Systematic Review and Meta-Analysis

Medicine

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Incremental benefits of catheter ablation in patients with structural heart disease undergoing implantable cardioverter-defibrillator therapy for ventricular arrhythmias

A PRISMA compliant systematic review and meta analysis

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Abstract

Background: Structural heart disease (SHD) significantly increases the risk of life-threatening ventricular arrhythmias (VAs), contributing to sudden cardiac death. Implantable cardioverter-defibrillators are the cornerstone of prevention but do not eliminate arrhythmia recurrences or reduce the arrhythmogenic substrate. Catheter ablation has emerged as a potential adjunctive therapy to reduce VA burden and implantable cardioverter-defibrillator (ICD) interventions in patients with SHD. This meta-analysis aimed to evaluate the incremental benefits of catheter ablation compared to antiarrhythmic drug (AAD) therapy or standard care in patients with SHD undergoing ICD implantation for VAs.

Methods: A systematic search was conducted till April 2025 across PubMed/MEDLINE, Cochrane, google scholar and science direct following Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Studies included patients with SHD receiving ICD therapy, comparing catheter ablation with any alternative treatment. Outcomes assessed included mortality, arrhythmia recurrence, disease burden, and ICD interventions. Statistical analysis was performed using Review Manager, calculating odds ratios (ORs) and 95% confidence intervals (CI), with heterogeneity assessed via I^2 statistics.

Results: Eight studies were included, encompassing 536 patients in the catheter ablation group and 560 patients in the control group. Catheter ablation did not significantly reduce all-cause mortality (OR = 0.79, 95% CI: 0.48–1.29, $P = .34$), cardiovascular mortality (OR = 0.73, 95% CI: 0.37–1.43, $P = .36$), or death (OR = 0.86, 95% CI: 0.53–1.38, $P = .52$). However, catheter ablation was associated with a significant reduction in recurrent ventricular tachycardia (VT) (OR = 0.42, 95% CI: 0.27–0.64, $P < .001$) and cardiac hospitalization (OR = 0.55, 95% CI: 0.34–0.89, $P = .015$). No significant differences were observed for VT storm or electrical storm. Importantly, catheter ablation significantly reduced inappropriate ICD shocks (OR = 0.36, 95% CI: 0.20–0.66, $P < .001$), while rates of appropriate ICD shocks and antitachycardia pacing were similar between groups.

Conclusion: Catheter ablation offers significant benefits in reducing arrhythmia burden and inappropriate ICD shocks but does not impact overall mortality compared to antiarrhythmic therapy in patients with SHD undergoing ICD implantation.

Abbreviations: ATP = appropriate anti tachycardia pacing, CI = confidence interval, ICD = implantable cardioverter-defibrillator, OR = odds ratio, PRISMA = preferred reporting items for systematic reviews and meta-analyses, RCT = randomized controlled trial, SCD = sudden cardiac death, SHD = structural heart disease, VAs = ventricular arrhythmias.

Keywords: catheter ablation, implantable cardioverter-defibrillator, structural heart disease, ventricular arrhythmias

The authors have no funding and conflicts of interest to disclose.

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

During the manuscript preparation process, the authors employed AI-assisted tools (ChatGPT-4 and DeepSeek) for linguistic refinement and structural organization. The authors assume full responsibility for the accuracy and integrity of the final content.

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How to cite this article: Amir M, Hassan A, Ali EF, Noor M, Nazir A, Kamran M, Rizwan A, Fahim MA, Usman M, Awais MN, Waleed M, Tahir MU, Khan MH, Haroon A. Incremental benefits of catheter ablation in patients with structural heart disease undergoing implantable cardioverter-defibrillator therapy for ventricular arrhythmias: A PRISMA compliant systematic review and meta analysis. Medicine 2026;105:3(e47261).

Received: 22 July 2025 / Received in final form: 19 September 2025 / Accepted: 1 December 2025

http://dx.doi.org/10.1097/MD.0000000000047261

1. Introduction

Structural heart diseases (SHDs) are highly prevalent in the general population and can lead to several serious complications, including sudden cardiac death (SCD). The primary mechanism behind SCD is the development of ventricular arrhythmias (VAs), which typically present as life-threatening rhythms such as supraventricular tachycardia and ventricular fibrillation.[1] The ventricular arrhythmia develop due to abnormal pulse generation and conduction leading to reentry.[2] SHDs include a broad spectrum of conditions such as coronary artery disease with previous myocardial infarction, congenital heart disease, various cardiomyopathies, and inherited syndromes like Brugada syndrome.[1]

One of the main goals in managing SHD is the prevention of these life-threatening complications, especially SCD. The definitive treatment lies in surgically or catheter-based correction of the underlying structural abnormality.[1] However, if VAs develops in the interim, pharmacological options such as beta-blockers and AADs are often used. While these drugs may provide some therapeutic benefit, they are frequently associated with limited efficacy and significant side effects.[3]

As a result, implantable cardioverter-defibrillators (ICDs) and catheter ablation have become central to the management of patients with SHD and VAs. ICDs work by detecting abnormal cardiac rhythms and delivering defibrillation shocks to terminate them, thereby preventing SCD.[4] However, it's important to recognize that while ICDs can prevent fatal arrhythmic events, they do not treat the underlying arrhythmogenic substrate. Consequently, they do not prevent the recurrence of Vas.[5] Additionally, repeated shocks from the ICD can negatively impact the patient's quality of life, leading to anxiety and psychological distress.[3]

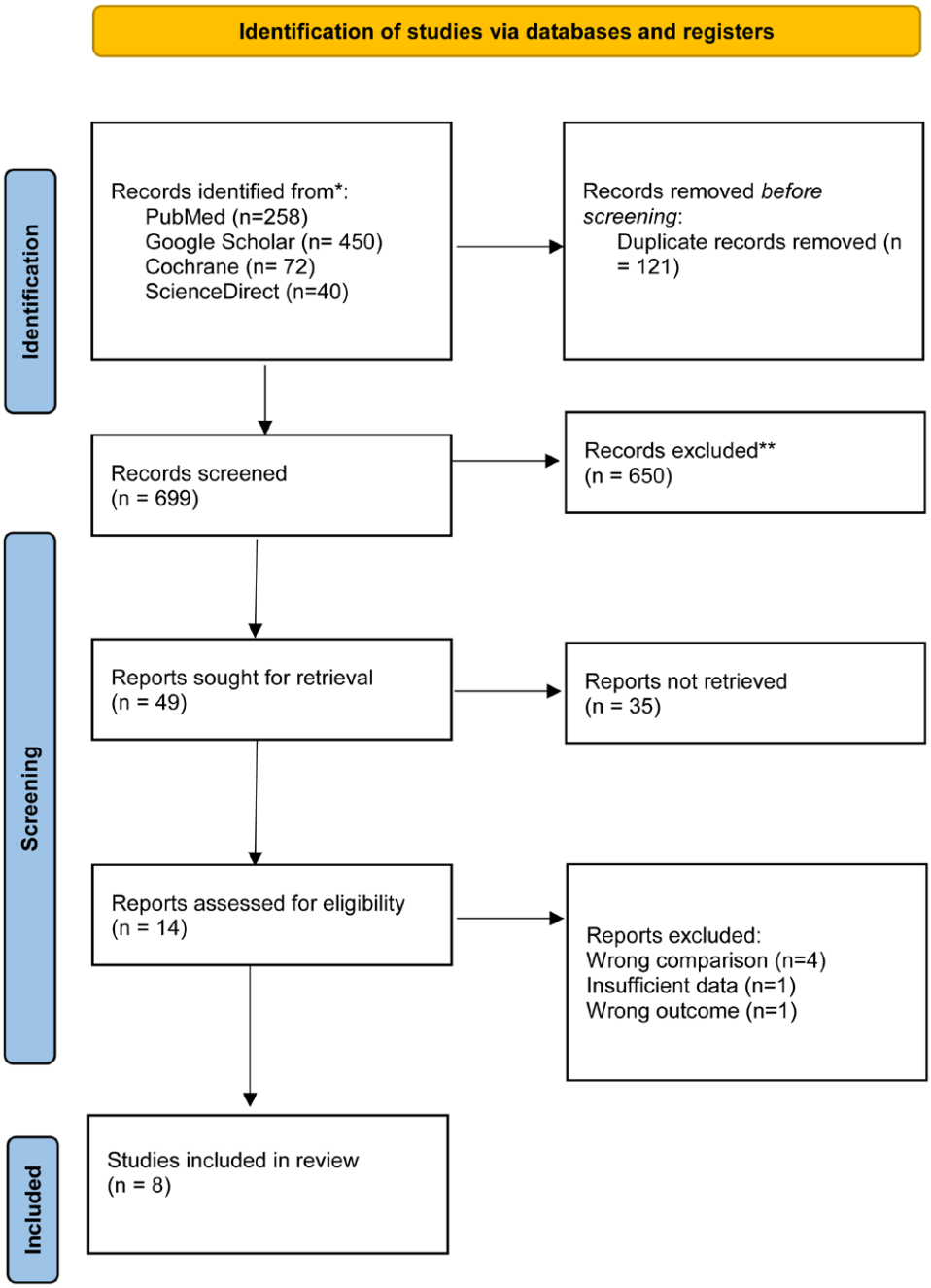

Figure 1. PRISMA flow chart for systematic review and meta-analysis. PRISMA = preferred reporting items for systematic reviews and meta-analyses.

Table 1

Study characteristics table.

Study author	Study year	Study design	Country of study	Sample size in CA	Sample size in control
Al-Khatib et al[9]	2014	Multicenter randomized clinical trial	USA	13	14
Krummen et al[10]	2021	Prospective 2-center study	USA	6	6
Bella et al[11]	2022	Prospective, multicenter, randomized clinical trial	Italy, France, Switzerland, Portugal, Germany	23	24
Arenal et al[12]	2022	Multicenter randomized controlled trial	Spain	71	73
Sapp et al[13]	2025	Multicenter RCT	Canada, USA, France	203	213
Mowraski et al[14]	2017	Single center retrospective study	Poland	28	42
Sapp et al[15]	2016	Multicenter RCT	Canada, Europe, USA and Australia	132	127
Tung et al[16]	2022	Multicenter RCT	China, Japan, South Korea, Taiwan	60	61

CA = catheter ablation, RCT = randomized controlled trial.

Catheter ablation, on the other hand, offers a more targeted approach by addressing the root cause of arrhythmia. It modifies the abnormal electrical substrate responsible for VAs, potentially reducing the frequency of arrhythmia recurrence and the number of ICD shocks.[6] This makes catheter ablation a highly valuable therapeutic option in this patient population.[7]

Several clinical trials have evaluated the role of catheter ablation in treating VAs.[8] however, there is a need to more precisely define its clinical efficacy and incremental benefits in patients with SHD who are also receiving ICD therapy.

The objective of this meta-analysis is to compare catheter ablation with standard treatment or control in terms of mortality, morbidity, recurrence of VAs, ICD shocks, and other clinical outcomes. Our goal is to contribute to the growing body of evidence in this field and support future research directions in the management of SHD-associated VAs.

2. Methodology

2.1. Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for conducting the study. An initial comprehensive literature search was performed till April 2025 to ensure inclusion of the most recent evidence prior to submission. The databases searched included PubMed/MEDLINE, Cochrane Library, Google Scholar, and ScienceDirect. Keywords such as "Catheter Ablation," "Implantable Cardioverter-Defibrillator," and "SHD" were used in all databases, supplemented by manually selected additional terms to maximize retrieval of relevant studies.

In adherence with the PICO criteria, all studies were included having Patients with SHD undergoing ICD therapy for Vas; The intervention being assigned as Catheter Ablation; The comparison group being any alternative treatment, for example, antiarrhythmic drugs (AADs), placebo, or no catheter ablation; Any outcomes obtained comparing catheter ablation to alternative treatments, including recurrence of arrhythmias, mortality and efficacy of one treatment modality over the other; Only studies in English language were considered eligible; and only randomized controlled trials (RCTs), controlled clinical trials and cohort studies were included.

We excluded studies in which the patient population did not have SHD, or did not have ICDs. Studies were also excluded if the primary intervention was not catheter ablation, or if there was no control arm for comparison. All studies were excluded that were published in languages other than English. Studies for which full text articles could not be obtained were also omitted, as were all case reports, case series, editorials, reviews, and cross-sectional studies.

2.2. Data extraction and quality assessment

Data extraction was performed using a structured Google Sheet. A template was created with the author's name, study title, study design, type of study, sample population and year of publication listed for each article. Two types of variables were extracted: baseline characteristics and outcome measures. Baseline characteristics included age, sex, BMI, history of cardiac interventions such as coronary artery bypass grafting or percutaneous coronary intervention, comorbidities such as hypertension, diabetes, and renal insufficiency, ejection fraction percentage, and presence of atrial fibrillation or flutter. Outcome variables included mortality outcomes such as all-cause mortality, cardiovascular mortality and death. Arrhythmia recurrence and disease burden outcomes reported including recurrent VT, VT storm, Electrical storm and Cardiac hospitalization. Lastly ICD-related intervention outcomes were noted such as inappropriate ICD shocks, appropriate ICD shocks and appropriate anti tachycardia pacing (ATP). Two independent reviewers extracted data from each eligible study, which was then independently reevaluated and cross-checked by another pair of authors to ensure that key information was not missed and all relevant data were accurately identified.

The quality of the study was determined using the Cochrane risk of bias assessment tool (ROB 2.0) used for RCTs included in the study. The tool is employed to assess the methodological quality and to identify sources of potential bias in the included RCT.

2.3. Statistical analysis

Review manager was used for the statistical analyses. For dichotomous variables, odds ratios (ORs) with 95% confidence intervals were calculated, while for continuous variables, means and standard deviations were reported. Heterogeneity across studies was assessed using Cochran Q test and the I^2 statistic. A fixed-effect model was applied when heterogeneity was low ($I^2 \leq 50\%$ and $P \geq .05$). In cases of substantial heterogeneity ($I^2 > 50\%$ and/or $P < .05$), a random-effects model was employed to account for between-study variability. These thresholds were chosen in line with commonly accepted meta-analysis guidelines.

2.4. Ethical approval and patient consent

This study is a systematic review and meta-analysis of previously published data; as such, it did not require direct ethical approval from an institutional review board Moreover no new patient consent was required, as only aggregated, de-identified data were analyzed..."

3. Results

3.1. Study selection process

The systematic literature searches across 4 databases initially identified 820 potentially relevant records. Following the removal of 121 duplicate records, 699 unique records underwent title and abstract screening by 2 independent reviewers. From these, 19

Table 2

Baseline characteristics of the study population.

Study author	Age in CA (mean ± SD)	*A* age in Ctrl (Mean ± SD)	Male sex in CA (n)	Male sex in Ctrl (n)	Previous CABG in CA (n)	Previous CABG in Ctrl (n)	Previous PCI in CA (n)	Previous PCI in Ctrl (n)	HTN in CA (n)	HTN in Ctrl (n)	Diabetes in CA (n)	Diabetes in Ctrl (n)	EF in CA (%) (mean ± SD)	EF in Ctrl (%) (mean ± SD)	Renal insufficiency in CA (n)	Renal insufficiency in Ctrl (n)	Atrial fibrillation/ flutter in CA (n)	Atrial fibrillation/ flutter in Ctrl (n)
Al-Khatib et al[9]	63 ± 30.73	63.67 ± 32.95	13	12	8	8	6	8	9	12	6	5	35 ± 41.53	26 ± 29.35	2	2	5	4
Krummen et al[10]	60 ± 10	65 ± 15			2	1	NA	NA	3	5	0	2	38 ± 20	28 ± 6	NA	NA	3	4
Bella et al.[11]	71.2 ± 8.1	65.6 ± 9.6	19	21	NA	NA	NA	NA	17	15	4	9	31.9 ± 9.0)	32.4 ± 8.3	3	6	9	9
Arenal et al.[12]	69.33 ± 9.08	70.33 ± 9.08	70	68	18	12	26	26	56	47	21	15	LVEF < 30%: 31	LVEF < 30%: 36	8	7	9	8
Sapp et al[13]	67.7 ± 8.6	68.4 ± 8.0	193	197	82	88	128	121	160	169	79	83	34.0 ± 11.0	34.3 ± 10.3	31	23	70	72
Mowraski et al[14]	65.75 ± 8.93	64.02 ± 11.8	26	38	8	5	NA	NA	16	28	12	13	27.11 ± 6.27	25.59 ± 7.95	8	18	13	18
Sapp et al[15]	67.0 ± 8.6	70.3 ± 7.3	123	118	63	55	50	62	92	88	37	40	31.1 ± 10.4	31.2 ± 10.7	23	26	52	47
Tung et a[16]	53.83 ± 14.81	55.67 ± 12.15	44	54	NA	NA	NA	NA	19	21	8	15	44 ± 22.03	39.33 ± 13.67	6	6	9	8

CA = catheter ablation, CABG = coronary artery bypass grafting, Ctrl = control, EF = ejection fraction, HTN = hypertension, LVEF = left ventricular ejection fraction, PCI = percutaneous coronary intervention, SD = standard deviation.

records were considered potentially eligible and proceeded to full-text review. Ultimately, 8 studies met all pre-specified inclusion criteria and were included in the final analysis. The study selection process is visually represented using a PRISMA flow diagram (Fig. 1), illustrating the number of records identified, screened, assessed for eligibility, and ultimately included in the final review. Table 1 [9-16] shows the characteristics of the studies included in this review. Table 2 [9-16] shows the baseline characteristics of the patients included in the study. Table 3 [9-16] shows the control groups used in included studies.

Table 3

Shows the control group used in included studies.

Al-Khatib et al[9]	**In the CALYPSO pilot study, control therapy followed 2006 ACC/AHA guidelines, allowing use of amiodarone and sotalol as first-line therapies, with mexiletine, ranolazine, and dofetilide as second-line options.**
Al Krummen et al[10]	Sotalol, dofetilife, amiodarone, mexilitene
Belle et al[11]	ICD therapy plus optimal heart failure medication, Amiodarone was not allowed in the trial except in two specific circumstances: As a bridge to ablation during an electrical storm (VT storm). For treating atrial tachyarrhythmias (e.g., atrial fibrillation/flutter
Arenal et al[12]	Unless contraindicated, patients in the AAD group were treated with amiodarone + beta-blockers (strategy #1), those with contraindication to amiodarone were treated with sotalol ± beta-blockers (strategy #2), and those with contraindication or intolerance to beta-blockers received only amiodarone (strategy #3).
Sapp et al[13]	Sotalol 120 mg twice daily or Amiodarone starting at 400 mg BID → 400 mg QD → 200 mg QD maintenance
Mowraski et al[14]	RFCA was abandoned in 20 patients during hospitalization despite undetected and potentially reversible cause of electrical instability, due to the disappearance of arrhythmia as a result of the intensification of antiarrhythmic therapy (increased doses of β-blockers (20 patients) and to the inclusion of treatment with antiarrhythmic class III drugs (14 patients; 13 with amiodarone, 1 with sotalol)
Sapp et al[15]	Escalation of antiarrhythmic drug therapy consisted of switching from sotalol to amiodarone, increasing the dose of amiodarone to at least 300 mg per day, or adding mexiletine to amiodarone.
Tung et al[16]	Beta blocker and anti-arrhythmic drugs

AAD = antiarrhythmic drug, BID = bis in die (twice daily), ICD = implantable cardioverter-defibrillator, QD = quaque die (once daily), RFCA = radiofrequency catheter ablation, VT = ventricular tachycardia.

Table 4

Compares the outcome of catheter ablation versus control group.

Outcome	Effect model	OR/RR	Heterogenity	Odds ratio	*P* value
All-cause mortality	RE	OR	I^2 = 39%	0.48 (0.15–1.57)	.22
Cardiovascular mortality	FE	OR	I^2 = 0%	0.79 (0.45–1.38)	.41
Death	RE	OR	I^2 = 52%	0.62 (0.26–1.48)	.28
Recurrent VT	FE	OR	I^2 = 14%	0.54 (0.33–0.89)	.02
Cardiac Hospitalization	FE	OR	I^2 = 18%	0.64 (0.44–0.94)	.02
VT storm	FE	OR	I^2 = 0%	0.67 (0.41–1.10)	.12
Electrical storm	FE	OR	I^2 = 0%	0.64 (0.33–1.23)	.18
Inappropriate ICD shocks	FE	OR	I^2 = 0%	0.49 (0.31–0.80)	.004
Appropriate ICD shocks	FE	OR	I^2 = 0%	0.85 (0.55–1.31)	.46
Appropriate ATP	FE	OR	I^2 = 0%	0.82 (0.53–1.28)	.39

ATP = appropriate anti tachycardia pacing, FE = fixed effect, ICD = implantable cardioverter-defibrillator, OR = odds ratio, RE = random effect, RR = risk ratio, VT = ventricular tachycardia.

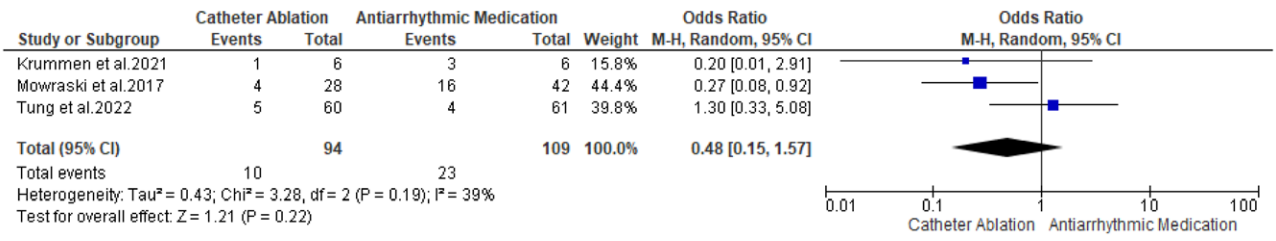

Figure 2. Forest plot of all-cause mortality in catheter ablation versus control group.

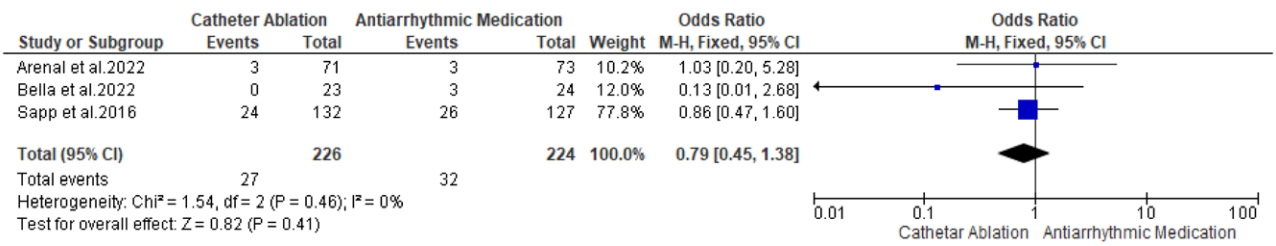

Figure 3. Forest plot of cardiovascular mortality in catheter ablation versus control group.

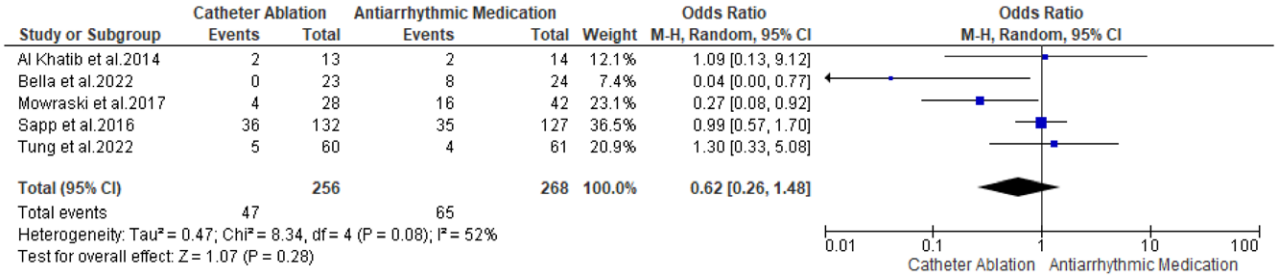

Figure 4. Forest plot of death in catheter ablation versus control group.

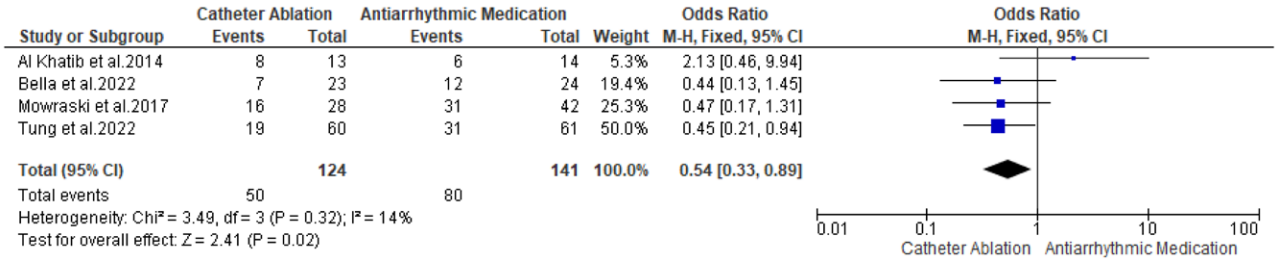

Figure 5. Forest plot of recurrent VT in catheter ablation versus control group. VT = ventricular tachycardia.

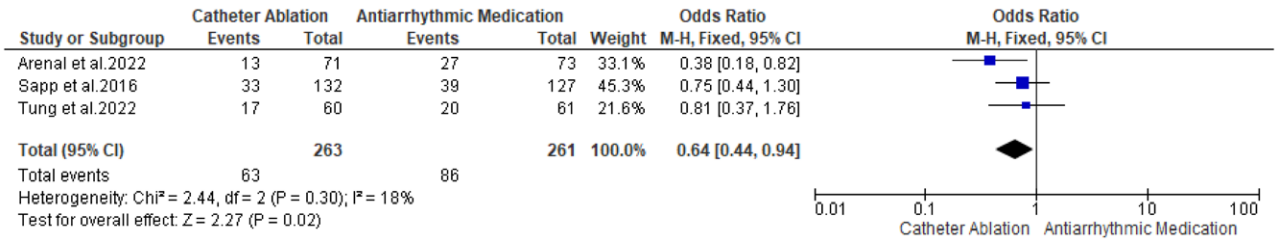

Figure 6. Forest plot of cardiac hospitalization in catheter ablation versus control group.

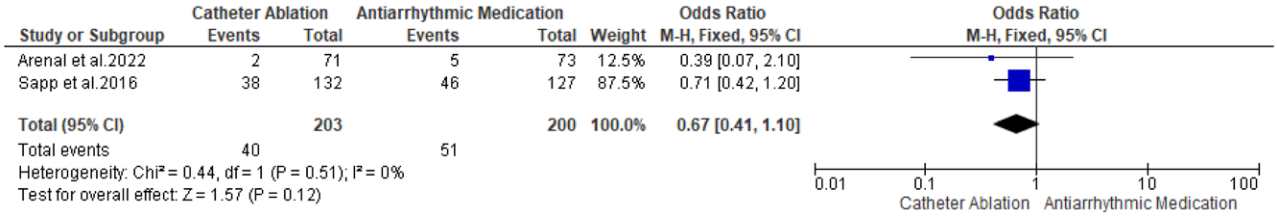

Figure 7. Forest plot of VT storm in catheter ablation versus control group. VT = ventricular tachycardia.

3.2. Outcomes

Our analysis identified ten predefined outcomes to evaluate the incremental benefits of catheter ablation in patients with ventricular tachycardia (VT) who underwent implantation of an implantable cardioverter defibrillator (ICD). These outcomes were grouped into 3 main categories: mortality outcomes, arrhythmia recurrence and disease burden, and ICD intervention outcomes. Table 4 shows the effect size, *P* value and heterogeneity of outcomes assessed.

3.3. Mortality outcomes

The mortality outcomes assessed in this analysis included all-cause mortality, cardiovascular mortality, and overall death. Across all 3 measures, the ORs favored the catheter ablation group, indicating that mortality events were reported less frequently among patients who underwent catheter ablation compared to those receiving AAD therapies. However, none of these differences reached statistical significance, reflecting that mortality outcomes were essentially equivalent between the catheter ablation and antiarrhythmic therapy groups. Figures 2–4 show forest plots of all-cause mortality, cardiovascular mortality and death in catheter ablation versus control group

3.4. Arrhythmia recurrence and disease burden outcomes

The arrhythmia recurrence and disease burden included the following outcomes: recurrent VT, VT storm, electrical storm, and cardiac hospitalization. These outcomes were reported less frequently in the catheter ablation group compared to the antiarrhythmic therapy group. Among these, recurrent VT and cardiac hospitalization showed statistically significant differences, reflecting a meaningful

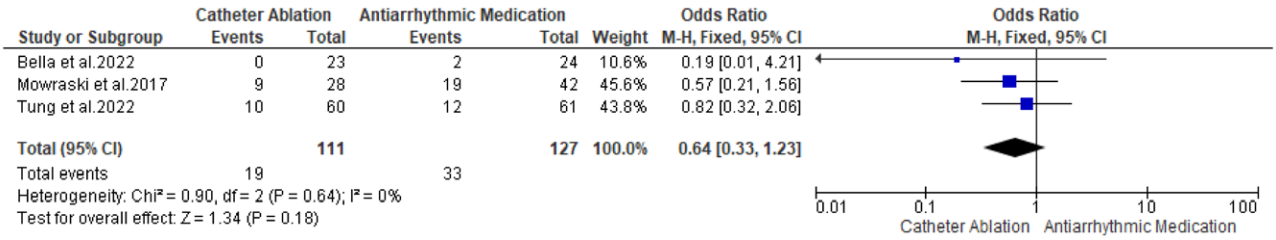

Figure 8. Forest plot of electrical storm in catheter ablation versus control group.

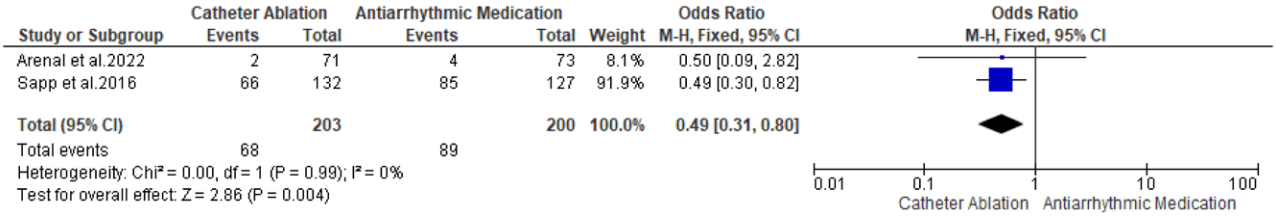

Figure 9. Forest plot of inappropriate ICD shocks in catheter ablation versus control group. ICD = implantable cardioverter-defibrillator.

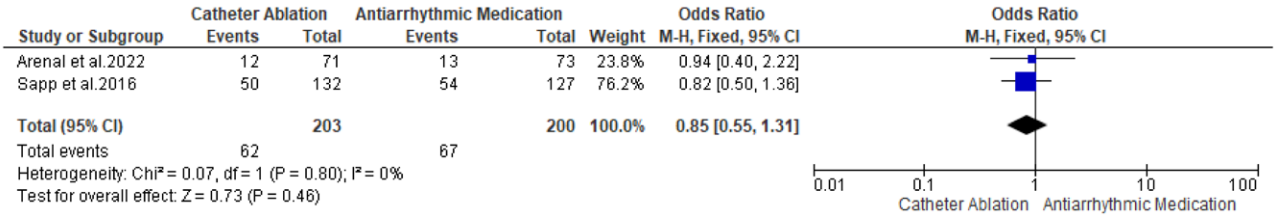

Figure 10. Forest plot of appropriate ICD shocks in catheter ablation versus control group. ICD = implantable cardioverter-defibrillator.

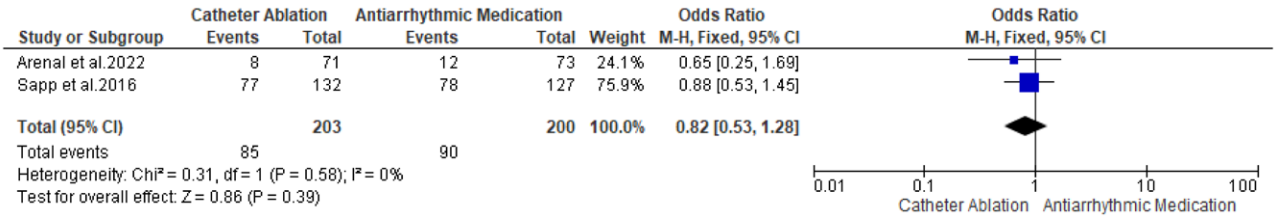

Figure 11. Forest plot of ATP in catheter ablation versus control group. ATP = anti-tachycardia pacing.

reduction in these events with catheter ablation. This underscores a greater advantage of catheter ablation in controlling arrhythmia burden and lowering the need for hospital admissions. In contrast, no significant differences were observed for VT storm or electrical storm, with outcomes remaining comparable between the 2 treatment approaches. Figures 5–8 show forest plots of recurrent VT, cardiac hospitalization, VT storm and electrical storm in Catheter ablation versus Control group.

3.5. ICD intervention outcomes

The ICD intervention outcomes encompassed appropriate ICD shocks, appropriate ATP, and inappropriate ICD shocks. For each of these outcomes, event rates were lower in the catheter ablation group compared to the antiarrhythmic therapy group. Among them, inappropriate ICD shocks reached statistical significance, reflecting a substantial decrease in unnecessary device therapies with catheter ablation. This finding supports the role of ablation in reducing patient exposure to avoidable interventions and enhancing device-related safety. In contrast, no significant differences were observed in the rates of appropriate ICD shocks or ATP, suggesting that both treatment strategies performed similarly in delivering necessary device therapies. Figures 9–11 show forests plots of inappropriate ICD shocks, appropriate ICD shocks and ATP in catheter ablation versus control group.

3.6. Risk of bias assessment

A total of 8 studies were included, comprising 6 RCTs and 2 non-randomized studies. For RCTs, the Cochrane risk of bias 2.0 (ROB 2) tool was applied. As illustrated in the ROB 2 traffic-light plot (Fig. 12) and summary plot (Fig. 13), variable risks were identified across domains. The most frequent concerns arose in RCTs and 2 non-randomized studies. For RCTs, the Cochrane risk of bias 2.0 (ROB 2) tool was applied. As illustrated in the ROB 2 traffic-light randomization (Domain 1) and deviations from intended interventions (Domain 2). Conversely, most studies were judged at low risk for missing outcome data (Domain 3), outcome measurement (Domain 4), and selective reporting (Domain 5). Two RCTs were judged to have an overall high risk of bias, while the remaining 4 were judged as either low risk or with some concerns.

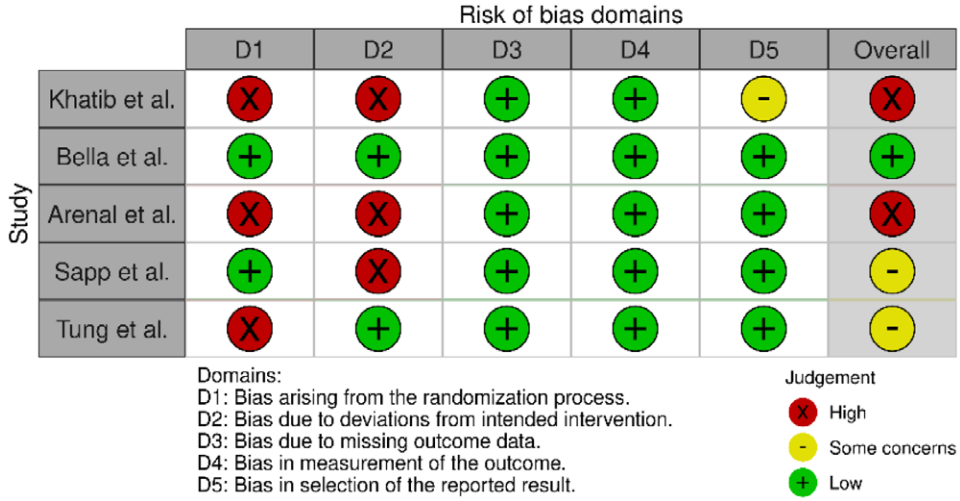

Figure 12. ROB 2 traffic plot. ROB 2 = Cochrane risk of bias 2.0.

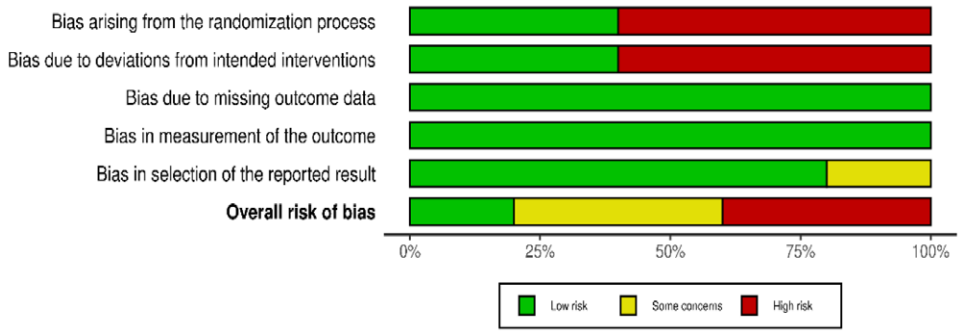

Figure 13. ROB 2 summary plot. ROB 2 = Cochrane risk of bias 2.0.

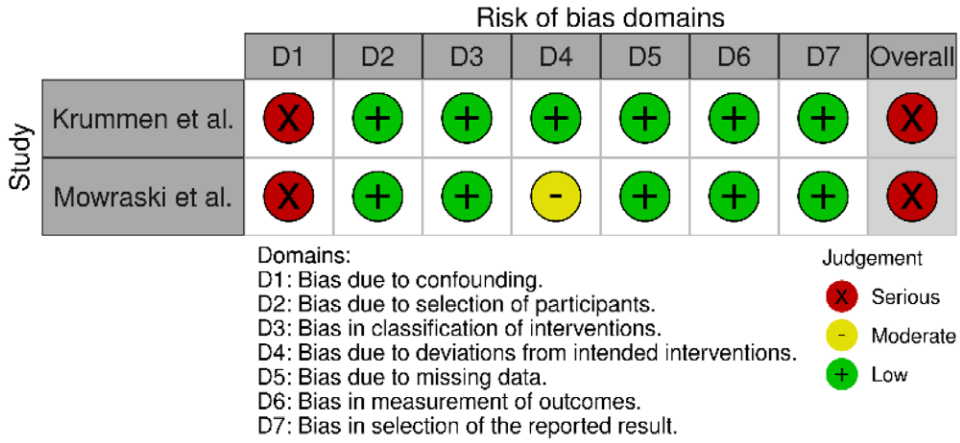

Figure 14. ROBINS-I traffic plot.

For the 2 non-randomized studies, the ROBINS-I tool was applied. Figure 14 shows the traffic plot and Figure 15 shows the summary plot for the non-randomized studies. Both were judged to have a serious overall risk of bias, primarily due to confounding and selection of participants (Domain 1). In one of these studies, additional concerns arose in bias due to deviations from intended interventions (Domain 4).

The results of these assessments were considered in data synthesis. Sensitivity analyses were performed to explore the impact of excluding studies at high or serious risk of bias, and no major changes in overall effect estimates were observed. Nonetheless, the presence of bias – particularly related to randomization and confounding – may have contributed to heterogeneity and should be considered when interpreting the findings.

3.7. Sensitivity analysis

All-cause mortality and overall death outcomes showed mild heterogeneity, with I^2 values of 39% and 52%, respectively. Upon exclusion of the study by Tung et al[16] heterogeneity in

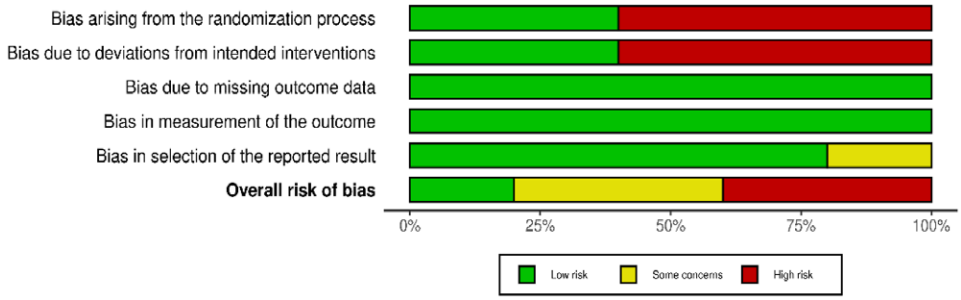

Figure 15. ROBINS-I summary plot.

Table 5

Sensitivity analysis of outcomes in catheter ablation versus control group.

Outcomes	Initial heterogeneity, %	Excluded study	New heterogeneity, %	*P*-value
All-cause mortality	39	Tung et al (2022)	0	.02
Death	52	Bella et al (2022)	26	.49

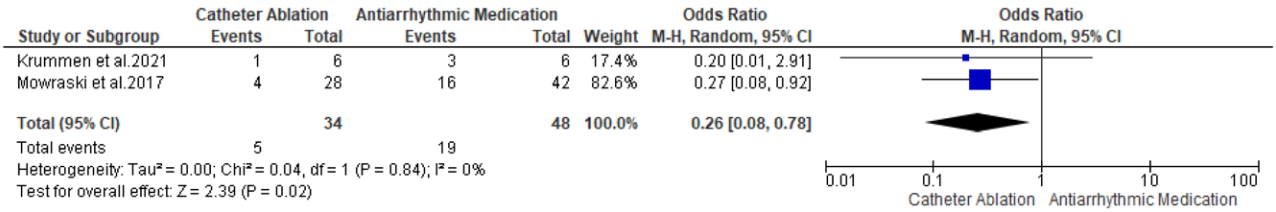

Figure 16. Forest plot of all-cause mortality for sensitivity analysis.

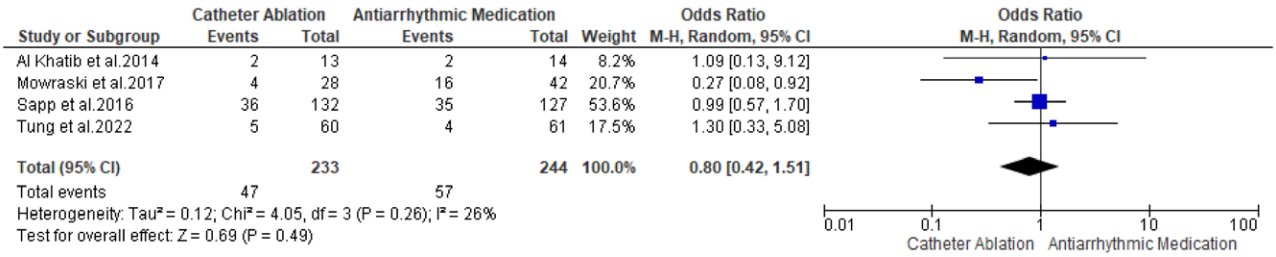

Figure 17. Forest plot of death for sensitivity analysis.

all-cause mortality was eliminated, pointing to its influence on variability across studies. In the case of overall death, removing Bella et al[11] reduced heterogeneity to 26%, reflecting a more consistent pattern in the remaining data. Table 5 presents the sensitivity analysis for all-cause mortality and overall death, highlighting the impact of individual studies on between-study heterogeneity. Figure 16 show Forrest plot of all-cause mortality and Figure 17 shows forest plot of death for sensitivity analysis.

3.8. Publication bias

Given that Egger[17] test has limited statistical power when applied to fewer than ten studies, current methodological guidelines advise against its use in such cases. As our analysis included only 9 studies, we did not perform Egger[17] test to assess publication bias.

4. Discussion

In this meta-analysis of 6 RCT and 2 non-randomized trials, we evaluated the incremental benefits of catheter ablation in patients with SHD undergoing ICD therapy for VAs. Three major categories of outcomes were analyzed: mortality, arrhythmia recurrence and disease burden, and ICD-related interventions, comparing patients undergoing catheter ablation for ventricular tachycardia to those not receiving ablation. Three major categories of outcomes were analyzed: mortality, arrhythmia recurrence and disease burden, and ICD-related interventions, comparing patients undergoing catheter ablation for ventricular tachycardia to those not receiving ablation.

Mortality outcomes, including all-cause mortality, cardiovascular mortality, and overall death, were comparable between the 2 groups, with no statistically significant differences observed. However, the lack of a mortality benefit must be interpreted with caution. Follow-up duration in most included studies was relatively short (ranging from 1–3 years), which may not be sufficient to detect long-term differences in survival. Mortality reduction associated with decreased arrhythmia burden often emerges after longer observation periods, suggesting that extended follow-up may be required to fully capture potential benefits. In addition, it is plausible that specific subgroups – such as patients with frequent VT recurrences, those experiencing

electrical storm, or those with more advanced left ventricular dysfunction – may derive greater survival benefit from early ablation compared to broader, less selected populations.

In contrast, patients who underwent catheter ablation demonstrated significant improvements in VT recurrence and cardiac hospitalization. Outcomes for VT storm and electrical storm were similar across both groups, suggesting no added benefit of ablation in mitigating these particular disease burdens. Additionally, patients in the catheter ablation group experienced fewer inappropriate ICD shocks, thereby avoiding unnecessary device interventions. Appropriate ICD therapies and antitachycardia pacing (ATP), however, showed no significant differences between the groups, indicating comparable effectiveness in necessary device-based treatments. Collectively, these findings indicate that while catheter ablation consistently reduces arrhythmia burden, its translation into survival improvement remains uncertain. From a clinical decision-making perspective, this suggests that the timing of ablation should be individualized. Early referral for ablation may be reasonable in patients with high arrhythmic burden or recurrent shocks, even in the absence of proven mortality reduction, because improvements in quality of life and reductions in hospitalizations are well established.

This is the first meta-analysis to assess the benefits of catheter ablation specifically in patients with SHD who are already receiving ICD therapy for VAs. Previous meta-analyses have primarily focused on patients with ischemic heart disease.[18] The findings of our study align with those prior reports, showing no significant improvement in mortality outcomes, including all-cause and cardiac-related mortality, following catheter ablation. Similar interventions in patients with ischemic heart disease have also demonstrated comparable results.[18] However, one study reported that catheter ablation for ventricular tachycardia, when compared with medical therapy alone, was associated with a significant reduction in mortality and cardiac hospitalization. The study included patients with SHD and ICDs and followed them for a period of 3 years. Improved outcomes were observed in the group receiving catheter ablation in addition to medical therapy, as opposed to those managed with medical therapy alone, highlighting the potential benefit of early interventional rhythm control in this population.[19] The SMASH-VT trial, a non-blinded randomized controlled study, suggested a potential reduction in mortality in the catheter ablation group; however, the difference did not reach statistical significance. The trial enrolled patients with a history of myocardial infarction who had received ICDs. Participants in the ablation arm underwent prophylactic substrate-based ablation, without the induction of ventricular tachycardia or the routine use of AADs.[20] VTACH, a multicenter randomized open trial, recruited patients with a stable VT, myocardial infarction and reduced left ventricular ejection fraction. Patients receiving prophylactic ablation alongside ICD therapy were generally healthier than those presenting with spontaneous VT; nevertheless, at the two-year follow-up, their mortality rates were not significantly different from those of untreated patients.[21] A study examining complications associated with catheter ablation reported 2 patient deaths directly attributed to the procedure. These complications were observed prospectively across diverse patient populations, including those with ventricular tachycardia, atrial fibrillation, supraventricular tachycardia, and SHD. Importantly, outcomes were assessed after adjusting for patient demographics, underscoring that while catheter ablation is generally safe, it carries a non-negligible risk.[22]

Our meta-analysis further demonstrated that VT recurrence was significantly lower in patients who underwent ablation therapy. Multiple studies targeting reentry circuits through VT ablation have reported reductions in recurrence ranging from 35 to 60% This is supported by findings from a study involving 33 patients with intra-cardiac shocks, as well as the SMS trial, both of which showed reduced episodes of VT following ablation.[23,24]

A case series on radiofrequency ablation also reported that VT was not inducible at a three-week follow-up.[25] In a multicenter intention-to-treat analysis, 26% of patients remained free of inducible ventricular tachycardia, while 34% experienced VT recurrence at the two-year follow-up.[26] Similarly, a 52-patient case series reported a recurrence rate of 33%.[27] Eligible patients had a history of monomorphic stable VT, VT due to coronary artery disease and had failed AAD therapies prior to enrollment. These patients underwent radiofrequency catheter ablation, which was aimed to evaluate efficacy of this ablation system.[26,27] Moreover, recurrence appeared to be more likely in patients who had undergone repeated ablation procedures. This observation was reported the International VT Ablation Center Collaborative (IVTCC), which conducted a retrospective multicenter analysis involving patients with SHD. The study evaluated the safety and efficacy of radiofrequency catheter ablation across a large cohort, focusing on procedural outcomes and complication rates.[28]

In terms of broader disease burden, our meta-analysis found no significant reduction in VT storm or electrical storm with catheter ablation. But both the SMS trial and a sub study of the VANISH trial reported significant reductions in VT event burden, particularly those associated with ICD shocks.[24,29] The discrepancy in findings compared to other studies may be observed because the SMS trial enrolled patients with coronary artery disease, unstable VT, cardiac syncope, and reduced left ventricular ejection fraction, and performed ablation following standard lesion mapping. In contrast, the VANISH trial included patients with a history of myocardial infarction who had failed AAD therapy, and assessed arrhythmia burden using the Andersen–Gill recurrent event model.

Finally, our analysis highlighted the efficacy of catheter ablation in reducing inappropriate ICD shocks, interventions that are unnecessary and potentially harmful. In contrast, appropriate ICD therapies and ATP did not differ significantly between the groups. Interestingly, the SMS trial and a sub study of the VANISH trial reported a significant reduction in appropriate ICD shocks and arrhythmia-induced ATP episodes following ablation.[24,29] In both these studies, randomization was categorized according to AAD therapy which may explain the improved outcomes.

This meta-analysis has several important strengths. It includes 8 studies with a large overall sample size, which increases the accuracy and reliability of the results. It is also the first meta-analysis to focus specifically on patients with SHD who are already receiving ICD therapy, a group not previously analyzed. Sensitivity analyses were performed to explore differences between studies, and those contributing to high variability were identified and noted. The clinical importance of this study is high, as repeated ICD shocks can be harmful to patients, AADs are often not effective and catheter ablation is usually started at a later stage of disease, when other treatments have failed. By including a diverse patient population based on demographics and characteristics, this meta-analysis helps to show the real-world benefits of catheter ablation in different settings where current treatments may not be enough.

4.1. Clinical implications

The findings of this meta-analysis highlight the importance of translating the benefits of catheter ablation into practical clinical decision-making. Based on the evidence, several considerations can guide patient management.

Patient selection for early ablation: Catheter ablation should be strongly considered in patients with SHD and ICDs who experience recurrent VT episodes, frequent ICD shocks, or

arrhythmia-related hospitalizations despite medical therapy. Subgroups with advanced left ventricular dysfunction, electrical storm, or high arrhythmic burden may derive the greatest benefit from earlier referral, given the consistent reductions observed in VT recurrence and inappropriate ICD therapies.

Optimal timing relative to ICD implantation: The analysis suggests that waiting until late disease stages may forfeit opportunities to reduce arrhythmia burden and hospitalizations. While a mortality benefit was not evident in the relatively short follow-up periods of most included trials, early ablation at or soon after ICD implantation – particularly in patients with frequent or symptomatic VT – may provide substantial quality-of-life and healthcare utilization benefits. This aligns with recommendations from recent consensus statements that support considering ablation after the first sustained VT or ICD shock rather than delaying until drug-refractory arrhythmias develop. While a mortality benefit was not evident in the relatively short follow-up periods of most included trials, early ablation at or soon after ICD implantation – particularly in patients with frequent or symptomatic VT – may provide substantial quality-of-life and healthcare utilization benefits. This aligns with recent consensus statements supporting consideration of ablation after the first sustained VT or ICD shock rather than delaying until drug-refractory arrhythmias develop.

Integration with AAD therapy: AADs remain an important adjunct, particularly in stabilizing patients acutely or when ablation targets are difficult to localize. However, the pooled evidence suggests that ablation provides superior reduction in VT recurrence and inappropriate shocks compared with drug therapy alone. A reasonable strategy is to use AADs for acute suppression and stabilization, with early transition to ablation in patients with recurrent arrhythmia or ICD interventions, rather than prolonged reliance on drug escalation.

Taken together, these data support a paradigm in which catheter ablation is integrated earlier in the treatment pathway for patients with SHD and ICDs. While further trials with extended follow-up are needed to clarify long-term mortality effects, current evidence justifies a proactive approach to reduce arrhythmia burden, limit ICD therapies, and improve patient quality of life.

4.2. Limitations

This meta-analysis has several limitations that should be acknowledged. First, the inclusion of 2 non-randomized trials introduces a potential risk of selection bias and contributes to heterogeneity in the pooled estimates. Second, the comparator arm varied across studies and consisted either of AAD therapy or a non-ablation control group. Among studies using drug comparators, there was considerable variability in drug types, regimens, and dosages. In some cases, AADs were used primarily to prevent emergency arrhythmic events, rather than as part of a consistent long-term treatment strategy. Third, the patient population across all included studies was restricted to individuals with SHD, which limits the generalizability of the findings to broader VT populations. Additionally, inconsistencies in the classification of VT morphology, with many studies failing to clearly report whether monomorphic VT was included or excluded, complicate interpretation and may have influenced outcomes. A key methodological limitation of our meta-analysis is that most included studies reported only dichotomous event counts without hazard ratios, restricting us to OR–based analyses at fixed follow-up points; therefore, the results should be interpreted with caution given the heterogeneity in follow-up durations across studies. Although sensitivity analyses excluding high- or serious-risk studies did not materially alter effect estimates, the presence of bias related to randomization and confounding remains an important limitation and may partly explain observed heterogeneity Lastly, in some studies, key outcomes were reported as median and interquartile range, which required statistical conversion to mean and standard deviation for inclusion in the meta-analysis, potentially affecting precision.

4.3. Future implications

While catheter ablation has shown benefits in treating stable arrhythmias, its effectiveness in managing unstable ventricular arrhythmia remains limited. Further research is needed to develop effective therapies for this high-risk subgroup. In addition, most current evidence is derived from controlled clinical trials, which may not fully reflect real-world practice. Future studies should explore the real-world application and long-term outcomes of catheter ablation to provide a more accurate understanding of its effectiveness. The potential role of newer technologies, such as cooled radiofrequency ablation, also warrants further investigation. In some patients, identifying the precise location of the arrhythmic focus remains challenging; therefore, integration of artificial intelligence (AI) and advanced imaging technologies may aid in improving the accuracy and success of ablation procedures. Lastly, future trials should more thoroughly account for patient demographics, as factors such as age, sex, comorbidities, and disease severity may significantly influence treatment outcomes.

5. Conclusion

Catheter ablation has shown notable benefits in patients with VAs by reducing VT recurrence, cardiac hospitalizations, and inappropriate ICD shocks. Since ICD shocks are associated with reduced quality of life and increased psychological distress, a therapy that minimizes these events is clinically valuable. Given the limitations of AADs, catheter ablation appears to be a promising approach and may potentially serve as a primary treatment option in selected patients.

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