Integrated Optimization of Atrial Fibrillation Catheter Ablation: Advances in Pre-Procedural Imaging, Determinants of Lesion Formation, Anatomical Predictors of Recurrence, and Procedural Efficiency

PhD thesis

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1. INTRODUCTION

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia in adults and represents a major cause of stroke, heart failure, impaired quality of life, hospital admissions, and healthcare expenditure. As the prevalence of AF rises with population ageing and the growing burden of cardiovascular comorbidities, the need for effective rhythm control strategies is also increasing.

Catheter ablation has become a cornerstone of rhythm control therapy in patients with AF. Pulmonary vein isolation (PVI) remains the fundamental procedural endpoint, based on the recognition that ectopic triggers arising from the pulmonary veins (PVs) frequently initiate AF. Nevertheless, despite major technological progress, AF ablation is still limited by several clinically relevant challenges, including limitations of pre-procedural imaging, non-durable lesion formation, patient-specific anatomical variability and post-ablation arrhythmia recurrence, as well as increasing demands on procedural capacity.

Pre-procedural imaging plays a dual role in AF care. First, it supports the exclusion of left atrial appendage (LAA) thrombus before cardioversion or catheter ablation, thereby reducing the risk of thromboembolic complications. Transesophageal echocardiography (TEE) remains widely used for this purpose, but it is semi-invasive, operator-dependent, and often uncomfortable for patients. Second, imaging can provide detailed information on left atrial (LA) and pulmonary vein (PV) anatomy, which is important for procedural planning and may also reveal anatomical features associated with recurrence. Non-invasive imaging strategies may therefore offer advantages in both pre-procedural assessment and patient experience. In particular, the left lateral ridge between the LAA and the left superior pulmonary vein (LSPV) represents an anatomically complex region, where local myocardial thickness and potential epicardial connections may influence lesion durability. Imaging-derived

characterization of this region may therefore provide additional information for recurrence risk assessment and support a more individualized ablation strategy.

Durable lesion formation is another key determinant of successful ablation. In radiofrequency ablation, lesion creation depends on multiple factors, including delivered power, application duration, catheter-tissue contact, tissue heating, irrigation, and local myocardial anatomy. Radiofrequency lesion formation involves both resistive and conductive tissue heating. Resistive heating occurs directly in tissue adjacent to the electrode, whereas conductive heating transfers thermal energy progressively into deeper tissue layers and is therefore more dependent on application duration. High-power short-duration strategies aim to increase the relative contribution of resistive heating while limiting prolonged conductive heating. Accordingly, very high-power, short-duration (vHPSD) radiofrequency ablation was introduced to create effective lesions using shorter applications. Characterizing the biophysical behavior of vHPSD ablation is therefore important for optimizing lesion delivery in clinical practice.

More recently, pulsed-field ablation (PFA) has emerged as a major innovation in electrophysiology. Unlike thermal ablation, PFA is based on irreversible electroporation and has the potential to preferentially affect myocardial tissue while sparing surrounding structures. Beyond safety, current PFA platforms may simplify PVI and improve procedural reproducibility. Such workflow advantages may become increasingly important as the demand for AF ablation grows.

This dissertation examines AF ablation as an integrated clinical workflow. It addresses four interconnected areas: optimization of pre-procedural imaging, identification of anatomical predictors of recurrence, characterization of vHPSD radiofrequency lesion formation, and comparison of procedural efficiency between pulsed-field and vHPSD ablation. Together, these studies address

several practical limitations of contemporary AF ablation and explore opportunities to improve its clinical implementation.

2. OBJECTIVES

The overall objective of this dissertation was to evaluate practical opportunities to improve the contemporary AF ablation pathway from pre-procedural assessment to lesion delivery, recurrence prediction, and procedural efficiency.

The specific objectives were:

1. To assess the feasibility of the novel non-contrast-enhanced Bright-blood and black-BlOOd phase SensiTive inversion recovery (BOOST) cardiac magnetic resonance (CMR) sequence for pre-procedural LAA thrombus assessment using TEE as the clinical reference modality, and to compare patients' subjective experiences during TEE and BOOST CMR examinations. As a secondary exploratory objective, we assessed the utility of BOOST CMR for pre-procedural anatomical assessment and catheter ablation planning in comparison with contrast-enhanced computed tomography (CT).

2. To investigate whether the proximity of the LAA to the LSPV, assessed using cardiac CT, predicts AF recurrence after point-by-point PVI.

3. To characterize temperature-controlled vHPSD radiofrequency applications and assess the relationship between contact force, temperature, impedance drop, and delivered power.

4. To compare room time and procedural workflow between PFA and vHPSD radiofrequency ablation and to assess the influence of operator experience on procedural efficiency.

3. METHODS

All investigations were conducted at the Heart and Vascular Center of Semmelweis University, Budapest, Hungary. The studies were performed in accordance with the Declaration of Helsinki and applicable Hungarian regulations. The dissertation included both prospective and retrospective clinical cohorts, each addressing a different but complementary element of the AF ablation pathway.

3.1. Pre-procedural imaging with BOOST CMR

A prospective pilot study was performed in symptomatic AF patients scheduled for either electrical cardioversion (ECV) or radiofrequency catheter ablation. Each patient underwent non-contrast-enhanced BOOST CMR followed by TEE on the same day, usually within 2-3 hours. The primary comparison focused on the assessment of LAA thrombus status by the two modalities.

BOOST CMR was performed using a 1.5 T scanner and included standard cine imaging as well as a dedicated 3D whole-heart BOOST prototype sequence covering the LA, PV ostia, and LAA. The BOOST acquisition provided an isotropic spatial resolution of 1.4 x 1.4 x 1.4 mm. The scans were performed without contrast agents. CMR datasets were analyzed using dedicated post-processing software. TEE examinations were performed by experienced operators according to institutional practice.

In patients scheduled for ablation, contrast-enhanced left atrial CT was also performed in a subset of cases as part of routine pre-ablation planning. CT imaging was not mandatory in the study protocol, because the primary aim was to compare BOOST CMR with TEE for LAA thrombus assessment. In patients

with both BOOST CMR and CT available, PV ostial areas and the practical usability of the images for ablation planning were compared. Electrophysiologists rated image usability on a 10-point scale for both modalities.

Patient experience was assessed within one week using a custom-developed questionnaire. The questionnaire addressed the clarity of pre-procedural information, mental and physical discomfort, perceived examination duration, and patients' preferred modality for a potential future examination.

Between-group comparisons were performed using Fisher's exact test for categorical variables and the Mann-Whitney U test for continuous variables.

3.2. Anatomical predictor of AF recurrence

A retrospective cohort study was conducted in patients undergoing point-by-point radiofrequency ablation for paroxysmal AF. All patients had undergone pre-procedural contrast-enhanced cardiac CT for comprehensive LA and PV anatomical assessment. Within 24 hours before RFCA, all patients underwent TEE to exclude LAA thrombus. Patients with non-paroxysmal AF, prior left atrial ablation, inadequate CT image quality, or non-point-by-point ablation were excluded.

Three experienced readers evaluated the CT datasets. LAA morphology, LAA volume, LAA orifice area, and the minimal endocardial distance between the LAA and the LSPV were assessed. An endocardial distance of less than 2 mm defined an abutting LAA-LSPV configuration.

All patients underwent PVI, and procedural success was confirmed by entrance and exit block. Patients attended follow-up visits at 3, 6, and 12 months and at least annually thereafter, including clinical evaluation and 24-hour Holter ECG

monitoring. AF recurrence was defined as any documented atrial tachyarrhythmia lasting at least 30 seconds beyond the 90-day blanking period. Predictors of AF recurrence were assessed using univariable and multivariable Cox proportional hazards regression. Kaplan-Meier analysis was used to estimate recurrence-free survival, with between-group differences evaluated using the log-rank test.

3.3. vHPSD radiofrequency ablation

A prospective single-center cohort study was performed in patients undergoing their first radiofrequency catheter ablation for AF. Procedures were performed using the QDOT Micro ablation catheter (Biosense Webster, Inc., Irvine, CA, USA) in temperature-controlled vHPSD mode. Radiofrequency energy was delivered at 90 W for 4 seconds with an irrigation rate of 8 mL/min.

After transseptal puncture, a three-dimensional electroanatomical map of the left atrium was created. Point-by-point ablation lesions were delivered around the PV antra, with interlesion distances maintained below 5 mm. PVI was confirmed by both entrance and exit block. If first-pass isolation was not achieved, additional ablation was performed until complete isolation.

For each vHPSD application, procedural and biophysical parameters were systematically recorded, including delivered power, maximum temperature, temperature change, generator impedance drop (ID), mean contact force, minimum contact force, and maximum contact force. Associations between these parameters were analyzed using Spearman's rank correlation.

3.4. Comparison of PFA and vHPSD ablation workflow

A prospective workflow study was performed in adult patients scheduled for AF ablation. Patients underwent either pulsed-field ablation using the Farapulse

system (Boston Scientific, Corp, Marlborough, MA, USA) or vHPSD radiofrequency ablation performed as described above. PFA was performed using the Farawave catheter (Boston Scientific, Corp, Marlborough, MA, USA) with PVI as follows: 4-4 applications in basket and flower configurations, with a 30-degrees catheter rotation after every 2 applications in each configuration. Very high-power short-duration ablation was typically performed under conscious sedation, whereas PFA procedures were usually carried out under deep sedation, with general anesthesia reserved for selected cases. The main endpoint was room time, defined as the interval from patient entry into the operating room to patient exit.

In addition, the duration of predefined procedural phases and other time intervals was recorded, including door-in to puncture time, puncture to transseptal time, transseptal to first ablation time, ablation time, last ablation to sheath-out time, sheath-out to door-out time, left atrial dwell time, and procedure time. Acute procedural success, fluoroscopy time, complications, hospital stay, and arrhythmia recurrence at 6 months were also assessed. The influence of operator experience was evaluated by comparing room times between expert operators (>1,000 prior AF ablations) and experienced operators (300-1,000 prior AF ablations) within the PFA and vHPSD groups.

Between-group comparisons were performed using parametric or non-parametric tests according to data distribution, with a two-sided p-value <0.05 considered statistically significant.

4. CONCLUSIONS

Our imaging studies addressed two complementary aspects of pre-procedural assessment in AF. Non-contrast-enhanced BOOST CMR showed concordant

LAA thrombus assessment with TEE in 94% of patients and provided usable LA and PV anatomical information for ablation planning in most RFCA candidates. BOOST CMR was also substantially better tolerated than TEE, with 89% of patients preferring CMR for a potential future examination, supporting its potential role as a more patient-friendly pre-procedural imaging modality. However, larger studies with a higher prevalence of LAA thrombus are needed to define its diagnostic performance more precisely. Beyond modality selection, pre-procedural imaging also provided prognostic information: an abutting LAA-LSPV configuration, defined as an endocardial distance <2 mm on contrast-enhanced CT, was present in 54% of patients and independently predicted AF recurrence (adjusted HR 1.55, 95% CI 1.04-2.31). As this anatomical relationship can be readily assessed on routine pre-procedural CT, it may help identify patients in whom lesion delivery along the left lateral ridge requires particular attention and may support a more individualized ablation strategy.

Our ablation studies subsequently focused on lesion formation and procedural efficiency. During temperature-controlled vHPSD radiofrequency ablation, contact force was closely related to tissue heating, with a CF of approximately 5 g appearing sufficient to achieve effective tissue heating. Above this level, temperature-controlled power modulation reduced delivered power as tissue temperature increased, suggesting that once adequate catheter-tissue contact is achieved, further increases in CF are not required to maintain effective tissue heating. At the procedural level, PFA shortened median room time by 17 minutes compared with vHPSD radiofrequency ablation (71 vs 88 minutes) while maintaining comparable acute procedural success, safety, and 6-month efficacy. The difference in room time was more pronounced among experienced than expert operators, indicating that large-footprint single-shot PFA may reduce the impact of operator experience on procedural efficiency.

Overall, these findings show that improvements at different stages of the AF ablation pathway can complement each other. Pre-procedural imaging may contribute not only to thrombus exclusion and procedural planning but also to the identification of anatomical features associated with recurrence, while optimization of lesion delivery and the use of more streamlined ablation technologies may improve the efficiency and reproducibility of the procedure itself. Integrating these elements may therefore support a more individualized and efficient approach to AF ablation.

6. BIBLIOGRAPHY OF THE CANDIDATE'S PUBLICATIONS

Publications related to the thesis:

Orbán G, Salló Z, Perge P, Ábrahám P, Piros K, Nagy VK, et al. Characteristics of Very High-Power, Short-Duration Radiofrequency Applications. Front Cardiovasc Med. 2022;9:941434. **IF: 3.6**

Szegedi N, Simon J, Szilveszter B, Salló Z, Herczeg Sz, Száraz L, et al. Abutting Left Atrial Appendage and Left Superior Pulmonary Vein Predicts Recurrence of Atrial Fibrillation After Point-by-Point Pulmonary Vein Isolation. Front Cardiovasc Med. 2022;9:708298. **IF: 3.6**

Orbán G, Dohy Z, Suhai FI, Nagy AI, Salló Z, Boga M, et al. Use of a new non-contrast-enhanced BOOST cardiac MR sequence before electrical cardioversion or ablation of atrial fibrillation-a pilot study. Front Cardiovasc Med. 2023;10:1177347. **IF: 2.8**

Orbán G, Boga M, Salló Z, Osztheimer I, Nagy VK, Perge P, et al. Comparison of room times between pulsed-field ablation and very high-power short-duration ablation. Heart Rhythm O2. 2025;6(10):1546-1555. **IF: 2.8**

Other publications:

Boussoussou M, Szilveszter B, Vattay B, Kolossváry M, Vecsey-Nagy M, Salló Z, et al. The effect of left atrial wall thickness and pulmonary vein sizes on the acute procedural success of atrial fibrillation ablation. Int J Cardiovasc Imaging. 2022;38(7):1601-1611. **IF: 2.1**

Salló Z, Perge P, Balogi B, Orbán G, Piros K, Herczeg Sz, et al. Impact of High-Power and Very High-Power Short-Duration Radiofrequency Ablation on

Procedure Characteristics and First-Pass Isolation During Pulmonary Vein Isolation. Front Cardiovasc Med. 2022;9:935705. **IF: 3.6**

Boga M, Suhai FI, Orbán G, Salló Z, Nagy VK, Szegedi L, et al. Incidence and predictors of stroke and silent cerebral embolism following very high-power short-duration atrial fibrillation ablation. Europace. 2023;25(11):euad327. **IF: 7.9**

Nagy B, Pál-Jakab Á, Kiss B, Orbán G, László Sélley T, Dabasi-Halázs Zs, et al. Remote Management of Patients with Cardiac Implantable Electronic Devices during the COVID-19 Pandemic. J Cardiovasc Dev Dis. 2023;10(5):214. **IF: 2.4**

Boga M, Orbán G, Perge P, Salló Z, Tanai E, Ferencz AB, et al. Adherence to the CLOSE Protocol and Low Baseline Generator Impedance Are Independent Predictors of Durable Pulmonary Vein Isolation. J Clin Med. 2024;13(7):1960. **IF: 2.9**

Boga M, Orbán G, Salló Z, Nagy KV, Osztheimer I, Ferencz AB, et al. Ablation Parameters Predicting Pulmonary Vein Reconnection after Very High-Power Short-Duration Pulmonary Vein Isolation. J Cardiovasc Dev Dis. 2024;11(8):230. **IF: 2.3**

Dohy Z, Kiss M, Suhai FI, Kunze K, Neji R, Orbán G, et al. Feasibility and image quality of bright-blood and black-blood phase-sensitive inversion recovery (BOOST) sequence in clinical practice using for left atrial visualization in patients with atrial fibrillation. Eur Radiol. 2024;34(4):2689-2698. **IF: 4.7**

Nagy B, Pál-Jakab Á, Orbán G, Kiss B, Fekete-Győr A, Koós G, et al. Factors predicting mortality in the cardiac ICU during the early phase of targeted

temperature management in the treatment of post-cardiac arrest syndrome - The RAPID score. Resusc Plus. 2024;19:100732. **IF: 2.4**

Szegedi N, Salló Z, Nagy VK, Osztheimer I, Hizoh I, Lakatos B, et al. Long-Term Durability of High- and Very High-Power Short-Duration PVI by Invasive Remapping: The HPSD Remap Study. Circ Arrhythm Electrophysiol. 2024;17(2):e012402. **IF: 9.8**

Boga M, Salló Z, Orbán G, Komlósi F, Padisák A, Tóth P, et al. Impact of response to electrical cardioversion before catheter ablation for persistent atrial fibrillation: a propensity score-matched analysis. Eur Heart J Open. 2025;5(4):oeaf084. **IF: 4.3**

Padisak A, Szegedi N, Tanai E, Salló Z, Nagy VK, Péter P, et al. Pulsed field ablation for ventricular arrhythmias with pentaspline catheter. Front Cardiovasc Med. 2025;12:1631253. **IF: 3.0**

Szegedi N, Gardziejczyk P, Salló Z, Orbán G, Boga M, Szymkiewicz P, et al. Impact of Pulsed-Field Ablation on the Left Atrial Appendage Diameter-Insights From Intra-Procedural Echocardiography. J Cardiovasc Electrophysiol. 2025;36(12):3149-3155. **IF: 2.4**

Komlósi F, Nagy KV, Perge P, Salló Z, Osztheimer I, Tanai E, et al. Oesophageal safety of high and very high power short duration pulmonary vein isolation: a randomized comparison of the 50 W and 90 W power settings-the HPSD oesophagus study. Eur Heart J Open. 2026;6(2):oeag041. **IF: 4.3**

Nagy B, Pál-Jakab Á, Kiss B, Morvai A, Sipos B, Pápai Gy, et al. Influence of extreme temperatures on out-of-hospital cardiac arrest cases in Hungary: a national time-series analysis. Resusc Plus. 2025;27:101194. **IF: 3.1**

Szakál I, Komlósi F, Tóth P, Arnóth B, Bohus Gy, Vámosi P, et al. Mineralocorticoid receptor antagonists in heart failure with sustained monomorphic ventricular tachycardia: comparative analysis of spironolactone versus eplerenone. Open Heart. 2026;13(1):e003858. **IF: 3.1**

Orbán G, Gellér L, Szegedi N. From Shots to Shocks: When Ethanol Isn't RF's Friend-Pericardial-Esophageal Fistula After Combined Ethanol and Radiofrequency Ablation. JACC Case Rep. 2026;31(2):106154. Editorial.

Orbán G, Straub É. Gyógyszeres és elektromos cardioversio. In: Szegedi, N (Ed.) Kardiológia zsebkönyv (szak)vizsgára készülőknek (pp. 121-127). Semmelweis Kiadó (2026). Book chapter.