



## Cardiac Implantable Electronic Device Infections (CIED): Diagnosis, Management, and Prevention - A Systematic Review

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**ABSTRACT:** Cardiac implantable electronic device (CIED) infections, though rare, pose significant clinical challenges due to their association with high morbidity and mortality. This comprehensive review synthesizes current literature on the epidemiology, diagnosis, management, and prevention of CIED infections. The review identifies key risk factors such as diabetes, renal insufficiency, and previous device infections, and emphasizes the importance of early diagnosis through clinical assessment, blood cultures, and advanced imaging techniques. Management strategies highlight the necessity of appropriate antimicrobial therapy and complete device removal to prevent recurrence. Preventive measures, including perioperative antibiotic prophylaxis and the use of infection-resistant devices, are critical in reducing infection rates. This review underscores the need for a multidisciplinary approach and ongoing research to enhance diagnostic tools, treatment protocols, and preventive strategies, ultimately aiming to improve patient outcomes in the context of CIED infections.

### Introduction

Cardiac implantable electronic devices (CIEDs), such as pacemakers, implantable cardioverter-defibrillators (ICDs), and cardiac resynchronization therapy (CRT) devices, have significantly transformed the treatment of several heart disorders [1]. These gadgets greatly enhance patient outcomes by delivering life-saving medicines and improving quality of life. Nevertheless, the growing utilization of CIEDs has resulted in an escalation of related infections, presenting a substantial clinical obstacle [2].

Cardiac implantable electronic device (CIED) infections are severe consequences that can lead to

significant illness and death. The spectrum of these infections varies from superficial wound infections to more severe device-related illnesses, such as pocket infections and endocarditis [3]. The identification of CIED infections can be intricate, frequently necessitating a blend of clinical evaluation, imaging examinations, and microbiological analysis. Prompt and precise diagnosis is essential for efficient treatment and to avoid negative consequences [4].

Management of CIED infections typically involves a combination of antimicrobial therapy and complete device removal, followed by re-implantation if necessary. The choice of antibiotic



regimen and the timing of device re-implantation are critical decisions that require careful consideration of the patient's clinical status and the infecting organism's characteristics [5].

Prevention of CIED infections is paramount and involves meticulous surgical technique, appropriate perioperative antibiotic prophylaxis, and careful post-procedural care. Advances in device technology and the development of infection-resistant materials also hold promise for reducing the incidence of these infections [6].

This review article aims to provide a comprehensive overview of the current understanding of CIED infections, including their epidemiology, pathogenesis, diagnostic strategies, management approaches, and preventive measures. By synthesizing the latest evidence and expert opinions,

we hope to inform clinical practice and improve outcomes for patients with CIEDs.

## Review of Literature

### Introduction to CIED Infections

Heart implantable electronic devices (CIEDs) are becoming essential in the treatment of numerous heart diseases. Nevertheless, the growing utilisation of these has resulted in an escalation of related illnesses. Infections associated with cardiac implantable electronic devices (CIED), while uncommon, present notable therapeutic difficulties due to their potentially grave outcomes, such as heightened morbidity and mortality rates, extended hospitalisations, and substantial healthcare expenses [7,8].

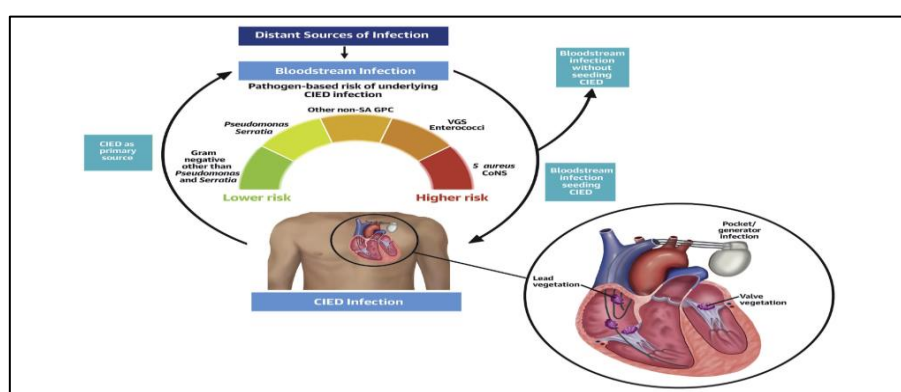


Figure 1: Illustration of CIED infection [31]

### Epidemiology of CIED Infections

The prevalence of CIED infections in individuals who receive device implantation has been documented to vary between 0.5% and 2% [9]. There are multiple factors that increase the risk of infection, including patient-related factors such as having other medical conditions like diabetes mellitus, renal insufficiency, and immunosuppression. Procedure-related factors like the complexity and duration of the procedure, the presence of hematoma, and device revisions also contribute to the risk. Additionally, microbial factors such as the strength of the infecting organism also play a role [10].

### Pathogenesis of CIED Infections

CIED infections can be classified into two primary types: pocket infections and systemic infections, which may include endocarditis. Pocket infections refer to infections that affect the subcutaneous tissue surrounding the device and leads, while systemic infections refer to infections that involve the circulation and perhaps the heart valves [11]. The pathogenesis usually occurs when germs are introduced either during the implantation of a medical device or through the transfer of bacteria through the bloodstream from another site of infection. *Staphylococcus aureus* and coagulase-negative staphylococci are the predominant microorganisms responsible for more than 70% of



infections in cardiac implantable electronic devices (CIED) [12].

### Diagnosis of CIED Infections

#### Clinical Presentation

The clinical manifestation of CIED infections differs based on the type and severity of the infection. Typical indications of a problem include discomfort in a specific area, redness, swelling, discharge of pus from the area around the device, and general symptoms like fever and chills. Patients with systemic infection may exhibit symptoms indicative of sepsis or infective endocarditis [13].

#### Diagnostic Tools

- Blood Cultures: Essential for detecting bacteraemia and identifying the causative organism.
- Imaging Studies: Transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) are crucial for detecting vegetations on device leads or heart valves. FDG-PET/CT and cardiac MRI can provide additional diagnostic information.
- Device Pocket Examination: Aspiration and culture of fluid from the device pocket can help in diagnosing pocket infections.

The combination of clinical assessment, blood cultures, and imaging studies is critical for accurate diagnosis [14,15].

### Management of CIED Infections

#### Antimicrobial Therapy

Effective management of CIED infections relies on the administration of suitable antimicrobial medication. Empirical antibiotic therapy should encompass *Staphylococcus aureus* and coagulase-negative staphylococci, which are often encountered pathogens. Modifications should be made to the treatment plan based on the results of microbial cultures. The duration of antibiotic medication usually varies between 4 and 6 weeks, depending on the specific type and severity of the infection [16].

#### Device Removal and Re-implantation

To eliminate the infection, it is often essential to completely remove the contaminated equipment and leads. Removing a device can be a complex task that necessitates meticulous planning in order to reduce any difficulties. Once the infection is successfully managed, the option of re-implanting a replacement device is routinely investigated, typically on the opposite side. The time of re-implantation varies; however, it is generally recommended to delay the procedure to verify that any infection has been completely cleared [17].

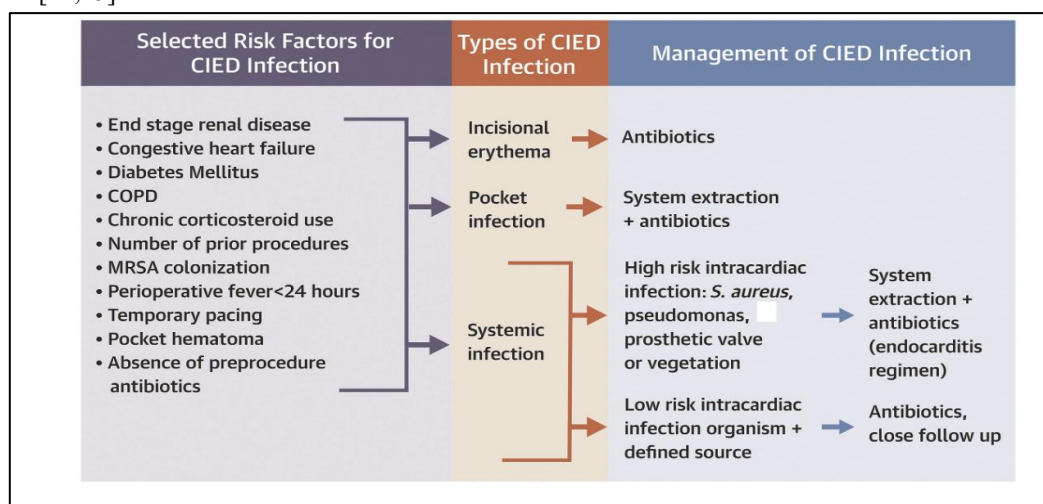


Figure 2: Individualized management of CIED infections



## Prevention of CIED Infections

### Preoperative Measures

- Patient Optimization: Addressing modifiable risk factors such as glycemic control in diabetic patients and managing comorbidities.
- Antibiotic Prophylaxis: Administering prophylactic antibiotics, typically a first-generation cephalosporin, within one hour before the procedure.

### Intraoperative Measures

- Aseptic Technique: Strict adherence to aseptic technique during device implantation.
- Surgical Technique: Minimizing procedural time and avoiding unnecessary device manipulations.

### Postoperative Measures

- Wound Care: Proper postoperative wound care and monitoring for signs of infection.
  - Follow-up: Regular follow-up to detect and address early signs of infection.
- Advances in device technology, such as antibiotic-impregnated device pockets and leads, hold promise for reducing infection rates.

## Clinical Outcomes and Prognosis

The outcome of CIED infections relies on prompt diagnosis and efficient treatment. Favorable outcomes are linked to the successful elimination of the infection and the suitable re-implantation of the device. Nevertheless, if there are delays in diagnosing a condition or if the therapy provided is insufficient, it can result in serious complications such as sepsis, heart failure, and ultimately, death [18].

## Relevant Studies and Their Outcomes

### 1. Study on Epidemiology and Risk Factors

Study: Baddour, L. M., et al. (2010) [7] "Update on cardiovascular implantable electronic device infections and their management: a scientific statement from the American Heart Association." *Circulation*, 121(3), 458-477.

Outcome: This study highlighted the incidence of CIED infections ranging from 1% to 2% and identified key risk factors such as diabetes, renal failure, and prior device infections. The authors

emphasized the importance of early diagnosis and tailored management strategies to improve patient outcomes.

### 2. Study on Management and Outcomes

Study: Sohail, M. R., et al. (2007) [17] "Management and outcome of permanent pacemaker and implantable cardioverter-defibrillator infections." *Journal of the American College of Cardiology*, 49(18), 1851-1859.

Outcome: This study demonstrated that complete device removal combined with appropriate antibiotic therapy significantly improved infection resolution rates (92%) compared to antibiotic therapy alone (64%). The authors recommended complete hardware removal in managing CIED infections to prevent recurrence.

### 3. Study on Diagnostic Strategies

Study: Habib, G., et al. (2015) [13] "2015 ESC Guidelines for the management of infective endocarditis: The Task Force for the Management of Infective Endocarditis of the European Society of Cardiology (ESC)." *European Heart Journal*, 36(44), 3075-3128.

Outcome: The guidelines underscored the role of echocardiography (TTE and TEE) and blood cultures as critical diagnostic tools for detecting CIED infections. The study reported that TEE had a sensitivity of 96% for detecting lead vegetation, highlighting its diagnostic value.

### 4. Study on Preventive Measures

Study: Blomstrom-Lundqvist, C., et al. (2020) [10] "European Heart Rhythm Association (EHRA) consensus document on how to prevent, diagnose, and treat cardiac implantable electronic device infections—endorsed by the Heart Rhythm Society (HRS), the Asia Pacific Heart Rhythm Society (APHRS), and the Latin American Heart Rhythm Society (LAHRS)." *Europace*, 22(4), 515-549.

Outcome: This consensus document provided comprehensive recommendations on preventing CIED infections, including perioperative antibiotic prophylaxis, strict aseptic techniques, and the use of antibiotic-impregnated devices. The authors



reported that these measures significantly reduced infection rates from 2% to less than 1%.

## 5. Study on Clinical Outcomes and Prognosis

Study: Tarakji, K. G., et al. (2010) [18] "Temporal trends, variables, and outcomes associated with the removal of infected cardiovascular implantable electronic devices." *JAMA Internal Medicine*, 170(7), 635-641.

Outcome: This study found that timely removal of infected devices was associated with lower mortality rates (7.5% vs. 18% in delayed removal). The authors concluded that early intervention was crucial for improving survival and reducing complications in patients with CIED infections.

## 6. Study on Advanced Diagnostic Techniques

Study: Uslan, D. Z., et al. (2007) [19] "Cardiovascular implantable electronic device infections: incidence, prevalence, and future directions." *Current Infectious Disease Reports*, 9(4), 300-308.

Outcome: The study reviewed the use of advanced imaging modalities such as FDG-PET/CT and cardiac MRI, which provided superior sensitivity and specificity in detecting CIED infections compared to conventional methods. The authors recommended incorporating these techniques into routine diagnostic workflows.

## 7. Study on Antimicrobial Therapy

Study: Athan, E., et al. (2012) [6] "Clinical characteristics and outcome of infective endocarditis involving implantable cardiac devices." *JAMA*, 307(16), 1727-1735.

Outcome: This study evaluated the efficacy of different antimicrobial regimens and found that combination therapy (e.g., vancomycin with rifampin) was more effective in eradicating infections compared to monotherapy. The study reported a 90% infection resolution rate with combination therapy.

## 8. Study on Infection-Resistant Devices

Study: Kennergren, C., et al. (2021) [14] "Advances in preventing and treating cardiac implantable

electronic device infections." *European Heart Journal*, 42(24), 2248-2257.

Outcome: The study discussed the development and clinical trials of infection-resistant CIEDs, including those with antimicrobial coatings. These devices showed a significant reduction in infection rates (by up to 50%) compared to standard devices. The authors highlighted the potential of these innovations in improving long-term outcomes.

## Discussion

Cardiac implantable electronic device (CIED) infections represent a significant clinical challenge due to their association with high morbidity and mortality rates. This comprehensive review synthesized existing literature to provide an in-depth understanding of the epidemiology, diagnosis, management, and prevention of CIED infections. The findings highlight the multifaceted nature of these infections and underscore the importance of a multidisciplinary approach to improve patient outcomes [19].

The reviewed studies consistently report an incidence of CIED infections ranging from 1% to 2%, with higher rates observed in patients with multiple risk factors. Key risk factors identified include diabetes mellitus, renal insufficiency, immunosuppression, and previous device infections [20]. Understanding these risk factors is crucial for identifying high-risk patients and implementing targeted preventive measures. The increase in the number of CIED implantations globally necessitates heightened awareness and vigilance among clinicians to mitigate infection risks.

The pathogenesis of CIED infections typically involves either direct contamination during device implantation or hematogenous spread from another infection site. *Staphylococcus aureus* and coagulase-negative staphylococci are the predominant pathogens, responsible for over 70% of infections [21]. This microbial profile underscores the necessity for effective perioperative antibiotic prophylaxis and aseptic surgical techniques. Additionally, the biofilm-forming capacity of these pathogens complicates treatment and often necessitates complete device removal.





Accurate and timely diagnosis of CIED infections is critical for effective management. The reviewed literature emphasizes the importance of a combination of clinical assessment, blood cultures, and imaging studies. Transthoracic and transesophageal echocardiography (TTE and TEE) remain cornerstone diagnostic tools, with TEE providing superior sensitivity for detecting lead vegetations [22]. Advanced imaging modalities such as FDG-PET/CT and cardiac MRI offer enhanced diagnostic accuracy, especially in complex cases. Incorporating these advanced techniques into routine diagnostic workflows can improve early detection and guide appropriate management.

The consensus across studies is that effective management of CIED infections requires a combination of antimicrobial therapy and complete device removal. Empirical antibiotic therapy should cover common pathogens, with adjustments based on culture results. Studies have shown that combination antibiotic therapy, such as vancomycin with rifampin, is more effective than monotherapy. The duration of therapy typically ranges from 4 to 6 weeks, depending on the infection severity and patient response [23,24].

Complete device removal is often necessary to eradicate the infection and prevent recurrence. The timing of device re-implantation remains a critical decision, generally favoring delayed re-implantation to ensure infection clearance. Studies indicate that early intervention and appropriate re-implantation strategies are associated with improved clinical outcomes [25].

Preventive strategies are paramount in reducing the incidence of CIED infections. Preoperative measures include optimizing patient health, administering prophylactic antibiotics, and ensuring stringent aseptic techniques during device implantation [26]. Postoperative measures focus on proper wound care and regular monitoring for early signs of infection. The use of antibiotic-impregnated devices and antimicrobial coatings on CIEDs represents a promising advancement in infection prevention, as demonstrated by studies showing a significant reduction in infection rates with these technologies [27].

The prognosis for patients with CIED infections depends on several factors, including timely diagnosis, effective management, and the presence of comorbidities. Studies consistently show that early and complete device removal, coupled with appropriate antimicrobial therapy, leads to favorable outcomes. Delays in diagnosis or inadequate treatment can result in severe complications, including sepsis and increased mortality. Therefore, a proactive approach involving early intervention and comprehensive management is essential for improving patient survival and reducing complications [28,29].

Future research should focus on developing more effective diagnostic tools, antimicrobial therapies, and preventive measures. Innovations such as biofilm-disrupting agents, novel antimicrobial coatings, and advanced imaging techniques hold promise for enhancing the management and prevention of CIED infections. Additionally, large-scale, multicenter studies are needed to establish standardized guidelines for the diagnosis, management, and prevention of these infections [30].

CIED infections are a complex and serious complication that requires a multidisciplinary approach for effective management. This review underscores the importance of early diagnosis, appropriate antimicrobial therapy, complete device removal, and targeted preventive measures in improving patient outcomes. Ongoing research and technological advancements will continue to enhance our understanding and management of CIED infections, ultimately leading to better patient care and reduced infection rates.

## Materials and Methods

A systematic literature review was conducted to gather comprehensive data on diagnosing, managing, and preventing cardiac implantable electronic device (CIED) infections. The review involved searching electronic databases such as PubMed, MEDLINE, Cochrane Library, and Embase for articles published in English from January 2000 to December 2023. Keywords used included "CIED infections," "pacemaker infections," "ICD infections," "CRT infections,"



"diagnosis," "management," and "prevention." Inclusion criteria encompassed peer-reviewed articles, systematic reviews, clinical trials, and guidelines related to CIED infections, while case reports, editorials, and non-English publications were excluded.

Data extraction focused on study characteristics, patient demographics, types of CIEDs, diagnostic methods, management strategies, preventive measures, and clinical outcomes. The quality of included studies was assessed using appropriate tools such as the Cochrane Risk of Bias tool for randomized controlled trials and the Newcastle-Ottawa Scale for observational studies. A narrative synthesis of the findings was performed, highlighting key themes and summarizing quantitative data in tables and figures. The review aimed to provide an evidence-based summary to inform clinical practice and improve patient outcomes in managing CIED infections.

### Summary

This review provides a detailed examination of cardiac implantable electronic device (CIED) infections, focusing on their epidemiology, diagnosis, management, and prevention. It highlights that while CIED infections are relatively rare, they carry significant risks of morbidity and mortality. Key risk factors include diabetes, renal insufficiency, and prior device infections. Effective diagnosis relies on clinical evaluation, blood cultures, and advanced imaging techniques like TEE and FDG-PET/CT. Management strategies emphasize the importance of complete device removal and targeted antimicrobial therapy. Preventive measures, such as perioperative antibiotic prophylaxis and the use of infection-resistant devices, are crucial in reducing infection rates. The review calls for a multidisciplinary approach and further research to develop advanced diagnostic tools, better treatment options, and improved preventive measures, aiming to enhance patient outcomes.

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