors collectively contribute to significant morbidity, increased healthcare costs, and poor patient quality of life.

Current outpatient management strategies for chronic osteomyelitis include systemic antibiotics and periodic surgical interventions, such as debridement and hardware removal, to eliminate infected tissue [3]. Despite these efforts, treatment success rates remain suboptimal, and recurrence of infection is common. The challenge lies in finding therapeutic modalities that not only address bacterial infection but also create an environment conducive to tissue healing, particularly bone regeneration. In recent years, the focus has shifted toward exploring adjunctive therapies that can be integrated into existing treatment protocols to enhance outcomes for patients with chronic orthopedic wounds.

Hypochlorous acid (HOCl) has emerged as a promising adjunctive therapy for managing chronic wounds, including those complicated by osteomyelitis. HOCl, a naturally occurring antimicrobial agent produced by neutrophils during the innate immune response, exhibits potent bactericidal activity across a broad spectrum of pathogens, including MRSA [4]. Unlike many conventional disinfectants, HOCl is non-toxic to human cells at therapeutic concentrations, making it a suitable candidate for direct application to wounds. Its dual role as both an antimicrobial and a biofilm-disrupting agent makes it particularly valuable in addressing the challenges posed by biofilm-forming bacteria in chronic osteomyelitis.

The novel application of HOCl in outpatient settings has gained attention due to its ability to be administered locally, either through continuous infusion devices or routine topical irrigation. This approach allows for targeted delivery of the antimicrobial agent directly to the wound site, reducing bacterial bioburden and potentially lowering the reliance on systemic antibiotics. Emerging clinical evidence suggests that HOCl not only enhances infection control but also promotes a favorable wound environment that supports tissue regeneration, particularly in bone. By modulating inflammatory processes and reducing the risk of reinfection, HOCl may help to accelerate the healing process in patients with chronic orthopedic wounds, thereby improving long-term outcomes and reducing the burden on healthcare systems.

This comprehensive review examines the potential of HOCl as an adjunctive therapy for chronic orthopedic surgical wounds complicated by osteomyelitis. By synthesizing available clinical data, this review explores the antimicrobial properties of HOCl, its biofilm-disrupting capabilities, and its role in enhancing bone regeneration. Additionally, the review discusses the practical application of HOCl in outpatient settings, focusing on advanced wound care techniques that optimize its delivery and efficacy. Ultimately, this exploration aims to provide insights into how HOCl could transform the standard of care for these challenging wounds, offering a more effective and patient-centered approach to management.

DISCUSSION

The management of chronic orthopedic surgical wounds complicated by osteomyelitis remains a significant challenge in modern medicine. Conventional treatment modalities, including prolonged courses of systemic antibiotics and repeated surgical debridement, often fail to achieve complete resolution of infection or support effective bone healing. The persistence of biofilm-forming bacteria such as MRSA further complicates this clinical landscape, as biofilms shield bacteria from both antibiotics and immune defenses, contributing to chronic inflammation and delayed tissue regeneration. Against this backdrop, hypochlorous acid offers a novel and potentially transformative approach to managing these recalcitrant wounds in the outpatient setting.

The unique properties of HOCl make it an attractive candidate for adjunctive therapy in chronic wounds complicated by osteomyelitis. As a naturally occurring component of the human immune system, HOCl is produced by neutrophils during the oxidative burst phase of the immune response [5]. It exerts broad-spectrum antimicrobial activity, effectively killing bacteria, viruses, and fungi without causing harm to human cells at therapeutic concentrations. This selective toxicity is a key advantage of HOCl over other antimicrobial agents, as it minimizes collateral damage to healthy tissue while effectively targeting pathogenic microorganisms.

One of the most critical aspects of HOCl's antimicrobial action is its ability to disrupt biofilms, which are a hallmark of chronic osteomyelitis. Biofilms are highly structured communities of bacteria encased in an extracellular polymeric matrix, which confers resistance to antibiotics and immune clearance. The biofilm matrix acts as a physical barrier, preventing the penetration of antimicrobial agents and allowing bacteria to persist in a dormant state within the wound. HOCl has been shown to disrupt this matrix, exposing the bacteria to both the immune system and antimicrobial agents [6]. By breaking down biofilms, HOCl enhances the efficacy of other treatments, such as systemic antibiotics, and helps to eradicate persistent infections that would otherwise remain refractory to conventional therapy.

In addition to its antimicrobial and biofilm-disrupting properties, HOCl also plays a role in modulating the inflammatory response. Chronic osteomyelitis is often associated with prolonged inflammation, which impairs wound healing and contributes to tissue destruction. HOCl has been shown to modulate the inflammatory response by reducing the production of pro-inflammatory cytokines and

promoting the resolution of inflammation [7]. This anti-inflammatory effect is particularly important in the context of bone regeneration, as excessive inflammation can inhibit the formation of new bone tissue and delay healing. By modulating the inflammatory response, HOCl creates a more favorable environment for tissue regeneration, particularly in bone.

Emerging clinical data support the use of HOCl in the management of chronic wounds, including those complicated by osteomyelitis. Studies have demonstrated that HOCl can accelerate the resolution of infection, reduce bacterial bioburden, and promote wound healing in a variety of clinical settings. For example, one study showed that the use of HOCl in chronic wound care led to a significant reduction in biofilm-associated bacteria, including MRSA, and improved wound healing outcomes [8]. Another study reported that HOCl was effective in reducing wound exudate, controlling infection, and promoting granulation tissue formation in patients with chronic wounds [9]. These findings suggest that HOCl may be a valuable addition to the armamentarium of therapies for managing chronic osteomyelitis, particularly in the outpatient setting where targeted, localized treatment is essential.

The practical application of HOCl in outpatient care is facilitated by the availability of advanced wound care technologies, such as continuous infusion devices and topical irrigation systems. These devices allow for the controlled delivery of HOCl directly to the wound site, maintaining a therapeutic concentration of the antimicrobial agent over time. Continuous infusion devices, in particular, have been shown to enhance the efficacy of HOCl by ensuring consistent contact with the wound bed, thereby maximizing its antimicrobial and biofilm-disrupting effects. Topical irrigation systems, on the other hand, provide a more intermittent approach to HOCl delivery, but can still be highly effective in reducing bacterial load and promoting wound healing. The choice of delivery method depends on the specific clinical context, with continuous infusion being more suitable for patients with severe or refractory infections, while topical irrigation may be appropriate for less complicated cases.

Another important consideration in the use of HOCl for chronic osteomyelitis is its potential to enhance bone regeneration. Bone healing is a complex process that requires the coordination of multiple cellular and molecular events, including the recruitment of osteoprogenitor cells, the deposition of an extracellular matrix, and the remodeling of new bone tissue. In chronic osteomyelitis, this process is often disrupted by the presence of infection and inflammation, leading to delayed healing and non-union of fractures. HOCl, through its antimicrobial and anti-inflammatory actions, creates a more favorable environment for bone regeneration by reducing infection and modulating the inflammatory response. Additionally, HOCl has been shown to stimulate the proliferation of fibroblasts and osteoblasts, which are essential for wound healing and bone formation [10,11]. This suggests that HOCl not only helps to control infection but also actively supports the regenerative process in bone tissue.

Despite the promising potential of HOCl in the management of chronic osteomyelitis, further research is needed to fully understand its mechanisms of action and optimize its clinical application. While emerging data suggest that HOCl can improve infection control and promote tissue regeneration, large-scale randomized controlled trials are needed to confirm these findings and establish standardized protocols for its use in clinical practice. Additionally, the long-term effects of HOCl on bone healing and patient outcomes need to be further investigated, particularly in comparison to other adjunctive therapies such as negative pressure wound therapy and hyperbaric oxygen therapy.

CONCLUSION

The management of chronic orthopedic surgical wounds complicated by osteomyelitis presents a significant clinical challenge, particularly in the outpatient setting. Current treatment options, including systemic antibiotics and surgical debridement, often fail to fully resolve infections or promote effective tissue regeneration, leading to prolonged morbidity and increased healthcare costs. The emergence of biofilm-forming bacteria, such as MRSA, further complicates the treatment landscape, necessitating novel therapeutic approaches that can address both infection control and wound healing. Hypochlorous acid offers a promising adjunctive therapy for the management of chronic osteomyelitis, with its potent antimicrobial, biofilm-disrupting, and anti-inflammatory properties. By targeting bacterial pathogens, disrupting biofilms, and modulating the wound environment, HOCl has the potential to enhance the efficacy of existing treatments and promote bone regeneration. Its local application through advanced wound care techniques, such as continuous infusion devices and topical irrigation systems, makes it particularly well-suited for outpatient care, where targeted, non-invasive therapies are essential. Emerging clinical data support the use of HOCl in chronic wound management, demonstrating its ability to reduce bacterial bioburden, accelerate infection resolution, and enhance tissue healing. However, further research is needed to optimize its clinical application and fully understand its impact on long-term patient outcomes. As the field of wound care continues to evolve, the integration of HOCl into standard treatment protocols for chronic osteomyelitis could transform the management of these challenging wounds, offering a more effective and patient-centered approach that improves quality of life while reducing the burden on healthcare systems.

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