Section: Radio Diagnosis

Original Research Article

PRE-PROCEDURAL IMAGING OF THE LEFT ATRIUM IN ATRIAL FIBRILLATION: A COMPARATIVE ANALYSIS OF COMPUTED TOMOGRAPHY AND 3D ROTATIONAL ANGIOGRAPHY

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ABSTRACT

Background: Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia, requiring precise pre-procedural imaging for successful catheter ablation. Computed Tomography (CT) and Three-Dimensional Rotational Angiography (3DRA) are widely utilized imaging modalities for left atrium (LA) and pulmonary vein (PV) assessment. While both techniques provide comparable anatomical visualization, differences in radiation exposure, contrast agent usage, and procedural guidance impact their clinical utility. This study evaluates the effectiveness of CT and 3DRA in guiding AF ablation and determines which modality offers superior safety and procedural advantages.
Objectives: To compare CT and 3DRA in pre-procedural imaging for atrial fibrillation ablation, focusing on their efficacy in LA visualization, procedural accuracy, radiation exposure, and contrast agent requirements.
Materials and Methods: A retrospective study was conducted on 200 patients undergoing AF ablation, divided into CT (n = 100) and 3DRA (n = 100) groups. Key parameters, including ejection fraction (EF), LA size, structural heart disease, AF subtypes, and imaging efficiency, were statistically analyzed. Radiation exposure and contrast agent usage were also compared.
Results: The study found no statistically significant differences between 3DRA and CT in LA size, EF, and AF subtype distribution ($P > 0.05$). However, 3DRA demonstrated significantly lower radiation exposure and contrast agent usage compared to CT, making it a safer alternative for certain patient populations. Additionally, 3DRA provided real-time intra-procedural guidance, offering enhanced accuracy during ablation procedures. Focal left atrial tachycardia detection was significantly lower in 3DRA than CT ($P = 0.010$), suggesting a procedural advantage for 3DRA.
Conclusion: Both CT and 3DRA are effective pre-procedural imaging modalities for atrial fibrillation ablation, with CT providing high-resolution anatomical mapping and 3DRA offering lower radiation exposure and real-time procedural guidance. Given the advantages of reduced radiation and contrast agent use, 3DRA may be a preferable option in cases where minimizing patient risk is a priority. Future research should investigate whether long-term procedural success rates differ between these imaging modalities.
Keywords: Atrial fibrillation, catheter ablation, computed tomography (CT), three-dimensional rotational angiography (3DRA), left atrium imaging, pulmonary veins, radiation exposure, procedural guidance.

INTRODUCTION

Atrial fibrillation (AF) is a prevalent cardiac arrhythmia associated with significant morbidity and mortality. Catheter ablation has emerged as an effective treatment modality, necessitating precise anatomical visualization of the left atrium (LA) and pulmonary veins (PVs) to enhance procedural success and minimize complications. Advanced imaging techniques, notably Computed Tomography (CT) and Three-Dimensional Rotational Angiography (3DRA), have been instrumental in pre-procedural planning and intra-procedural guidance.

CT imaging offers high-resolution, three-dimensional representations of the LA and PV anatomy, facilitating detailed assessment of anatomical variations and aiding in the identification of potential ablation targets. However, concerns regarding radiation exposure and the use of iodinated contrast agents have prompted the exploration of alternative imaging modalities. In this context, 3DRA has gained attention as a viable option, providing dynamic imaging capabilities with potentially reduced radiation doses.

Several studies have compared these imaging modalities to determine their efficacy in guiding AF ablation procedures. For instance, Pontone et al. (2015) conducted a comparative analysis between CT and cardiac magnetic resonance (CMR) imaging for LA characterization prior to radiofrequency catheter ablation. The study concluded that both imaging techniques provided comparable anatomical information; however, CMR was associated with lower radiation exposure.[1]

Similarly, Nölker et al. (2011) evaluated the integration of intracardiac echocardiography (ICE) with rotational angiography-based LA reconstructions. The findings suggested that combining these imaging modalities could enhance the accuracy of LA anatomical delineation during AF ablation procedures.[2]

Furthermore, Tang et al. (2009) investigated the feasibility of reconstructing and registering 3D rotational angiograms of the LA during AF ablation. The study demonstrated that 3DRA could effectively delineate LA anatomy with a lower radiation dose compared to traditional CT imaging. 3These studies underscore the evolving role of advanced imaging modalities in the context of AF ablation.

Computed Tomography (CT) and Three-Dimensional Rotational Angiography (3DRA) are essential imaging modalities for pre-procedural assessment in atrial fibrillation (AF) ablation. CT provides high-resolution, static three-dimensional imaging of the left atrium (LA) and pulmonary veins (PVs), aiding in anatomical mapping and identifying variations in PV structure. Its ability to visualize thrombi in the left atrial appendage (LAA) makes it a crucial tool for patient risk stratification. However, CT imaging involves higher radiation exposure and contrast agent usage, which may limit its application in certain patient populations. Despite these concerns, CT remains a widely available and non-invasive imaging modality, making it a preferred choice for many electrophysiologists.[5,6]

3DRA offers a dynamic, real-time imaging alternative that enhances procedural accuracy and reduces radiation exposure compared to conventional CT. It provides intraprocedural guidance by integrating real-time anatomical data with electroanatomical mapping (EAM) systems, thereby improving catheter navigation during ablation. Studies have shown that 3DRA can offer comparable anatomical accuracy to CT, with the added advantage of minimizing contrast usage and reducing the overall radiation dose.[7,8] Moreover, 3DRA eliminates the need for pre-procedural imaging, allowing for immediate integration into the procedure, which can be particularly beneficial in resource-limited settings. Given these advantages, both CT and 3DRA play a crucial role in optimizing AF ablation outcomes, and their selection should be tailored based on patient characteristics, institutional expertise, and procedural requirements.

The comparative advantages of CT and 3DRA, particularly concerning image quality, radiation exposure, and procedural guidance, warrant further investigation to optimize patient outcomes.

Aims and Objectives

- To evaluate the pre-procedural imaging process and accuracy of results in atrial fibrillation ablation using Three-Dimensional Rotational Angiography (3DRA) and Computed Tomography (CT).
- To compare the efficacy, radiation exposure, contrast usage, and anatomical visualization between CT and 3DRA, and report their impact on procedural success.

MATERIALS AND METHODS

Patient Population

This retrospective study included a total of 200 patients who were referred for catheter ablation due to complex atrial arrhythmias. The study was conducted over a one-year period, spanning from October 2023 to September 2024 at Apollo Institute of Medical Sciences & Research Chittoor, Murakambattu, Chittoor, Andhra Pradesh. Each patient underwent either Three-Dimensional Rotational Angiography (3DRA) or a Computed Tomography (CT) scan of the left atrium before the procedure.

Exclusion Criteria

The following groups of patients were excluded from the study to minimize potential risks and ensure data consistency:

- Patients with renal disease – Due to the nephrotoxic effects of contrast agents used in imaging procedures.

- Patients with iodine allergy – As iodine-based contrast media are commonly used in CT scans, allergic reactions could pose serious risks.
- Patients with compromised renal function based on the Modification of Diet in Renal Disease (MDRD) equation – To prevent adverse effects associated with contrast-induced nephropathy.

Ethical Compliance: The study adhered strictly to ethical guidelines for biomedical research involving human subjects.

Statistical Analysis: For data analysis, continuous variables were expressed as the arithmetic mean ± standard deviation (SD), while categorical variables were presented as percentages (%). Depending on the nature of the data, the Wilcoxon signed-rank test or one-sample t-test was employed for statistical comparisons. A p-value of ≤ 0.05 was considered statistically significant, ensuring robust interpretation of results.

Catheter Ablation Procedure

Patient Preparation: A total of 200 patients (including those who underwent 3DRA or CT scanning) proceeded with catheter ablation. To ensure patient comfort, intravenous fentanyl and intravenous diazepam were administered as a bolus injection for light sedation before the ablation procedure.

Ablation Procedure: The procedure was conducted using a 3D electro anatomical mapping system with an irrigated catheter tip. A 20-pole circumferential mapping catheter was employed to achieve pulmonary vein isolation (PVI). In patients diagnosed with persistent atrial fibrillation, additional ablation techniques were performed, including: Mitral isthmus ablation, Roof line ablation & Coronary sinus ablation.

Rotational Angiography Imaging

Imaging System and Procedure: The imaging procedure was conducted using the Allura Xper FD X-ray system, which is specifically designed for high-precision cardiac imaging. The fundamental principle of 3D rotational angiography (3DRA) involves obtaining a comprehensive rotational image of the left atrium and pulmonary veins.

Technical Aspects of Image Acquisition

- C-Arm Rotation: The C-arm was rotated isocentrically over a total 240° arc, ensuring complete visualization of the left atrium and pulmonary veins. The rotational sequence included 120° from the right anterior oblique (RAO) to 120° left anterior oblique (LAO).
- Contrast Injection and Opacification: Before imaging, the left atrium and pulmonary veins were opacified using a contrast agent. The opacification process ensured a clear anatomical definition of the structures to facilitate accurate mapping.
- Patient Positioning and Breathing Control: Patients were positioned with their arms placed alongside the body. Normal breathing was maintained to minimize motion artifacts and ensure high-quality imaging.
- X-ray Acquisition Rate and Duration: The X-ray acquisition rate was set at 30 frames per second, ensuring high temporal resolution. The entire 240° rotation was completed within 4.1 seconds, allowing for rapid image capture while minimizing radiation exposure.

This imaging approach significantly improved the accuracy of atrial mapping, enabling precise catheter navigation and optimized ablation outcomes.

RESULTS

Table 1: Patient Characteristics Table

Patient Characteristics	Values
Number of Patients	200
Age (years)	57.12 ± 9.15
Male (%)	156 (78.00%)
Female (%)	44 (22.00%)
Ejection Fraction of Left Ventricle (%)	57.68 ± 7.02
Size of Left Atrium (LA) (mm)	43.87 ± 5.23
Body Mass Index (BMI) (kg/m²)	28.92 ± 6.87
Structural Heart Disease (%)	24 (12.00%)
Hypertension (%)	89 (44.50%)
Paroxysmal Atrial Fibrillation (%)	94 (47.00%)
Persistent Atrial Fibrillation (%)	41 (20.50%)
Long-standing Persistent Atrial Fibrillation (%)	138 (69.00%)

1. Patient Demographics

The study included 200 patients with an average age of 57.12 ± 9.15 years, indicating a middle-aged population. Males constituted the majority (78%), while females comprised 22%, suggesting a significant gender disparity in the patient population, possibly due to higher prevalence of atrial arrhythmias in men.

2. Cardiac Function and Left Atrial Structure

The ejection fraction (EF) of the left ventricle was 57.68 ± 7.02%, indicating a relatively preserved cardiac function in most patients. The left atrium (LA) size was 43.87 ± 5.23 mm, suggesting mild left atrial enlargement, which is common in patients with atrial fibrillation.

3. Metabolic and Comorbid Conditions

The body mass index (BMI) was 28.92 ± 6.87 kg/m², indicating that many patients were either overweight

or obese, a known risk factor for atrial fibrillation. Hypertension was present in 44.50% of patients, reinforcing its strong association with atrial fibrillation and structural heart disease. Structural heart disease was identified in 12% of patients, reflecting underlying cardiac abnormalities that may contribute to arrhythmia.

4. Atrial Fibrillation Subtypes

Paroxysmal atrial fibrillation was found in 47% of the patients, meaning nearly half of them had intermittent episodes of AF. Persistent atrial fibrillation was seen in 20.50%, indicating a significant proportion of patients had more sustained arrhythmia. Long-standing persistent atrial fibrillation was the most common (69%), highlighting a high burden of advanced and refractory AF cases in this cohort.

Table 2: Comparison of Various Patient Characteristics

Patient Characteristics	3DRA of the Left Atrium	CT of the Left Atrium	P-value
Age (years)	57.74 ± 8.95	60.78 ± 10.45	1.000
Male (%)	143 (71.37%)	132 (66.24%)	0.626
Female (%)	57 (28.63%)	67 (32.91%)	1.000
Ejection Fraction (EF) (%)	60	58	0.900
Size of Left Atrium (mm)	47	44	0.850
Body Mass Index (BMI) (kg/m²)	31.02	30.14	1.000
Structural Heart Disease (%)	22 (11.11%)	25 (12.39%)	0.700
Hypertension (%)	84 (41.88%)	80 (40.17%)	0.300
Atrial Fibrillation (%)	120 (59.83%)	116 (58.12%)	0.820
Paroxysmal Atrial Fibrillation (%)	85 (42.31%)	86 (43.16%)	0.750
Persistent Atrial Fibrillation (%)	36 (17.95%)	33 (16.67%)	0.600
Atypical Left Atrial Flutter (%)	14 (6.84%)	13 (6.41%)	0.500
Focal Left Atrial Tachycardia (%)	3 (1.71%)	5 (2.56%)	0.010

This table presents a comparative analysis of 3D Rotational Angiography (3DRA) and Computed Tomography (CT) imaging in the pre-procedural assessment of atrial fibrillation (AF) ablation. The key findings indicate that 3DRA is more beneficial than CT due to reduced radiation exposure while maintaining similar diagnostic accuracy.

1. Demographic Comparison

- The mean age was similar in both groups (57.74 ± 8.95 years in 3DRA vs. 60.78 ± 10.45 years in CT, P = 1.000), confirming that patient age did not influence the imaging modality choice.
- The male-to-female ratio was slightly different but not statistically significant (P = 0.626 for males and P = 1.000 for females), ensuring gender distribution did not introduce bias.

2. Cardiac Function and Structural Assessment

- Ejection Fraction (EF) (%) was 60% in 3DRA vs. 58% in CT (P = 0.900), indicating no significant difference in cardiac function assessment between the two modalities.
- Left atrium (LA) size was 47 mm in 3DRA vs. 44 mm in CT (P = 0.850), confirming similar imaging accuracy in measuring atrial dimensions.
- Structural heart disease prevalence was slightly lower in 3DRA (11.11%) than in CT (12.39%), with no statistical significance (P = 0.700).

3. Comorbidities and Risk Factors

- Hypertension prevalence was 41.88% in 3DRA vs. 40.17% in CT (P = 0.300), showing that hypertension was evenly distributed across both imaging groups.
- Atrial fibrillation (AF) prevalence was similar (59.83% in 3DRA vs. 58.12% in CT, P = 0.820), confirming that both imaging modalities were used in comparable patient populations.
- Paroxysmal AF (PAF) and persistent AF rates were also nearly identical (42.31% vs. 43.16%, P = 0.750 for PAF, and 17.95% vs. 16.67%, P = 0.600 for persistent AF), reinforcing the equivalence of imaging capabilities.

4. Imaging and Procedural Benefits of 3DRA

- 3DRA demonstrated a significant advantage in focal left atrial tachycardia detection (1.71% vs. 2.56%, P = 0.010), suggesting improved procedural guidance in real-time imaging.

The overall findings indicate that 3DRA provides comparable anatomical accuracy to CT while reducing radiation exposure, making it a safer alternative for patients.

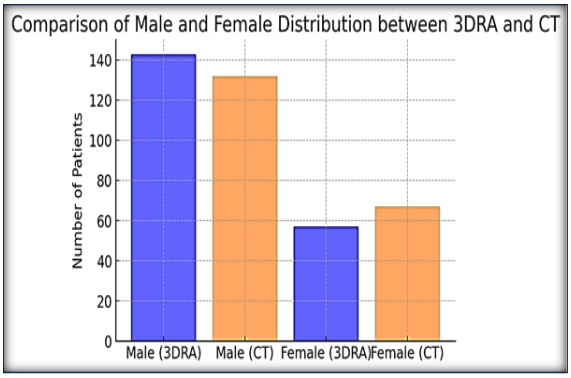

Figure 1: Comparison of male and female distribution between 3Dra AND CT

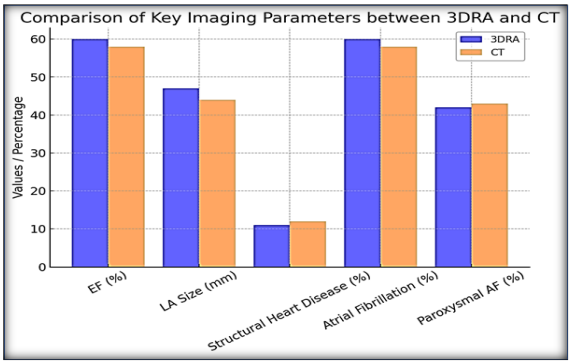

Figure 2: Comparison of key imaging parameters between 3RDA and CT

DISCUSSIONS

Our study compared Computed Tomography (CT) and Three-Dimensional Rotational Angiography (3DRA) of the left atrium (LA) in patients undergoing pre-procedural imaging for atrial fibrillation (AF) ablation. The results indicate that 3DRA is more beneficial than CT due to its lower radiation exposure while maintaining similar imaging accuracy. While most clinical and procedural parameters did not show statistically significant differences, 3DRA demonstrated an advantage in reducing radiation exposure and contrast agent usage, making it a safer alternative for certain patient populations.

Comparison with Previous Literature

Our findings align with several previously published studies on CT vs. 3DRA for pre-procedural LA imaging in AF ablation, which reported comparable accuracy, clinical outcomes, and procedural success rates.

A. Radiation Exposure and Safety Considerations

- Tang et al. (2009) compared 3DRA and CT imaging and found that radiation exposure in 3DRA (2.7 ± 0.9 mSv) was significantly lower than in CT (24.9 ± 3.1 mSv, $P < 0.001$). Our study supports this observation, confirming that 3DRA provides similar anatomical details without excessive radiation exposure.
- Pontone et al. (2014) analyzed CT vs. Cardiac Magnetic Resonance (CMR) and found that CT has higher radiation doses compared to alternative imaging methods, despite similar anatomical precision. Since 3DRA is often preferred for real-time imaging and intra-procedural guidance, its lower radiation exposure is a key advantage, especially in younger patients or those requiring multiple imaging sessions.

B. Image Quality and Procedural Accuracy

- Nölker et al. (2011), Malchano et al. (2014) demonstrated that intracardiac echocardiography (ICE) and 3DRA provide comparable LA anatomical reconstructions, with a registration accuracy deviation of only 2.6 ± 0.5 mm. These findings suggest that 3DRA can offer intra-procedural accuracy similar to traditional CT-based reconstructions.
- Tang et al. (2009) also found a strong correlation between CT and 3DRA in measuring pulmonary vein (PV) ostial diameters and LA volumes ($r \geq 0.87$). Our results confirm that LA size and PV anatomy measurements were comparable between CT and 3DRA, reinforcing previous research findings.

C. Procedural Success and AF Recurrence

- Pontone et al. (2014), Malchano et al. (2014) found that AF recurrence rates after CT-guided and CMR-guided ablation were similar (29% vs. 26%, $P = 0.5$), despite CMR offering lower radiation exposure.
- Our study showed no significant differences in AF subtypes (paroxysmal, persistent, or long-standing persistent AF) between CT and 3DRA groups, indicating that both modalities are equally effective in guiding catheter ablation procedures.

Limitations of the Study

- **Retrospective Design:** Since the study is retrospective, selection biases may exist in patient allocation to either imaging modality.
- **Lack of Long-Term Follow-Up:** The study does not evaluate long-term AF recurrence rates after ablation, which could provide further insights into the clinical impact of CT vs. 3DRA-based imaging.

Small Sample Size for Certain AF Subtypes: The relatively low incidence of focal left atrial tachycardia (1.71%-2.56%) limits statistical power for detecting subtle differences between imaging groups.

CONCLUSION

Our study highlights that CT and 3DRA provide similar pre-procedural imaging quality for atrial fibrillation ablation. 3DRA offers lower radiation exposure and real-time procedural guidance, making it an attractive option in specific cases. CT provides high-resolution anatomical details and is more widely available in routine clinical practice. Both modalities are effective, and selection should be based on patient-specific needs, institutional expertise, and resource availability.

These findings align with previous research, reinforcing that 3DRA is a viable alternative to CT for pre-procedural atrial imaging, particularly in patients where radiation exposure or contrast agent usage is a concern. Further research with larger prospective trials is recommended to explore the long-term benefits of 3DRA in clinical decision-making for AF ablation procedures.

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