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Determinants of Heart Failure Induced by Fluid Overload in Atrial Fibrillation Ablation Procedures Utilizing Irrigation Catheters

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Abstract

Background:

Catheter ablation has become a cornerstone therapy for managing atrial fibrillation (AF), with the use of irrigation catheters enhancing lesion efficacy and reducing thromboembolic events. However, excessive irrigation volumes can result in volume overload, predisposing patients to heart failure (HF) during or after the procedure. Early recognition of predictors is crucial to minimize procedural risks and optimize patient outcomes.

Aim and Objective:

To evaluate clinical, echocardiographic, and procedural predictors of heart failure caused by volume overload in patients undergoing catheter ablation for atrial fibrillation using irrigation catheters.

Methods:

This prospective observational study was conducted at Department of Cardiology, Fortis Escort Heart Institute, New Delhi, India, from January 2023 to December 2023 . A total of 120 consecutive patients diagnosed with atrial fibrillation and scheduled for radiofrequency catheter ablation using open-irrigation catheters were enrolled. Comprehensive pre-procedural clinical evaluation, laboratory

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testing, and echocardiographic assessment were performed. Intra-procedural data, including irrigation volume and ablation duration, were recorded. Post-procedure, patients were closely monitored for signs of heart failure due to volume overload. Multivariate logistic regression analysis was applied to identify independent predictors.

Results:

Out of 120 patients, 18 (15%) developed heart failure secondary to volume overload following the procedure. Multivariate analysis identified reduced left ventricular ejection fraction (LVEF <45%), elevated left atrial volume index (LAVI >40 mL/m²), elevated baseline brain natriuretic peptide (BNP >200 pg/mL), prolonged procedural time (>180 minutes), and higher total irrigation volume (>2000 mL) as significant independent predictors ($p < 0.05$). Early identification of these high-risk factors allowed for timely intra-procedural fluid management and post-procedural care, reducing adverse clinical outcomes.

Conclusion:

Heart failure related to volume overload after AF ablation using irrigation catheters is influenced by multiple clinical, echocardiographic, and procedural factors. Pre-procedure risk stratification and careful intra-procedural fluid management are essential to reduce the incidence of volume overload and associated complications in susceptible patients.

Introduction

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia encountered in clinical practice, associated with significant morbidity and increased risk of stroke, heart failure, and mortality **[1]**. The global prevalence of AF continues to rise, largely due to aging populations and increasing prevalence of associated comorbidities such as hypertension, diabetes mellitus, and structural heart disease. Catheter ablation has emerged as an effective rhythm control strategy for patients with symptomatic, drug-refractory AF, offering improved symptom control, quality of life, and potentially better long-term cardiovascular outcomes **[2,3]**.

Among the available catheter ablation techniques, radiofrequency (RF) ablation using open-irrigation catheters has become widely adopted due to its superior lesion formation, improved safety profile, and reduced risk of thrombus formation **[4]**. Irrigated-tip catheters deliver saline during RF energy

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application to cool the electrode-tissue interface, allowing for deeper and more effective lesion formation while minimizing complications such as char formation and steam pops. However, the continuous infusion of irrigation fluid can result in significant intravascular volume load, particularly during prolonged procedures, placing susceptible patients at risk of volume overload and subsequent heart failure **[5,6]**.

Volume overload-induced heart failure during or after catheter ablation represents a clinically significant complication, particularly in patients with underlying left ventricular dysfunction, diastolic dysfunction, or structural heart disease. The ability to predict which patients are at higher risk for developing volume overload is crucial for pre-procedural planning, optimal intra-procedural fluid management, and timely post-procedural care **[7,8]**.

While several studies have addressed the safety and efficacy of catheter ablation, data specifically focusing on predictors of volume overload-related heart failure in this setting remain limited. Understanding the interplay of clinical characteristics, echocardiographic parameters, and procedural variables may allow for better patient selection, individualized procedural strategies, and reduction in adverse outcomes.

In this context, the present study was undertaken to systematically evaluate the clinical, echocardiographic, and procedural predictors of heart failure caused by volume overload in patients undergoing catheter ablation for atrial fibrillation using open-irrigation catheters at Fortis Escort Heart Institute, New Delhi, India.

Materials and Methods

This prospective observational study was conducted in Department of Cardiology, Fortis Escort Heart Institute, New Delhi, India, from January 2023 to December 2023. The study was aimed to evaluate the predictors of heart failure due to volume overload during catheter ablation for atrial fibrillation using open-irrigation catheters.

Study Population:

A total of 120 adult patients diagnosed with atrial fibrillation who were scheduled for catheter ablation using open-irrigation catheters were consecutively enrolled in the study.

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Inclusion Criteria:

- Age ≥ 18 years.
- Documented paroxysmal or persistent atrial fibrillation.
- Scheduled for radiofrequency catheter ablation using open-irrigation catheters.
- Failure of at least one antiarrhythmic drug.
- Provided written informed consent.

Exclusion Criteria:

- Decompensated heart failure at baseline.
- Significant valvular heart disease.
- Severe renal impairment (eGFR <30 mL/min/1.73 m^2).
- Active systemic infections.
- Severe pulmonary hypertension (pulmonary artery systolic pressure >60 mmHg).
- Patient refusal to participate.

Pre-procedural Evaluation:

All patients underwent comprehensive clinical evaluation including detailed history, assessment of comorbidities (hypertension, diabetes, ischemic heart disease, renal dysfunction), physical examination, and laboratory tests:

- Complete blood count, renal function, liver function, serum electrolytes, coagulation profile, and brain natriuretic peptide (BNP).
- Standard 12-lead ECG.
- Transthoracic echocardiography assessing left ventricular ejection fraction (LVEF), left atrial volume index (LAVI), diastolic function, valvular status, and pulmonary artery systolic pressure.

Catheter Ablation Procedure:

Ablation was performed under conscious sedation or general anesthesia as per operator preference. Electroanatomical mapping guided the ablation strategy, primarily focusing on pulmonary vein isolation (PVI), with additional substrate modification where required.

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- Open-irrigation catheters were utilized in all procedures.
- Irrigation rates varied from 17–30 mL/min depending on power settings and anatomical location.
- Total procedural time, fluoroscopy time, total ablation time, and total irrigation volume were recorded for each patient.

Post-procedural Monitoring:

Patients were monitored for 48–72 hours in the cardiac care unit post-ablation. The following clinical features were closely assessed for detection of volume overload-induced heart failure:

- Dyspnea, orthopnea, peripheral edema.
- Elevated jugular venous pressure, pulmonary rales, weight gain.
- Chest radiography and echocardiography were repeated when clinically indicated.

Outcome Measures:

The primary outcome was the development of heart failure secondary to volume overload within 72 hours post-procedure. Diagnosis was based on clinical assessment, radiological evidence, and echocardiographic parameters suggestive of fluid overload.

Statistical Analysis:

Data were analyzed using SPSS software version XX. Continuous variables were expressed as mean ± standard deviation; categorical variables as frequencies and percentages. Univariate analysis identified potential predictors of volume overload-related heart failure. Variables with $p < 0.1$ on univariate analysis were subjected to multivariate logistic regression to identify independent predictors. A p-value < 0.05 was considered statistically significant.

Results

A total of 120 patients with atrial fibrillation underwent catheter ablation using open-irrigation catheters during the study period. The mean age of the study population was 61.8 ± 10.4 years, with a predominance of male patients (68.3%). Comorbidities such as hypertension (56.7%), diabetes mellitus (34.2%), and ischemic heart disease (20.8%) were frequently observed. The majority of

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patients had paroxysmal atrial fibrillation (63.3%), while the remaining had persistent atrial fibrillation (36.7%). Pre-procedural echocardiographic evaluation revealed a mean left ventricular ejection fraction (LVEF) of 51.6 ± 9.2%, with 22.5% of patients demonstrating an LVEF below 45%. The mean left atrial volume index (LAVI) was 42.5 ± 8.9 mL/m², and baseline BNP levels averaged 180 ± 95 pg/mL. The mean total procedural duration was 165 ± 28 minutes, and the mean total irrigation volume was 1850 ± 410 mL. Post-procedurally, 18 patients (15%) developed heart failure attributable to volume overload, as evidenced by clinical features and supportive investigations. On univariate analysis, factors significantly associated with post-ablation volume overload-induced heart failure included reduced LVEF (<45%), elevated LAVI (>40 mL/m²), high baseline BNP (>200 pg/mL), prolonged procedural time (>180 minutes), and higher irrigation volume (>2000 mL). Multivariate logistic regression confirmed these variables as independent predictors.

Timely identification and management of at-risk patients led to favorable clinical outcomes, with no procedure-related mortality. Most patients responded to conservative management involving fluid restriction, diuretics, and supportive care.

Table 1: Demographic Characteristics of Study Population

Table 1 presents the basic demographic distribution of the enrolled patients, highlighting the predominance of elderly and male patients undergoing ablation for atrial fibrillation.

Variables	Values
Total Patients	120
Age (mean ± SD)	61.8 ± 10.4 years
Gender (Male)	82 (68.3%)
Gender (Female)	38 (31.7%)

Table 2: Distribution of Atrial Fibrillation Types

Table 2 shows the proportion of paroxysmal and persistent atrial fibrillation types among the study participants undergoing catheter ablation.

Type of AF	Number of Patients (%)

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Paroxysmal AF	76 (63.3%)
Persistent AF	44 (36.7%)

Table 3: Prevalence of Comorbidities

Table 3 presents the frequency of comorbid conditions such as hypertension, diabetes, and ischemic heart disease seen in the study population.

Comorbidities	Number of Patients (%)
Hypertension	68 (56.7%)
Diabetes Mellitus	41 (34.2%)
Ischemic Heart Disease	25 (20.8%)
Chronic Kidney Disease	12 (10.0%)
Obesity (BMI >30 kg/m²)	18 (15.0%)

Table 4: Pre-Procedural Echocardiographic Parameters

Table 4 shows the baseline echocardiographic characteristics of patients, including left ventricular ejection fraction and left atrial volume index before ablation.

Parameters	Mean ± SD / Frequency
LVEF (%)	51.6 ± 9.2
LVEF <45%	27 (22.5%)
LAVI (mL/m²)	42.5 ± 8.9
LAVI >40 mL/m²	69 (57.5%)
Pulmonary Artery Pressure (mmHg)	36.8 ± 8.4

Table 5: Baseline BNP Levels

Table 5 presents the distribution of baseline brain natriuretic peptide (BNP) levels as an indicator of pre-procedural cardiac strain.

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BNP Levels (pg/mL)	Number of Patients (%)
BNP ≤200	81 (67.5%)
BNP >200	39 (32.5%)
Mean BNP (pg/mL)	180 ± 95

Table 6: Procedural Characteristics

Table 6 shows key procedural details such as total procedure time, ablation time, and total irrigation volume used during catheter ablation.

Parameters	Mean ± SD
Total Procedure Time (minutes)	165 ± 28
Total Ablation Time (minutes)	52 ± 15
Total Irrigation Volume (mL)	1850 ± 410

Table 7: Incidence of Post-procedural Volume Overload-Induced Heart Failure

Table 7 shows the incidence of patients who developed volume overload-induced heart failure following catheter ablation.

Outcome	Number of Patients (%)
Developed HF	18 (15.0%)
No HF	102 (85.0%)

Table 8: Comparison of LVEF Between HF and Non-HF Groups

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Table 8 presents the comparison of left ventricular ejection fraction between patients who developed heart failure and those who did not.

Group	LVEF (%) (mean ± SD)
HF Group	42.3 ± 5.1
Non-HF Group	53.1 ± 7.2
p-value	< 0.001

Table 9: Comparison of LAVI Between HF and Non-HF Groups

Table 9 shows the differences in left atrial volume index (LAVI) between the heart failure and non-heart failure groups post-ablation.

Group	LAVI (mL/m²) (mean ± SD)
HF Group	49.2 ± 7.8
Non-HF Group	40.8 ± 7.3
p-value	< 0.001

Table 10: Comparison of Procedural Time Between HF and Non-HF Groups

Table 10 presents the differences in total procedural time between patients who developed heart failure and those who remained stable.

Group	Procedural Time (min) (mean ± SD)
HF Group	182 ± 20
Non-HF Group	161 ± 26

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p-value	< 0.001

Table 11: Comparison of Irrigation Volume Between HF and Non-HF Groups

Table 11 shows the comparison of total irrigation volumes delivered during ablation between the two patient groups.

Group	Irrigation Volume (mL) (mean ± SD)
HF Group	2200 ± 350
Non-HF Group	1780 ± 390
p-value	< 0.001

Table 12: Multivariate Logistic Regression for Predictors of Volume Overload-Induced Heart Failure

Table 12 presents the independent predictors identified on multivariate logistic regression analysis for volume overload-induced heart failure following ablation.

Predictor Variables	Odds Ratio (OR)	95% CI	p-value
LVEF <45%	3.85	1.80–8.22	0.001
LAVI >40 mL/m²	2.96	1.37–6.43	0.005
BNP >200 pg/mL	3.42	1.57–7.42	0.002
Procedural Time >180 min	2.74	1.18–6.36	0.019
Irrigation Volume >2000 mL	4.12	1.85–9.19	<0.001

Table 1 presented demographic characteristics; **Table 2** displayed AF type distribution; **Table 3** highlighted comorbidities; **Table 4** and **Table 5** described echocardiographic and BNP data; **Table 6** summarized procedural details; **Table 7** showed incidence of post-procedural HF; **Tables 8–11** compared key parameters between HF and non-HF groups; and **Table 12** identified independent predictors for volume overload-induced heart failure.

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Discussion

Atrial fibrillation remains a globally prevalent cardiac arrhythmia associated with significant morbidity, increased risk of stroke, and progressive heart failure. Over recent years, catheter ablation has emerged as a highly effective rhythm control strategy, especially in patients who remain symptomatic despite pharmacological therapy **[9]**. The advent of open-irrigation catheters has revolutionized ablation techniques by allowing efficient lesion formation while minimizing the risk of thromboembolic events and catheter-tip overheating. However, the inherent risk of intravascular volume overload caused by the continuous infusion of irrigant during lengthy procedures raises concern for the development of heart failure, particularly in susceptible individuals **[10]**.

In the present study, 120 patients with atrial fibrillation undergoing radiofrequency catheter ablation with open-irrigation catheters were prospectively evaluated to identify predictors of volume overload-induced heart failure. The incidence of post-procedural heart failure was noted in 15% of patients, highlighting the clinical relevance of this complication despite advancements in procedural safety. The analysis focused on patient-specific clinical parameters, echocardiographic findings, and procedural characteristics that contribute to this risk **[11,12]**.

The demographic data showed a predominance of elderly males, a finding consistent with global epidemiological trends in atrial fibrillation. The majority of the study population had paroxysmal atrial fibrillation, which aligns with current ablation indications. Importantly, comorbid conditions such as hypertension, diabetes mellitus, ischemic heart disease, and chronic kidney disease were highly prevalent in this cohort, suggesting their contributory role in both atrial remodeling and volume intolerance **[13,14]**.

Pre-procedural echocardiographic evaluation revealed that a significant proportion of patients had impaired left ventricular systolic function (LVEF <45%) and enlarged left atrial volume (LAVI >40 mL/m²). Both parameters reflect the chronic structural changes secondary to longstanding atrial fibrillation and coexistent cardiac pathology. Elevated BNP levels (>200 pg/mL) were also observed in approximately one-third of the population, further indicating pre-existing subclinical fluid overload or diastolic dysfunction **[15,16]**.

Procedural characteristics, including prolonged ablation time and higher irrigation volumes, were found to strongly correlate with post-ablation fluid overload. The mean procedural duration was

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approximately 165 minutes, while the mean total irrigation volume was 1850 mL, with some patients receiving irrigation volumes exceeding 2000 mL. These findings highlight the cumulative fluid burden imposed during ablation and the potential for volume intolerance in high-risk individuals **[17]**.

The multivariate logistic regression analysis identified several independent predictors for volume overload-induced heart failure. Reduced LVEF, elevated LAVI, high baseline BNP, procedural time exceeding 180 minutes, and irrigation volumes greater than 2000 mL emerged as statistically significant risk factors. These results emphasize the complex interplay of patient-related and procedural factors that collectively influence fluid tolerance during catheter ablation **[18,19]**.

The clinical implication of these findings lies in the need for meticulous pre-procedural risk stratification. Identification of high-risk individuals enables personalized procedural planning, such as minimizing ablation time, optimizing fluid management, and early diuretic administration. Furthermore, real-time intra-procedural monitoring of fluid balance may serve as an effective preventive strategy to mitigate the occurrence of volume overload in vulnerable patients **[20]**.

The study's findings are consistent with prior literature that underscores the importance of left ventricular function, atrial size, and procedural fluid burden as key determinants of post-ablation heart failure. However, this study adds valuable insight by quantifying these parameters and establishing specific thresholds that may guide clinical decision-making. Although the study is limited by its single-center design and relatively small sample size, the prospective nature and comprehensive evaluation strengthen the validity of the observed associations.

In conclusion, volume overload-induced heart failure remains a notable complication following catheter ablation for atrial fibrillation, despite technological advancements. Careful assessment of patient risk factors and procedural optimization can substantially reduce this complication and improve procedural safety and patient outcomes.

Conclusion

The present study highlights the significant clinical concern of volume overload-induced heart failure following catheter ablation for atrial fibrillation using open-irrigation catheters. Despite the recognized efficacy of this ablation strategy, procedural fluid burden remains a crucial factor, particularly in patients with compromised cardiac reserve. Our findings demonstrate that reduced left

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ventricular ejection fraction, elevated left atrial volume index, higher pre-procedural BNP levels, prolonged procedural duration, and excessive irrigation volumes are independent predictors of post-procedural heart failure. Early identification of these predictors enables clinicians to implement tailored procedural modifications, optimize intra-procedural fluid management, and initiate timely preventive measures such as diuretic therapy. Meticulous pre-procedural risk stratification, combined with vigilant peri-procedural monitoring, can substantially reduce the incidence of this potentially avoidable complication. These findings support a patient-centered approach that balances the procedural benefits of catheter ablation with individualized risk assessment. Further multicenter studies with larger sample sizes are warranted to validate these predictors and refine risk-based management protocols. Overall, integrating these predictive parameters into routine practice may improve procedural safety and enhance long-term outcomes for patients undergoing atrial fibrillation ablation.

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