

‘CHG Disinfectants in the Medical Device Industry: A Comprehensive Review of Efficacy, Safety and Regulatory Compliance’

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Abstract

Chlorhexidine Gluconate (CHG) is a synthetic cationic bisbiguanide compound extensively used in healthcare for its broad-spectrum antimicrobial activity. It disrupts microbial cell membranes and provides long-lasting residual action, making it highly effective in both clinical and manufacturing environments. In the context of medical device production, maintaining sterility is critical, as contamination can lead to healthcare-associated infections (HAIs), product recalls, or regulatory non-compliance. This makes CHG especially valuable in cleanroom settings, equipment disinfection, and personnel hygiene protocols. Despite widespread usage, a comprehensive review focused on CHG's specific role in the medical device industry—covering its mechanism, spectrum, material compatibility, regulatory considerations, and emerging resistance issues—is limited. This review fills that gap by evaluating CHG's performance across all stages of device production and highlights its indispensable role in reducing infection risks, ensuring regulatory compliance, and enhancing patient safety.

Keywords:

Antimicrobial resistance, Biofilm management, Sterile manufacturing, Critical environment disinfection, Surface decontamination, Healthcare hygiene, Infection risk mitigation, Bioburden control, Regulatory standards

Introduction

Healthcare-associated infections (HAIs) represent one of the most critical challenges to patient safety worldwide. These infections, often acquired during medical care, significantly increase patient morbidity and mortality, prolong hospital stays, and pose immense financial burdens on healthcare systems. According to WHO estimates, millions of patients are affected by HAIs annually, with a substantial proportion linked to contaminated medical devices such as catheters, surgical instruments, implants, and diagnostic equipment [1]. Because these devices come into direct contact with sterile body sites or the bloodstream, even minimal contamination during manufacturing can lead to severe infections, prolonged recovery, and escalated healthcare costs.

The medical device manufacturing industry is therefore constantly under pressure to maintain aseptic processing and robust contamination control. Stringent regulatory frameworks—including ISO 13485 and the FDA’s Quality System Regulation (QSR)—mandate validated cleaning and disinfection protocols to ensure device sterility before market release. In this context, disinfection plays a central role in minimizing bioburden on surfaces, equipment, and personnel.

Among disinfectants, Chlorhexidine Gluconate (CHG) has become a key component of infection control protocols owing to its broad antimicrobial spectrum, enduring residual activity, and efficacy against biofilms. CHG, a synthetic cationic bisbiguanide compound, binds to negatively charged microbial membranes, disrupts membrane integrity, and leads to cell death. Unlike alcohol-based agents, which evaporate rapidly, CHG adheres to surfaces and skin, offering persistent antimicrobial effects and reducing the risk of microbial recolonization [2,3]. These attributes make CHG particularly well suited for cleanrooms, where maintaining sterility is essential.

Despite its widespread use, there is a lack of comprehensive reviews specifically focused on CHG’s role in the medical device industry—covering its mechanism of action, antimicrobial efficacy, material compatibility, safety profile, and regulatory aspects. Moreover, concerns about emerging microbial resistance to CHG and possible adverse effects underscore the need for continuous evaluation. This review seeks to fill that gap by analyzing CHG’s performance across stages of device manufacturing, highlighting its role in sterility assurance, regulatory compliance, and patient safety.

Literature Review

Comparative Efficacy of CHG Versus Other Disinfectants

Multiple studies have compared CHG with alternative disinfectants under conditions simulating device manufacturing. O’Donnell et al. evaluated CHG alongside hydrogen peroxide, isopropyl alcohol, and quaternary ammonium compounds (QACs) on surfaces analogous to device components; they observed that CHG not only achieved rapid kill rates against pathogens such as *Staphylococcus aureus* and *Pseudomonas aeruginosa* but also maintained residual antimicrobial activity, thus reducing recontamination risk between cleaning cycles [7].

Kampf emphasized CHG’s superiority against multidrug-resistant organisms (MDROs) including MRSA and VRE, recommending its routine deployment in continuous contamination risk zones (e.g., assembly lines, packaging areas) within medical device manufacturing settings [8]. In contrast, hydrogen peroxide, while broadly effective, often lacks lasting substantivity and may cause material corrosion with repeated exposure [4,8]. QACs, meanwhile, can struggle to penetrate biofilms or perform well under organic load conditions, limiting their utility in rigorous cleanroom contexts [7].

Role of CHG in Biofilm Management

Biofilms pose a formidable contamination challenge in device manufacturing. These structured microbial communities, embedded in an extracellular polymeric substance (EPS) matrix, shield organisms from disinfectants and antibiotics, contributing to recurrent contamination and device recalls

[10]. Bridier et al. have detailed the resistance mechanisms of biofilms and documented the limited penetration efficacy of ethanol and QACs in mature biofilm settings [10]. By contrast, CHG's cationic properties facilitate interaction with the biofilm matrix, allowing partial penetration and disruption of structure. Formulations combining CHG with surfactants like cetrimide show enhanced biofilm eradication through synergistic action [9].

In one in vitro study, Jain et al. reported a ~6-log reduction in biofilms on stainless steel surfaces within just five minutes of exposure to a CHG–cetrimide formulation, reinforcing CHG's potential in cleaning and reprocessing reusable medical devices susceptible to biofilm formation [9].

Substantivity and Residual Antimicrobial Activity

A distinguishing advantage of CHG is substantivity—the ability to adsorb onto surfaces or tissues and continue exerting antimicrobial activity over time. Kampf & Kramer have shown that CHG can maintain bacteriostatic effects up to six hours post-application, substantially outperforming alcohols that evaporate swiftly [11]. This residual activity helps suppress microbial regrowth between cleaning cycles, which is especially beneficial in dynamic manufacturing environments with material and personnel movement.

Personnel Hygiene and Hand Antisepsis

Personnel are well known to be primary vectors for microbial contamination in sterile environments. Transient skin flora acquired via contact can be transferred to surfaces and devices if hand hygiene is inadequate. Larson et al. compared CHG-based hand scrubs with alcohol-based systems and found CHG achieved superior sustained reductions of both transient and resident microorganisms, even under repeated glove use [5]. This makes CHG-based antiseptics a staple in cleanroom hygiene protocols.

Applications of CHG in Medical Device Manufacturing

Surface and Equipment Disinfection

CHG is commonly used to disinfect workbenches, manufacturing tools, and device components in cleanrooms. Its broad-spectrum efficacy and residual action help maintain microbial control during intervals between cleaning cycles, reducing downtime. Because CHG is relatively compatible with materials such as stainless steel, many plastics, and elastomers, repeated application generally does not compromise device integrity [7,8].

Hand Hygiene and Personnel Antisepsis

In critical manufacturing stages (assembly, packaging), personnel-driven contamination is a major risk. CHG-based hand antiseptics, by providing residual antimicrobial effect for hours, reduce the chance of recolonization during processing steps. This aligns with best practices in hygiene control and regulatory expectations.

Instrument Cleaning and Reprocessing

Reusable device components often require stringent cleaning before sterilization to remove bioburden and biofilms. CHG demonstrates good penetration into biofilms—especially in formulations with surfactants like cetrimide—thus enhancing cleaning efficacy. Its compatibility with many manufacturing materials ensures that repeated exposure is less likely to degrade components [8].

Additionally, CHG coatings or impregnations in devices are areas of active research (e.g., CHG + silver combinations for infection-resistant surfaces) [18,21].

Safety & Compatibility Considerations

Skin Irritation and Allergic Reactions

While CHG is widely considered safe for antiseptic use, repeated or prolonged exposure may provoke skin irritation or allergic contact dermatitis in sensitive individuals. Regulatory bodies like FDA have issued alerts regarding rare but serious hypersensitivity reactions tied to CHG in medical products (e.g., impregnated devices) [0search0]. In manufacturing settings, occupational health protocols—use of protective gloves, skin monitoring, and training—are essential.

Material Compatibility

Though generally benign, CHG at high concentrations or with prolonged exposure can cause surface pitting, discoloration, or mild corrosion in certain metals or polymers. Compatibility testing for each device material is critical before routine adoption [7,8]. For example, in prosthodontic context, CHG disinfection showed minimal dimensional change for some impression materials, but some silicones or acrylics exhibited surface alteration over longer exposures [1,10]. Also, in denture cleaning studies, CHG was among the few agents that killed microorganisms effectively while exhibiting acceptable compatibility with acrylic resin, whereas bleach, IPA, and other disinfectants caused material damage [15].

Environmental Impact

Due to its chemical stability and persistence, CHG poses environmental risks if not properly managed. It may contribute to aquatic toxicity or selection for biocide tolerance among environmental organisms. Manufacturers must adopt stringent disposal, wastewater treatment, and containment strategies, and research into greener CHG analogues or formulations is ongoing [3,7].

Regulatory Compliance in Medical Device Manufacturing (Expanded)

Standards and Guidelines

International standards like ISO 13485:2016 demand validated disinfection and sterilization protocols within a quality system. Similarly, the FDA's QSR mandates controlled environments and validated

processes to prevent contamination. In many jurisdictions, devices containing CHG (e.g., impregnated dressings, antimicrobial surfaces) require regulatory review, CE marking (in EU), or classification under antiseptic/medical device regulations [3].

Validation and Monitoring

Manufacturers must demonstrate CHG efficacy through microbial challenge tests, environmental monitoring (surfaces, air, personnel), and periodic bioburden assessments. Risk assessments must address CHG-related hazards (e.g., operator exposure, material degradation). Routine surveillance and trend analysis are essential.

Documentation and Traceability

Every phase—procurement, dilution, application, contact time, sampling, deviations, corrective actions—must be documented. Traceable logs of disinfection cycles and audits are vital for regulatory inspections and compliance.

Emerging Concerns: Microbial Resistance to CHG

Mechanisms of Resistance

Microorganisms may adapt to CHG via efflux pumps, changes in membrane charge or permeability, or biofilm-based protection. Some in vitro studies of CHG adaptation show cross-resistance potential with antibiotics [22]. A systematic review on antimicrobial devices containing CHG, rifampicin, or minocycline found that new resistance emergence attributed to CHG combinations was rare, though surveillance is still advised [12]. In fact, most studies reported no significant change in resistance after CHG exposure [12].

Implications for Infection Control

If CHG tolerance or cross-resistance to antibiotics emerges, the effectiveness of disinfection protocols could decline, and multidrug-resistant infections could become more difficult to manage. While clinical evidence of CHG-driven resistance remains limited, the possibility urges careful use.

Mitigation Strategies

Regular microbial susceptibility monitoring is critical. Rotational use of disinfectants, combining CHG with synergistic agents, strict adherence to recommended concentrations and contact times, and avoiding sublethal exposures can mitigate resistance risk [12,22].

Challenges and Future Directions

While CHG remains a cornerstone disinfectant in medical device manufacturing, several challenges require attention to optimize its use and sustainability.

- **Resistance Development:** Continuous monitoring and antimicrobial stewardship programs are critical to prevent the spread of CHG-resistant strains. Research into resistance mechanisms and novel inhibitors is ongoing.
- **Formulation Optimization:** Variability in CHG efficacy due to formulation differences, concentration, and environmental factors highlights the need for standardized, evidence-based protocols. Development of enhanced formulations with improved biofilm penetration and synergistic agents is a promising area.
- **Material Compatibility:** Emerging materials in advanced medical devices necessitate ongoing compatibility assessments to prevent unintended damage or reduced device lifespan.
- **Cost and Resource Management:** Balancing CHG's cost-effectiveness with the expense of environmental controls and occupational health safeguards is essential for sustainable manufacturing.
- **Environmental Sustainability:** Innovations aimed at biodegradable CHG formulations and improved waste treatment methods will reduce ecological impact.
- **Occupational Health:** Long-term effects of CHG exposure on manufacturing personnel warrant further study, with emphasis on minimizing sensitization and promoting safe handling practices.

Conclusion

Chlorhexidine Gluconate remains an indispensable disinfectant in the medical device manufacturing sector due to its broad-spectrum antimicrobial activity, sustained residual effect, biofilm penetration capabilities, and favorable safety profile. Its integration into surface disinfection, personnel hygiene, and instrument reprocessing protocols significantly reduces contamination risks, facilitates regulatory compliance, and enhances overall patient safety.

Nevertheless, emerging challenges such as microbial resistance, environmental concerns, and occupational health issues underscore the need for vigilant monitoring, stewardship, and continuous innovation. Future research focusing on advanced CHG formulations, sustainability initiatives, and comprehensive safety evaluations will be crucial in preserving CHG's critical role in sterile device production.

By maintaining best practices and embracing scientific advancements, the medical device industry can continue to leverage CHG effectively, ensuring that manufactured devices meet the highest standards of sterility and safety for patients worldwide.

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