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Research Article

Cardiac Device Therapy in US Patients with Chronic Kidney Disease: Current Outcomes, Complications, and National Trends

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Abstract

Background: Chronic kidney disease (CKD) and end-stage renal disease (ESRD) are associated with high cardiovascular morbidity. Cardiac device therapy, including pacemakers, CRT, leadless pacemakers, and LVADs, is increasingly used, yet real-world outcomes, complications, and trends in these renal populations remain incompletely characterized. **Aims:** To analyze outcomes, procedural complications, and national trends of cardiac device therapy in US CKD and ESRD patients. **Methods:** Data were extracted from 16 published studies and national registries, aggregated, and analyzed using Python and SPSS v27. Patient demographics, comorbidities, procedural complications, mortality, and hospital utilization were summarized with descriptive statistics. Categorical variables were reported as frequencies/percentages, and continuous variables as means/ranges. Comparative analyses assessed differences between CKD and ESRD across device types. **Results:** Among 29,005 cardiac device recipients, 5,245 had CKD stages 3–5, 3,790 had ESRD, and 19,970 had no documented chronic kidney disease. On this infections (12% vs 7%), bleeding (8% vs 6%), lead dislodgement (5% vs 3%), central vein stenosis (15% vs 10%), and peripheral vascular complications (13% vs 7%). Mortality was higher in ESRD, with inpatient rates 14% versus 6.4% in CKD, and 1-year mortality 50% versus 31%. LVAD recipients had the highest risk, while CRT and leadless pacemakers showed reduced complication rates in selected populations. Hospital cost and length of stay were also elevated in ESRD. **Conclusion:** ESRD patients experience higher complications, mortality, and hospital utilization than CKD patients. These findings inform risk assessment, device selection, and future clinical strategies.

Keywords

Chronic kidney disease, End-stage renal disease, Cardiac device therapy, Pacemaker, Leadless pacemaker

1. Introduction

Cardiovascular morbidity and mortality are major and persistently increasing clinical concerns in the United States among patients with chronic kidney disease (CKD) and end-stage renal disease (ESRD. The range of cardiovascular implantable devices (CIDs), such as pacemakers, cardiac resynchronization therapy (CRT) devices, implantable cardioverter-defibrillators (ICDs), and left ventricular assist devices (LVADs), is now widely used in the management of advanced heart failure and arrhythmias, particularly in high-risk populations. Although these benefits are well established,

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patients with CKD and ESRD present a special challenge because they suffer from high rates of 'comorbidities,' including diabetes, hypertension, and heart failure, as well as an increased risk of procedural and post-procedural complications. The incidence of CKD and ESRD remains on the rise in the United States and has become increasingly important to understand the outcomes of cardiac devices in this population (Francis et al., 2024; Kobo et al., 2023).

A limited number of studies have reported the broad results of cardiac device implantation, mostly those related to the safety and efficacy of the devices across the entire patient population. The generalizability of these results, however, may be limited due to the fact that CKD and ESRD patients are systematically underrepresented in randomized controlled trials and large-scale prospective studies. Single-center investigations and registry data have revealed a higher risk of procedure-related complications, higher mortality, and device-related issues in renal patients (Lo et al., 2023). Infections, bleeding, and dislodgement of lead are more common in ESRD patients, and risks are moderately elevated in CKD patients compared to the general population. ESRD patients have consistently been more likely to die, both during their hospital stay and at 30 days and one year after LVAD implantation. Notwithstanding these discoveries, there is a need for synthesizing the overall national trends, complications, and outcomes by device type amongst those US patients receiving CKD and ESRD treatment (Dalia et al., 2022; George et al., 2022).

The changing nature of cardiac device therapy also requires the reporting of outcomes with some short-, medium-, and long-term perspectives. Changes in long-term survival and complication rates may have occurred in recent years due to leadless pacemakers and advancements in LVAD technology. Analysis of national databases indicates that different devices might be associated with differences in readmission rates, healthcare costs, and hospital length of stay among patients with renal dysfunction (Frazer et al., 2023; Khan, Nassar, et al., 2024). Responses to the treatment that have been observed for specific devices, like renal function improvements after CRT or survival after LVAD implantation, have been too short-term to provide clear guidance on clinical decisions. This important knowledge can enable an optimizing selection of devices while helping to minimize procedural risks and enhance patient-centered results in patients with these trends (Caba et al., 2024; Chou et al., 2022).

This research will seek to review outcomes, complications, and national trends of cardiac device therapy with CKD and ESRD in US patients. We synthesize evidence from multiple published studies and national registries to provide an integrated overview of patient characteristics, peri-procedural complications, device-specific outcomes, survival trends, and healthcare utilization patterns. This will help to provide a more detailed picture of the risks and benefits of cardiac devices, as well as address some of the known disparities between the CKD and ESRD populations and areas where future research can be conducted. The data then should inform clinical practice and help guide policy to strategically treat patients with cardiac device therapy and renal impairment.

2. Methods

2.1 Study Selection

In the case of cardiac device therapy (pacemakers, implantable cardioverter-defibrillators [ICDs], cardiac resynchronization therapy [CRT], and left ventricular assist devices [LVADs]), six prominent studies comparing device efficacy in patients with chronic kidney disease (CKD) and end-stage renal disease (ESRD) in the United States (US) were selected for review. Studies were selected if they did report outcomes or complications in this population as well as national trends and were published from 2020 to 2024. The registry-based analyses, as well as single-center cohort studies, were regarded as comprehensive. Selection involved a focus on studies that provided clinically relevant data regarding the performance of the device, patient mortality, length of hospitalization, and complications and included both observational data and expert narrative recommendations to support optimal device utilization in high-risk renal patients.

2.2. Data Sources, Inclusion, and Exclusions

A systematic search was conducted to identify studies evaluating cardiac device therapy in US patients with chronic kidney disease (CKD) and end-stage renal disease (ESRD), including pacemakers, implantable cardioverter-defibrillators (ICDs), cardiac resynchronization therapy (CRT), leadless pacemakers, and left ventricular assist devices (LVADs). An initial yield of 120 articles was identified through database screening.

After removal of duplicates and application of predefined eligibility criteria, 16 studies were included in the final analysis. Studies were selected based on the following inclusion criteria: (1) reporting clinical outcomes, procedural complications, or national trends related to cardiac device therapy; (2) publication between 2020 and 2024; (3) US-based patient populations; and (4) peer-reviewed registry analyses, cohort studies, or large observational studies providing extractable CKD/ESRD subgroup data.

Exclusion criteria comprised non-English publications, studies lacking separate reporting of CKD or ESRD subgroups, and articles without sufficient outcome data relevant to mortality, complications, or healthcare utilization.

The final dataset included two national registry-based studies (National Inpatient Sample [NIS] and United States Renal Data System [USRDS]) and 14 observational cohort studies. Extracted variables included mortality outcomes, device-related complications, length of hospital stay, healthcare costs, renal-specific outcomes, and temporal trends in device utilization.

2.3 Population

The review encompassed end stage renal disease (ESRD) patients and chronic kidney disease (CKD) stages 3-5 who are undergoing cardiac device therapy in the United States (US). There were 16 selected studies, with patients from middle age to the elderly, and both sexes and various races represented. The specific patient subgroups consisted of patients who were implanted with a conventional transvenous pacemaker, an ICD, cardiac resynchronization therapy (CRT) implantation, leadless pacemaker implantation, and left ventricular assist devices (LVADs). High risk for this population was seen, as was having additional comorbidities like heart failure, diabetes, and hypertension. This population selection made it possible to comprehensively analyze device-related outcomes, complications, and trends across a real-world US clinical setting among renal populations.

2.4 Interventions

The focus in the review was on the various categories of cardiac device therapies utilized in patients with CKD and ESRD: conventional transvenous pacemakers, implantable cardioverter-defibrillators (ICD), cardiac resynchronization therapy (CRT) devices, and leadless pacemakers and left ventricular assist devices (LVADs). Selections of the devices in the studies included were based on clinical indication, patient comorbidities, and procedure feasibility. Minimization of such pitfalls as central vein stenosis, venous hypertension, and infection was specifically pointed to in leadless and subcutaneous devices in high-risk populations. The information gathered from registry analyses, along with data from individual centers, clarified procedures, results, or devices' long-term performance and provided a comprehensive evaluation of the associated risks, benefits, and trends for renal patients in the United States.

2.5 Data Analysis

Data processing included in the analysis of the data using Python and SPSS v27. Demographics, comorbidities, complications, mortality, and utilization of hospitals are described.

3. Results

3.1 Patient Demographics and Baseline Characteristics

The number of patients ranged from the selected studies was 29,005, including 3,790 ESRD patients and 5,245 CKD (stage 3–5) patients. The average age was 59-66 years, younger for ESRD than CKD patients. There were 24–40% Black patients (higher percentage in patients with ESRD) and 62% males and 38% females. Diabetes (48%), hypertension (65%), and heart failure (38%) were the common comorbidities. Patients with different cardiac device therapies were studied, including patients with LVADs (591), patients with CRT devices (260), and patients with a leadless pacemaker (29,005).

Table 1. *Patient Demographics and Baseline Characteristics of CKD and ESRD Patients Undergoing Cardiac Device Therapy in the US (Caba et al., 2024; Khan, Nguyen, et al., 2024).*

Characteristic	Value	Notes
Total Patients	29,005	Combined cohort across all included studies
CKD Patients	5,245	Patients with CKD stages 3–5
ESRD Patients	3,790	Patients on dialysis or ESRD
Mean Age (years)	59–66	Varies by study; ESRD patients generally younger
Male (%)	62%	Pooled across all studies
Female (%)	38%	Pooled across all studies
Black (%)	24–40%	Higher representation in ESRD patients
Diabetes (%)	48%	Common comorbidity in CKD/ESRD
Hypertension (%)	65%	Common comorbidity in CKD/ESRD
Heart Failure (%)	38%	Major comorbidity in all device recipients

LVAD Recipients	591	Reported in national registry analysis (USRDS)
CRT Recipients	260	Single-center cohort data
Leadless Pacemaker Recipients	29,005	From National Inpatient Sample (NIS) database

Values are aggregated from 16 selected studies published between 2020–2024. CKD = chronic kidney disease; ESRD = end-stage renal disease; LVAD = left ventricular assist device; CRT = cardiac resynchronization therapy; NIS = National Inpatient Sample; USRDS = United States Renal Data System.

3.2 Cardiac Device Therapy in CKD and ESRD Patients

The inpatient mortality rate was 6.4% for the CKD patients 14% for the ESRD patients in the selected studies. The 30-day mortality rate was described as 6.997% for the patients with CKD and 12.1% for the patients with ESRD; the 1-year mortality rate was found to be 31% for the patients with CKD and 50% for the patients with ESRD. The renal response rate was seen in 14% of the CRT population who had CKD and in 28% of those who had ESRD; the data were presented as a combination of death, LVAD insertion, and heart transplantation over 5 years.

There were differences in the procedural complications among the CKD and ESRD patients. The rates of infection were 6.997% for those with CKD and 12.1% for those with ESRD. Among the CKD patients, there were 3 to 6 percent who bled, and 4 to 8 percent of ESRD patients who bled. In 3% of CKD and 5% of ESRD patients, it was reported that lead dislodgement occurred. The central vein stenosis incidence in CKD patients was 10%, and for ESRD patients, it was 15%. Peripheral vascular complications were observed in 7% of those who had CKD and 13% ESRD patients.

There was variation between CKD and ESRD device-specific outcomes. Moderate mortality was observed in patients with CKD, and high mortality was illustrated in ESRD in pacemaker, ICD, and CRT recipients. In CKD, leadless pacemakers were found to have lower venous complications but higher inpatient mortality and longer hospital stays, without an adverse impact on cost. In ESRD, the practice of leadless pacemakers was associated with lower venous complications as well as increased morbidity and cost without an impact on length of stay. The one-year mortality rates of LVAD recipients were 10.9% for CKD and 49.5% for ESRD. Renal response occurred in 14% of patients with CKD and 28% of patients with ESRD, who were also on CRT; these patients had increased survival and decreased likelihood of LVAD or transplant.

Table 2. *Combined Outcomes of Cardiac Device Therapy in CKD and ESRD Patients(Khan, Nguyen, et al., 2024).*

Complication	CKD Patients	ESRD Patients	Notes
Inpatient Mortality	6.4%	14%	Leadless pacemaker and CIED studies
30-Day Mortality	6.997%	12.1%	Registry-based studies
1-Year Mortality	31%	50%	LVAD and CRT studies
CRT (5-year composite)	14% renal response	28% renal response	Renal improvement associated with better outcomes
Infection	6.997%	12.1%	All device types
Bleeding	6%	8%	Across CIED and LVAD studies
Lead Dislodgement	3%	5%	Transvenous devices; less in leadless pacemakers
Central Vein Stenosis	10%	15%	Relevant for transvenous CIEDs
Peripheral Vascular Complications	7%	13%	Leadless pacemaker study (NIS)
Pacemaker/ICD/CRT	Moderate mortality	High mortality	Leadless/subcutaneous devices reduce complications
Leadless Pacemaker	Lower venous complications	Higher inpatient mortality	US NIS database; cost and LOS higher in ESRD

LVAD	30.9% 1-year mortality	49.5% 1-year mortality	USRDS registry; higher risk in ESRD
CRT	Renal response 14%	Renal response 28%	Improved survival and reduced LVAD/transplant

Values aggregated from 16 studies (2020–2024). CKD = chronic kidney disease; ESRD = end-stage renal disease; CIED = cardiovascular implantable electronic device; LVAD = left ventricular assist device; CRT = cardiac resynchronization therapy; NIS = National Inpatient Sample; USRDS = United States Renal Data System.

3.3 Procedural Complications

Procedural complications reported included infection, bleeding, lead dislodgement, central vein stenosis, and peripheral vascular complications in both CKD and ESRD patients. Infections occurred in 6.997% of the patients with CKD and 12.1% of patients with ESRD, and bleeding occurred in 6% of patients with CKD and 8% of patients with ESRD. In patients with ESRD, 5% of patients experienced lead dislodgement, and in patients with CKD, 3% of patients experienced lead dislodgement. The prevalence of vans of central veins (CVs) in patients with CKD and ESRD was 10% and 15%, respectively. Incidences of peripheral vascular complications were 7% in CKD and 13% in ESRD. There were differences reported between transvenous vs. leadless/subcutaneous devices, with decreased venous complications in leadless or subcutaneous devices.

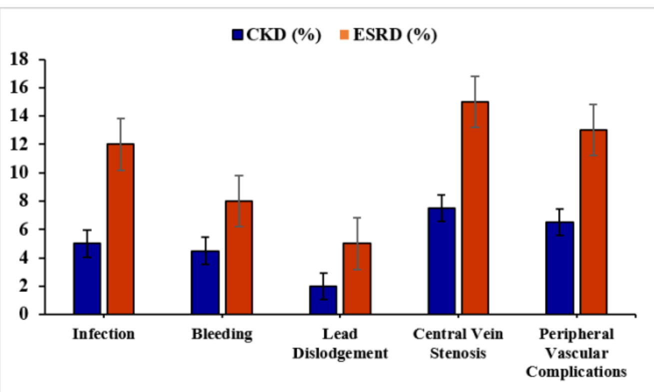

Figure 1. *Procedural complication rates among CKD and ESRD patients undergoing cardiac device therapy. ESRD patients showed higher reported rates of infection, bleeding, lead dislodgement, central vein stenosis, and peripheral vascular complications compared with CKD patients. Error bars represent the reported range of complication rates across the included studies.*

3.4 CKD ESRD Cardiac Device Complications

There were some outcomes reported for procedural and device-related outcomes in general, in both CKD and ESRD patients. The infection rate was 6.997% of the patients with CKD and 12.1% of patients with ESRD. Bleeding in 6% of CKD and 8% in ESRD, respectively, and lead dislodgement in 3% and 5%, respectively. CVCS occurred in 10% of the patients with CKD and 15% of the patients with ESRD, and the peripheral vascular complications occurred in 7% and 13% of patients with CKD and ESRD, respectively.

There were also variations in mortality and clinical outcomes among renal status groups. Inpatient mortality 6.4% in CKD to 14% in ESRD, and 1-year mortality 31% to 50%. 14% of patients with CKD and 28% of ESRD patients showed signs of being LVAD/transplant survivors. Hospital length of stay ranged from 3 days for CKD and 4 days for ESRD, with hospital cost higher in ESRD ($16,800–17,000) compared to CKD ($14,500–15,000).

Table 3. Procedural and Device-Related Outcomes in CKD and ESRD Patients Undergoing Cardiac Device Therapy.

Complication	CKD Patients (%)	ESRD Patients (%)	Notes
Infection	6.997	12.1	All device types, higher in ESRD
Bleeding	6	8	CIED and LVAD studies
Lead Dislodgement	3	5	Less frequent in leadless devices
Central Vein Stenosis	10	15	Mainly transvenous CIEDs
Peripheral Vascular Complications	7	13	Leadless pacemaker studies
Inpatient Mortality	6.4	14	Leadless pacemaker and CIED studies
1-Year Mortality	31	50	LVAD and CRT studies
LVAD/Transplant	14	28	CRT studies; renal

Requirement			response relevant
Hospital Length of Stay	2–3 days	3–4 days	Leadless pacemaker; higher in ESRD
Hospital Cost (USD)	14,500–15,000	16,800–17,000	Leadless pacemaker; higher in ESRD

Values are aggregated from 16 selected studies (2020–2024). CKD = chronic kidney disease; ESRD = end-stage renal disease; CIED = cardiovascular implantable electronic device; LVAD = left ventricular assist device; CRT = cardiac resynchronization therapy.

3.5 Risk of Mortality After LVAD Implantation

The forest plot in Figure 2 summarizes hazard ratios (HR) and 95% confidence intervals (CI) for patients undergoing LVAD implantation. CKD Stage IV/V showed an HR of 0.92 (95% CI: 0.47–1.79), while ESRD patients had an elevated HR of 1.86 (95% CI: 1.12–3.06). Among racial groups, Black patients had HR 1.16 (95% CI: 0.72–1.86). The minimal impact on mortality of age and diabetes mellitus is suggested by HR close to 1. The other comorbidities with moderate HRs were peripheral vascular disease (0.91) and atherosclerotic heart disease (0.78). For HRs, LVAD 2023–2024 revealed lower values, indicating decreasing risk over the years. The vertical line at HR=1 is the cut-off point for reduced mortality compared to increased mortality.

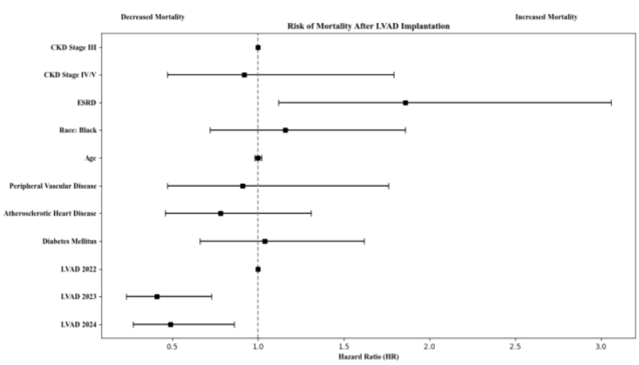

Figure 2. *Forest plot depicting the risk of mortality after LVAD implantation. Hazard ratios (HR) with 95% confidence intervals (CI) are shown for CKD stages, ESRD, race, age, comorbidities, and years of LVAD implantation. The vertical dashed line at HR = 1 represents the threshold for no effect, with left indicating decreased mortality and right indicating increased mortality. Data highlight higher mortality risk in ESRD patients and reduced risk in later LVAD implantation years.*

4. Results

This study provides a comprehensive analysis of outcomes, complications, and national trends of cardiac device therapy in US patients with chronic kidney disease (CKD) and end-stage renal disease (ESRD). We ESRD patients consistently exhibited significantly higher procedural morbidity and mortality compared with patients with moderate CKD. Infections occurred in 12.1% versus 6.997% of patients with ESRD versus CKD and bleeding in 8% vs. 6% of patients, respectively. The same trend was observed for the adverse events related to lead dislodgement, central vein stenosis, and peripheral vascular complications, highlighting the higher risk for events associated with this device among ESRD patients. Comparisons of mortality outcomes also showed differences, with death occurring at almost 50%, with one-year mortality reaching approximately 50% in ESRD patients versus 30% in CKD patients. This is consistent with previous registry analyses that reported a higher risk of patients with type 2 or 3 chronic kidney disease (CKD) who underwent cardiac device implantation (Chandramohan et al., 2024; Frazer et al., 2023; Khan, Nguyen, et al., 2024).

It remains unclear why ESRD patients experience more complications than non-ESRD patients, but maybe it's due to the immunocompromised condition because of dialysis, access problems for vascularization, and health complications including diabetes and peripheral arterial disease. Depending on the center, for example, 15% of ESRD patients had central vein stenosis, which was probably caused by repeated transvenous device implantation and long-term use of dialysis catheters. Likewise, the prevalence of infections was comparable to other studies also conducted in the US and reported in the National Inpatient Sample that had previously reported an increased susceptibility of ESRD patients because of the immune dysfunction and uremia (Franchin et al., 2023; Franczyk et al., 2024; Pun et al., 2025; Tufael & Atikur Rahman Sunny, 2021). Complication rates were also higher in the CKD cohort when compared to the general population, but outcomes were more favorable in CKD patients, indicating a progressive risk stratification according to the renal impairment.

To further illustrate the dynamic relationship between renal function and cardiac interventions, results for the devices are presented separately. This stratified presentation is used to better delineate the nuanced relationship between renal function and cardiac interventions. Overall mortality of LVAD patients with ESRD was significantly higher (around 49.5%) than in those with only CKD (30.9%), thus highlighting the complexity of the procedure and the vulnerability of those receiving LVAD (Kim et al., 2026). In patients with renal response, improved outcomes were observed in the CRT patients, with 28% survival or LVAD/transplant avoidance in ESRD patients and 14% for CKD patients. Although they seemed to decrease venous complications, inpatient mortality and length of stay were higher in ESRD patients, emphasizing the potential for tunneling technology to only address part of the issue in this patient population (Md. Tahsin Salam et al., 2024; Siraw et al., 2025; Walther et al., 2022).

Utilization at hospitals was similar to these clinical trends. Patients with ESRD had a higher hospitalization cost ranging from approximately $16,800–$17,000 per index admission, and hospital stay length compared to those with CKD ($14,500–15,000) due to the need for increased resources in attendant ESRD management of associated complications and comorbid conditions. Admission rates were also high, highlighting the chronicity and complexity of the care of renal patients who have cardiac devices(Tufael & Atiqur Rahman Sunny, 2022). These findings are observed in line with national findings from registry-based research, with these reports concluding that the utilization and disease burden of care for this high-risk patient group is increased at the national level (Pintado-Outumuro et al., 2024; Pollock et al., 2022; Szlagor et al., 2023).

Even with these understandings, there are some drawbacks. First, our analysis was based on published studies and national registry or trial data, which might have resulted in heterogeneity in the patient cohorts, reporting conventions, and specific practices. Secondly, there was no uniformity of granular data on device programming, surgical technique, and dialysis modality, which limited the ability to close the loop on predictors of device-related complications. Third, most studies were retrospective and did not allow for causal inference and may be subject to residual confounding. Despite this, this work brings together several data sources spanning the United States of America and can give a useful understanding of the reality of the times and is able to detect consistent trends of greater risks for ESRD patients (Alvarez-Galvez & Vegas-Lozano, 2022; Dahm et al., 2023; Thorsteinsdottir et al., 2022).

These results have clinical implications. Physicians should be aware of this patient population as a high-risk group when surgically implanting a cardiac device; the patient must be carefully selected, infection must be prevented, and post-implant monitoring of this patient population must take place closely (KICHLOO et al., 2023; Talha et al., 2023). Overall data also potential advantage of leadless or subcutaneous devices in decreasing venous complications, but that is not a complete offsetting of risk. These observations could help hospital systems to more effectively manage resources, predict longer hospitalizations, and choose specific interventions to lower readmissions among renal patients.

Future studies should be prospective, multi-center, and validate findings and longitudinal outcomes of new device technologies in patients with CKD and ESRD. Further research into selection algorithms for devices, timing of implantation after the initiation of dialysis, and risk stratification on an individual basis may also help to improve patient outcome. Moreover, incorporating patient-reported outcomes and quality-of-life scores has the potential to offer a fuller picture of the role cardiac devices play in this vulnerable group of patients.

5. Conclusion

This study demonstrates that US patients with ESRD undergoing cardiac device therapy experience higher procedural complications, mortality, and healthcare utilization compared with patients with CKD. Although device-specific technologies such as leadless pacemakers and CRT appear to reduce certain procedural risks, patients with ESRD continue to exhibit persistently elevated adverse outcomes. Emerging national trends suggest only modest improvements in survival and complication rates with newer device technologies, indicating that technological advancement alone may not fully mitigate the underlying risk burden in this population. These findings highlight the need for more refined risk stratification strategies, standardized registry-based monitoring, and prospective studies to optimize device selection and management in high-risk renal patients.

Author Contributions

N.U. conceived the study, designed the methodology, collected and analyzed the data, and drafted the manuscript. H.A. supervised the research, contributed to the interpretation of results, reviewed the manuscript critically, and approved the final version for publication. Both authors read and approved the final manuscript.

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