Dual-energy right atrial appendage tachycardia ablation in pediatrics

Guillermo Rad García, MD, Nerea Fernández Ortiz, MD, Enrique Robles Pérez, MD, Carmen Arveras Martínez, MD, Javier Navarrete Navarro, MD, Óscar Cano Pérez, MD, Maite Izquierdo De Francisco, MD, Josep Navarro Manchón, MD, Joaquín Osca Asensi, MD

From the Cardiac Arrhythmia Unit, Hospital Universitario y Politécnico La Fe, Valencia, Spain.

Focal atrial tachycardias (FAT) account for 10%–15% of supraventricular tachycardias in the pediatric population.[1,2] They arise from discrete foci of abnormal atrial activation—because of enhanced automaticity, triggered activity, or micro-reentry—producing centrifugal activation from that point. Common origins include the crista terminalis, coronary sinus (CS) ostium, pulmonary vein ostia, and valvular annuli.[3,4]

Right atrial appendage tachycardia (RAA-AT) is particularly uncommon, representing 2%–6% of all FATs.[5,6] The right atrial appendage (RAA) features prominent trabeculae, thin walls, and high mobility, which hamper stable catheter contact and carry an increased risk of perforation, with recurrence rates generally being higher than those at other atrial foci.[5,7,8] Experience in pediatric patients is even more limited.

Pulsed-field ablation (PFA) is a novel non-thermal energy modality based on irreversible electroporation, inducing direct cell death without heat generation.[9,10] Its high tissue selectivity for atrial myocardium offers potential advantages over radiofrequency (RF) in delicate structures such as the appendage, where irregular catheter contact may limit the efficacy and homogeneity of thermal lesions.[11,12] Dual-energy catheters capable of delivering both modalities from the same electrode allow a sequential approach without device exchange, and preclinical data suggest that sequential RF followed by PFA may achieve greater lesion depth than either modality alone.[13]

We present the case of a 13-year-old boy with incessant RAA-AT who underwent 2 ablation procedures. The case contributes information on high-density electroanatomic mapping of the pediatric RAA, the use of a dual RF + PFA catheter, and the differential electrophysiological response between both energy modalities at the tachycardia focus.

KEYWORDS Focal atrial tachycardia; Right atrial appendage; Catheter ablation; Pulsed-field ablation; Radiofrequency; Pediatric electrophysiology; Electroanatomical mapping

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Address reprint requests and correspondence: Dr Guillermo Rad García, Cardiac Arrhythmia Unit, Hospital Universitario y Politécnico La Fe, Avinguda de Fernando Abril Martorell 106, 46026 Valencia, Spain. E-mail address: guillerad98@gmail.com.

Case report

Clinical presentation

A 13-year-old boy (64 kg) with no relevant past medical history presented in November 2025 with palpitations and tachycardia detected by self-pulse check. The emergency 12-lead electrocardiogram (ECG) showed a regular narrow-QRS supraventricular tachycardia at 140–150 bpm. Echocardiography excluded structural heart disease.

Adenosine boluses (up to 12 mg) produced transient atrioventricular block without tachycardia termination, consistent with atrial tachycardia and supporting an automatic mechanism—in contrast to atrioventricular node-dependent tachycardias, which terminate with adenosine, and to most triggered-activity tachycardias, which may also be terminated via cyclic adenosine monophosphate-mediated mechanisms.[4] A surface ECG recording during adenosine administration was not obtained at the time of the acute assessment; however, the clinical response was clearly documented and is consistent with the diagnosis of automatic FAT.

The patient was admitted to the pediatric intensive care unit, where intravenous flecainide (2 mg/kg), esmolol, and amiodarone (5 mg/kg bolus followed by 24 h infusion) slowed but did not revert the tachycardia to sinus rhythm. Oral amiodarone 300 mg/12 h combined with bisoprolol 2.5 mg/12 h was initiated. Ambulatory Holter monitoring confirmed a virtually incessant tachycardia, and electrophysiology study with ablation was scheduled. A complete laboratory workup—biochemistry, blood count, coagulation, thyroid function, and venous blood gas—was normal.

ECG: P-wave morphology

During tachycardia (Figure 1A), the P wave was flat and of low amplitude, with a positive axis in inferior leads and in precordial leads, consistent with an origin from an anterior and superior right atrial structure—compatible with the

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KEY TEACHING POINTS

- Right atrial appendage (RAA) tachycardia is an uncommon arrhythmia in pediatric patients, characterized by an incessant presentation, high recurrence rates after ablation, and significant technical challenges due to the anatomic features of the right atrial appendage (RAA, prominent trabeculae, a thin wall, and high mobility). These features complicate stable catheter contact and increase the risk of perforation compared to other ablation sites.
- High-density electroanatomic mapping with EnSite X and HD Grid enables precise localization of the arrhythmic focus even in the presence of prior ablation scars, which may create conduction block lines that help delineate the residual arrhythmic substrate and guide catheter positioning in redo procedures.
- In this case, pulsed-field ablation (PFA) achieved immediate and sustained tachycardia termination at a site where repeated radiofrequency (RF) applications produced only transient slowing, highlighting the potential superiority of PFA over RF in thin-walled, trabeculated structures, such as the RAA. Whether this reflects an intrinsic electrophysiological advantage of irreversible electroporation at this site, the absence of thermal lesion heterogeneity, or greater tissue susceptibility to electroporation cannot be established from a single case.
- A sequential RF + PFA approach was employed using a single dual-energy catheter (Tactiflex DUO; Abbott). Preclinical data suggest that sequential RF followed by PFA may achieve greater lesion depth than either modality alone in atrial tissue; however, whether RF preconditioning contributed to the efficacy of PFA in this case—or whether PFA alone would have been equally effective—cannot be determined from this single observation.
- The dual RF + PFA catheter (Tactiflex DUO) enables a multimodal sequential ablation approach from a single vascular access without device exchange, simplifying procedural logistics in challenging anatomic locations. Safety considerations specific to RAA ablation—including perforation risk, phrenic nerve proximity, and the theoretical advantage of PFA's non-thermal mechanism in thin-walled structures—are particularly relevant in the pediatric population.

RAA.[3,14,15] On the post-ablation ECG in sinus rhythm (Figure 1B), P-wave morphology was noticeably more peaked and of greater amplitude, reflecting the different conduction velocity and activation vector between the ectopic RAA focus and the sinoatrial node. The side-by-side comparison of the tachycardia and post-ablation sinus ECG is informative both diagnostically and as confirmation of successful ablation.

First ablation procedure

Electrophysiology study confirmed atrial tachycardia with a normal PR interval, narrow QRS, and a cycle length of ~540 ms. Activation mapping with the HD Grid multipolar catheter (Abbott, Chicago, IL) in the right atrium identified the zone of maximum prematurity at the base of the RAA, with values up to −100 ms relative to the proximal CS. Multiple RF and PFA applications were delivered, achieving sustained tachycardia termination by the end of the procedure. However, tachycardia recurred 1 week later. On re-evaluation, a residual ablation scar was documented in the RAA, confirming prior energy delivery.

Second ablation procedure

The patient presented with atrial tachycardia at ~160 bpm. The procedure was performed under general anesthesia. Right femoral venous access was obtained with 3 catheters: (1) a decapolar catheter for CS reference, (2) an HD Grid multipolar catheter for high-density mapping, and (3) the dual-energy ablation catheter Tactiflex DUO (DF curve; Abbott), capable of delivering both RF and PFA from the same distal electrode. The electroanatomic navigation system was EnSite X (Abbott).

Tachycardia cycle length was 550 ms. The CS activation sequence was proximal-to-distal, indicating a superior and rightward origin. The high-density local activation time map confirmed the zone of maximum prematurity at the roof of the RAA, with values of −90 to −105 ms relative to the CS reference (Figures 2 and 3). Activation spread centrifugally from this focal point, propagating first toward the base of the RAA and subsequently engaging the right atrial free wall and interatrial septum. A lateral line of conduction block—resulting from scar from the first procedure—was identified adjacent to the focus (Figures 2–4), which constrained propagation and helped delineate the residual arrhythmic substrate.

Ablation strategy — Sequential RF + PFA

Once the Tactiflex DUO catheter was confirmed to be at the site of maximum prematurity (prematurity −90/−105 ms vs CS; contact force 5 g), the following sequential ablation scheme was executed:

- **RF applications (4 applications, 30 s each, 34 W):** Tachycardia warming (transient acceleration) followed by slowing was observed with each application, without termination of the arrhythmia. This behavior indicates

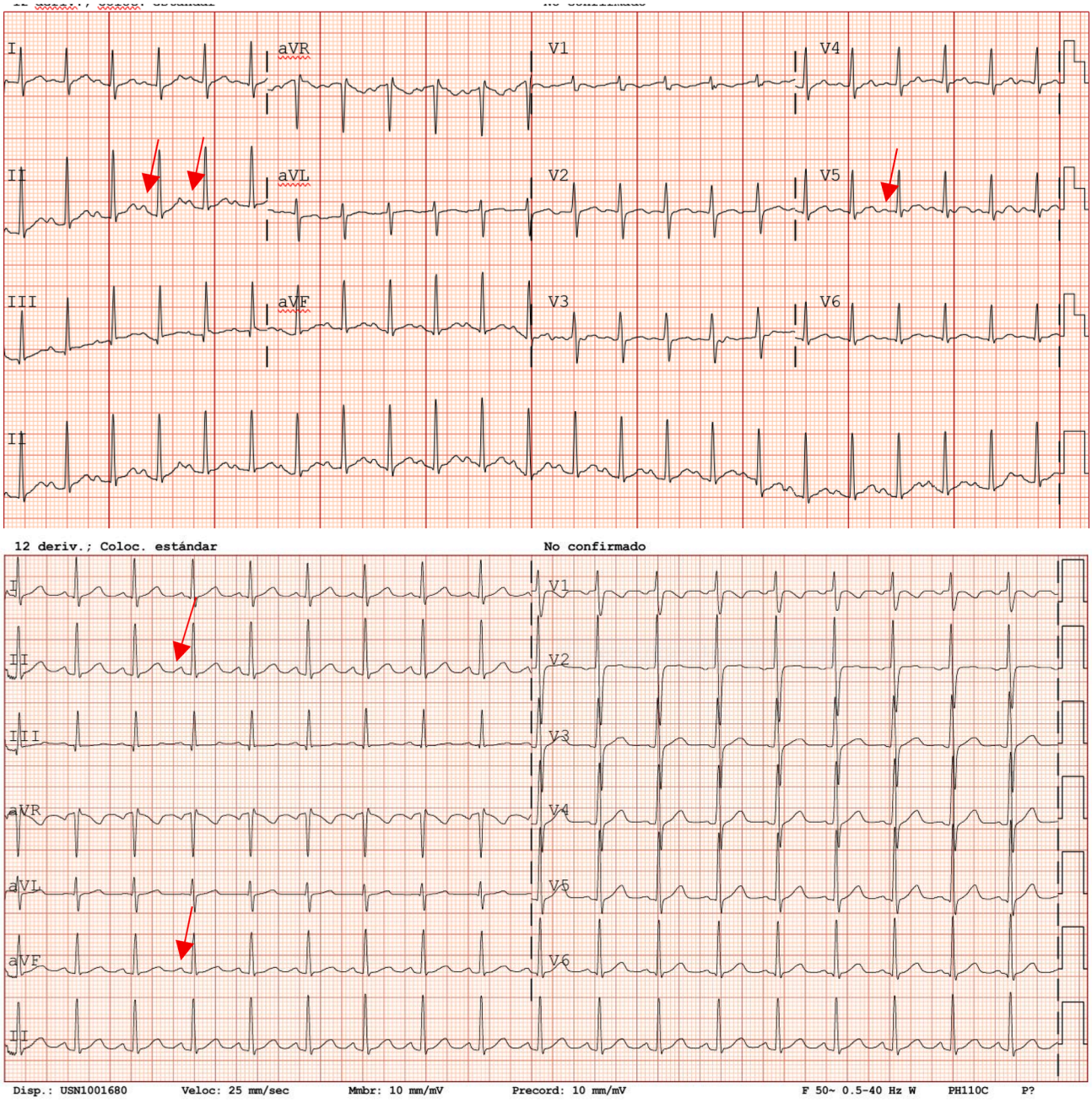


Figure 1 Twelve-lead ECG comparison. **A:** ECG during RAA atrial tachycardia (HR 138 bpm). *Red arrows* indicate P waves, which are flat and of low amplitude, positive in inferior leads (II, III, aVF) and in precordial leads, consistent with an anterior and superior right atrial origin (RAA). **B:** Post-ablation ECG in sinus rhythm. *Red arrows* indicate sinus P waves, which are notably more peaked and of greater amplitude than those during tachycardia, reflecting the different activation vector and conduction velocity between the ectopic RAA focus and the sinoatrial node, and confirming electrocardiographic normalization after successful ablation. ECG = electrocardiogram; HR = heart rate; RAA = right atrial appendage.

that RF modified the local substrate but did not achieve a sufficient transmural effect at this anatomic point.

- **PFA application (1 pulse, Tactiflex DUO PFA mode):** Following the RF applications, the tachycardia was terminated immediately and durably with the first PFA pulse. From that moment, the tachycardia did not recur during the procedure or at follow-up (Figure 5).

A total of 6 sequential RF + PFA schemes were applied in the focal area and perilesional zone to consolidate the ablation (Figure 6). The observed differential response—RF producing slowing without termination, while the first PFA pulse achieved immediate and durable tachycardia termination—was the most notable electrophysiological finding of this case. Importantly, we cannot establish from this single case whether the prior RF applications contributed to the efficacy of PFA (eg, via substrate modification or impedance reduction) or whether PFA alone would have been equally effective de novo. The case primarily demonstrates the superiority of PFA over RF at this specific site

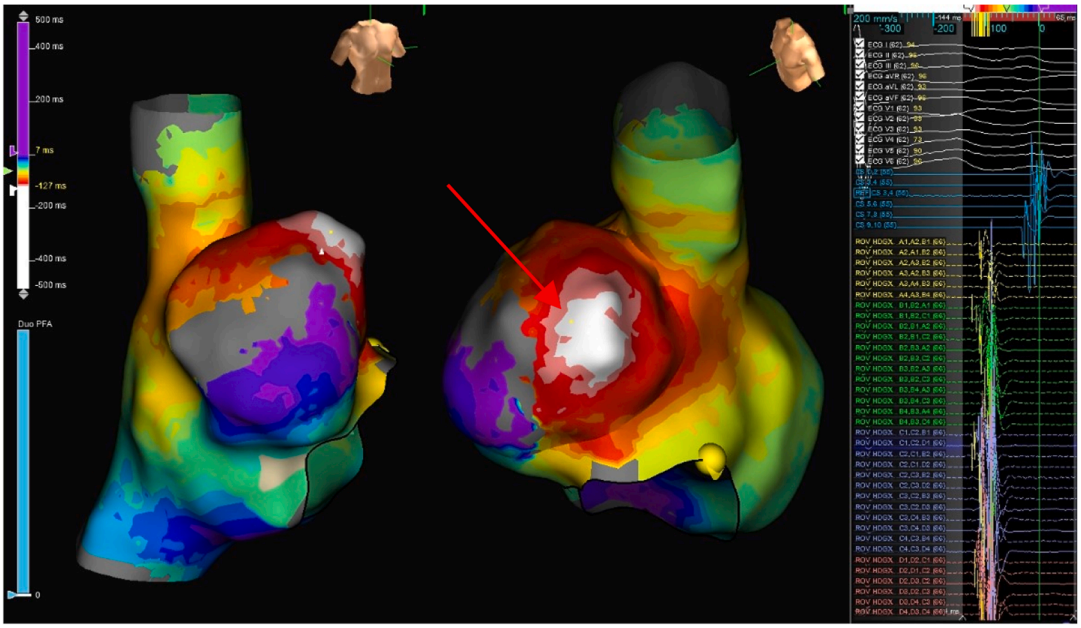


Figure 2 Isochronal LAT map of the right atrium (AP view, *left*; PA view, *right*). The *white/red zone* indicates the site of earliest activation (−90 to −105 ms relative to the proximal CS electrode) at the roof of the RAA. AP = anteroposterior; CS = coronary sinus; LAT = local activation time; PA = posteroanterior; RAA = right atrial appendage.

and illustrates the feasibility of a sequential dual-energy strategy using a single catheter.

Supporting this approach, preclinical data from a porcine model using the same dual-energy catheter demonstrated that sequential RF followed by PFA can achieve lesion depths of up to 9.1 ± 1.6 mm, compared to 5.9 ± 2.0 mm with a single nominal PFA application.[13] Although these findings support a potential additive rationale, definitive conclusions regarding synergy await prospective clinical data; even a modest increase in lesion depth may be relevant in structures such as the RAA, where trabeculations and thin walls make transmural lesion creation particularly challenging.

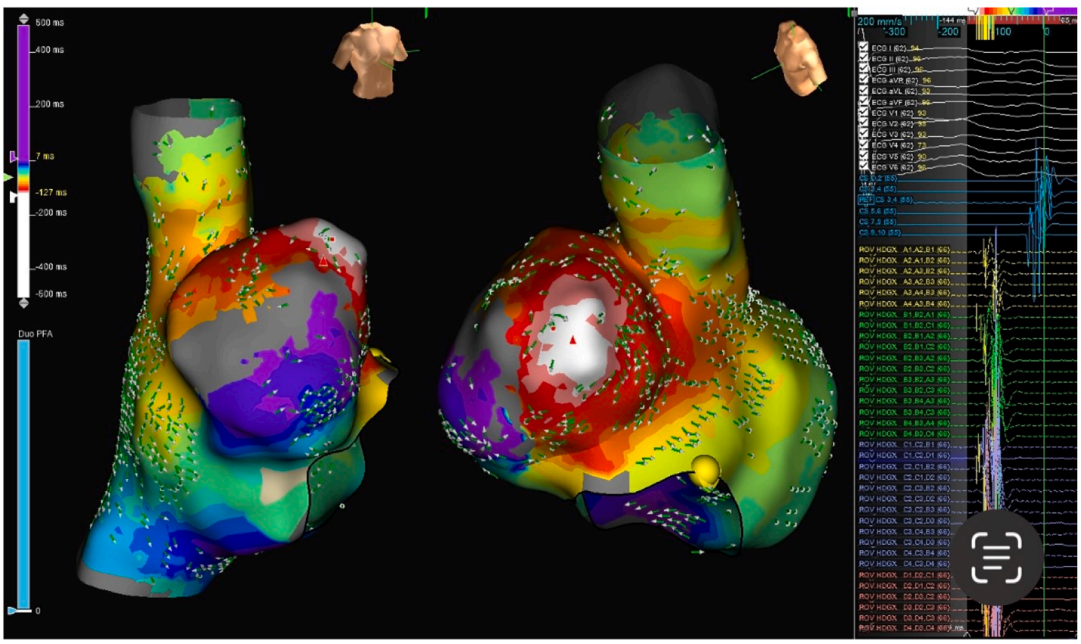


Figure 3 Isochronal LAT map of the right atrium (AP view, *left*; PA view, *right*). Activation spreads centrifugally from this focal point, propagating first toward the RAA base and then engaging the right atrial free wall and interatrial septum. A lateral conduction block line — consistent with scar from the first ablation procedure — is visible adjacent to the focus and constrains the early activation pattern. AP = anteroposterior; LAT = local activation time; PA = posteroanterior; RAA = right atrial appendage.

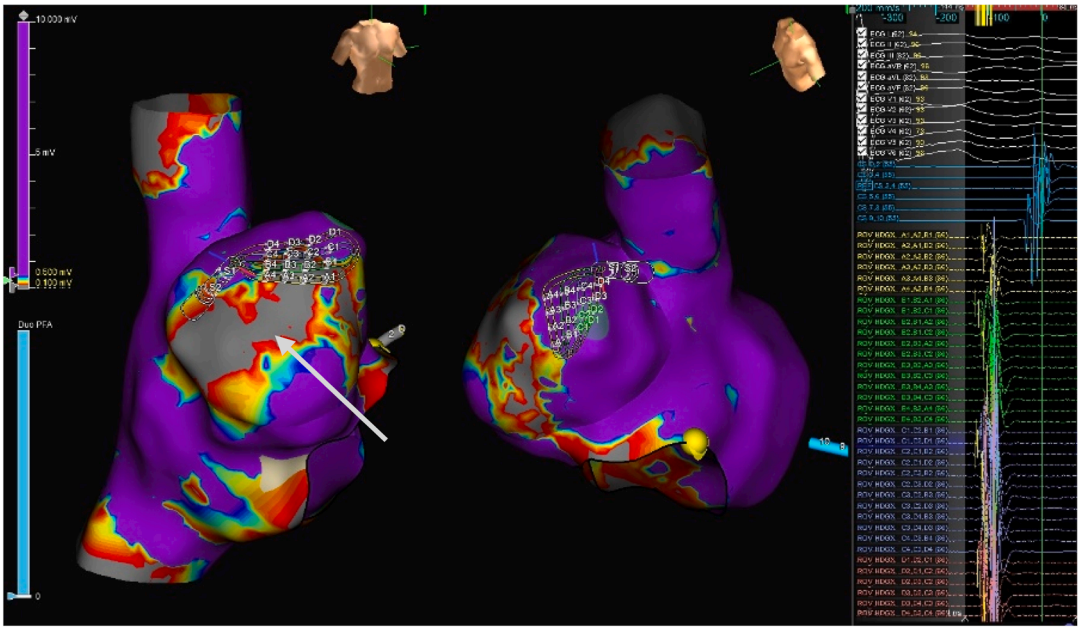


Figure 4 Voltage map of the right atrium with the HD Grid multipolar catheter positioned at the site of maximum prematurity (RAA roof). Low-voltage areas (*cold colors/purple*, 0.1 mV) reflect the ablation scar from the first procedure, predominantly involving the dorsal and anterior RAA, with preserved voltage in the basal region where the residual focus was located. RAA = right atrial appendage.

Regarding safety, post-procedure echocardiography excluded pericardial effusion. No phrenic nerve palsy or any other complication was observed. Isoproterenol infusion and programmed stimulation did not reinitiate the tachycardia at the end of the procedure. Patient follow-up with outpatient clinic evaluation, including ECG and Holter monitoring, has not revealed tachycardia recurrence.

Discussion

RAA-AT is a rare entity with scant representation in the literature, particularly in the pediatric population. Published cases highlight the technical difficulty of ablation in this location because of the anatomic characteristics of the appendage: prominent trabeculae, a thin wall, high mobility, and difficult catheter access.[5–8,16]

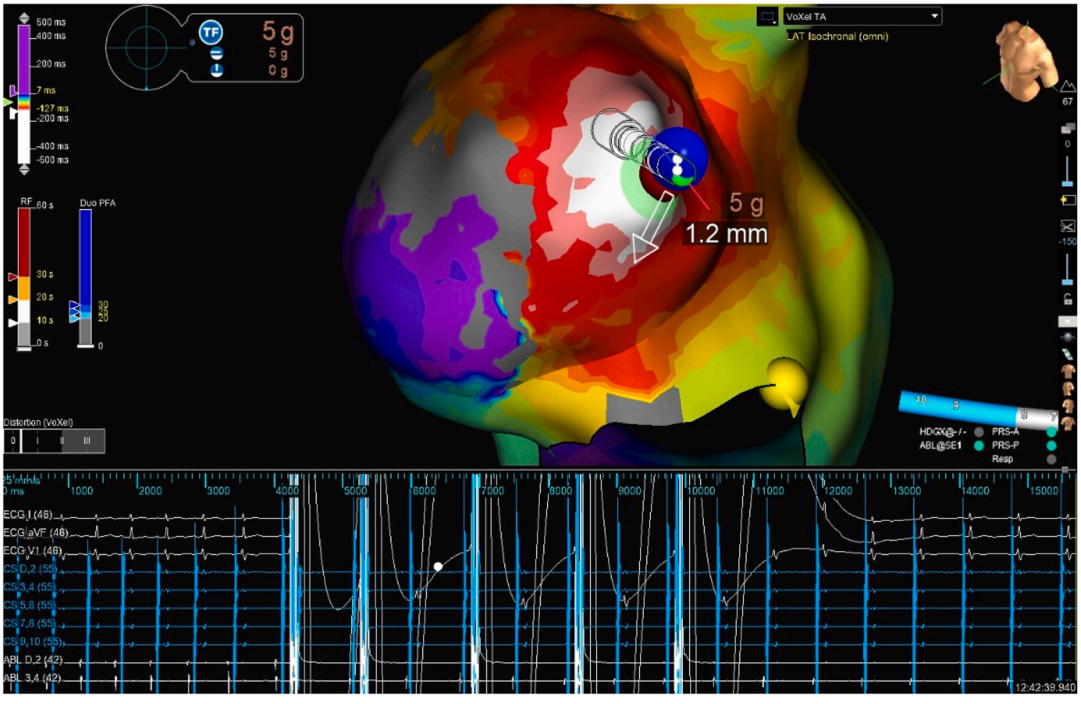


Figure 5 Lateral electroanatomic map with the Tactiflex DUO catheter showing RF + PFA ablation points at the RAA focus. Tachycardia was terminated by the first PFA pulse following 4 preceding RF applications. PFA = pulsed-field ablation; RAA = right atrial appendage; RF = radiofrequency.

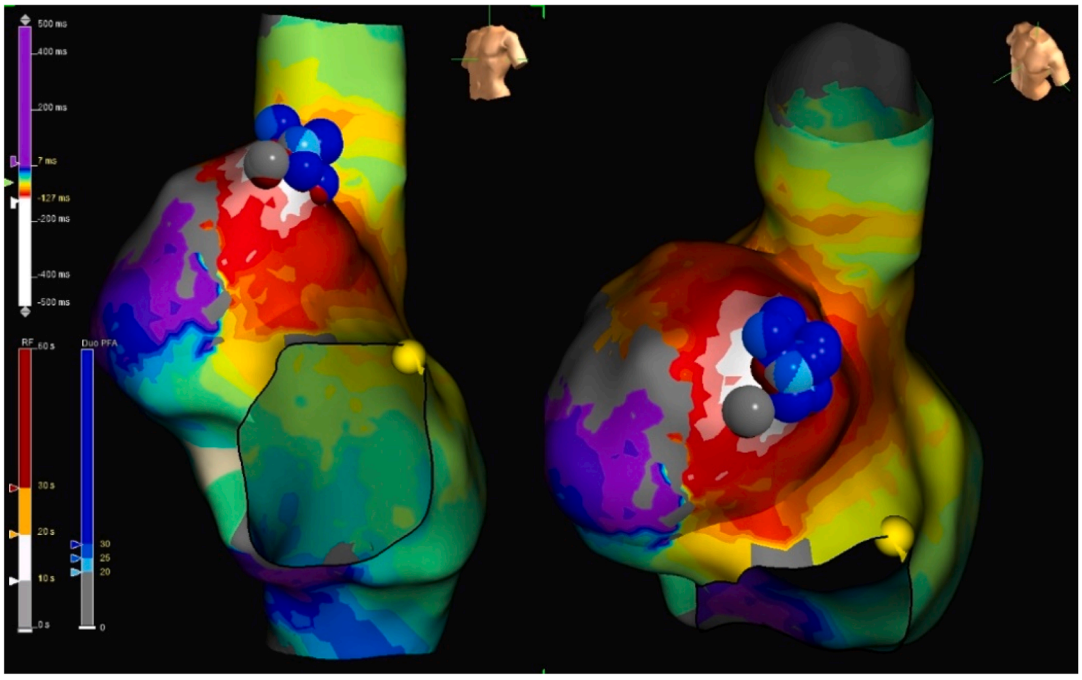


Figure 6 Electroanatomic activation map of the right atrium showing the final distribution of RF + PFA ablation points (*blue spheres*) overlaid on the isochronal activation map. The consolidated ablation zone covers the RAA focus and perilesional area. Most of the right atrial myocardium maintains normal activation patterns. PFA = pulsed-field ablation; RAA = right atrial appendage; RF = radiofrequency.

From the ECG standpoint, P-wave morphology in RAA-AT is typically positive in inferior leads and lead I, reflecting activation arising from an anterior and superior right atrial structure.[3,14,15] In our case, the P wave during tachycardia was flat and of lower amplitude than the sinus P wave, with an axis and orientation compatible with an RAA origin—a useful diagnostic clue given the rarity of this tachycardia substrate.

High-density mapping with EnSite X and HD Grid was essential for precise focus localization, especially in a second procedure, where prior scar modifies the substrate. The conduction block line created by the first procedure helped delineate the residual focus at the RAA roof and served as an anatomic landmark guiding catheter positioning.

The most striking finding in this case is the differential response to RF and PFA at the same anatomic site: RF produced tachycardia slowing without termination, whereas the first PFA pulse terminated the arrhythmia immediately and durably. This differential behavior is clinically noteworthy; however, definitive mechanistic conclusions cannot be drawn from a single case. Plausible hypotheses for PFA's superiority at this site include the greater lesion homogeneity of PFA in trabeculated tissue—where RF generates irregular lesions because of imperfect contact[17]—and the potentially greater susceptibility of thin, poorly organized appendage tissue to irreversible electroporation.[11,18] Recent reports suggest that PFA may be effective in atrial foci resistant to RF,[12,19,20] but evidence in this specific context remains scarce.

Of note, we cannot exclude the possibility that PFA alone—applied without prior RF—would have achieved identical results. The sequential RF + PFA approach was employed based on the rationale of potential complementarity and the availability of a single-catheter dual-energy platform, but the independent contribution of each modality cannot be discerned from a single observational case. Future prospective series will be needed to evaluate whether RF preconditioning genuinely enhances PFA efficacy in FATs or whether PFA alone is sufficient.

Safety considerations are particularly relevant in the RAA. The thin-walled and trabeculated anatomy carries an intrinsic risk of cardiac perforation and pericardial tamponade with standard RF ablation, especially when high contact forces are required to overcome catheter instability.[5,7] The absence of resistive heating with PFA represents a theoretical safety advantage in this context, as thermal injury to the thin appendage wall is avoided. Phrenic nerve proximity on the right side warrants careful monitoring during RAA ablation; in this case, continuous phrenic nerve pacing was maintained throughout, and no palsy was observed. Post-procedural echocardiography confirmed the absence of pericardial effusion. These considerations are especially pertinent in the pediatric population, where the long-term tissue effects of novel energy modalities require ongoing evaluation.

The Tactiflex DUO catheter enabled the sequential delivery of both energies without device exchange, simplifying procedural logistics and preserving catheter position between applications. This multimodal approach from a single vascular access may be particularly advantageous in complex anatomic locations, such as the RAA.

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Conclusion

This case illustrates the complexity of RAA ablation in pediatric patients and the feasibility of using a dual RF + PFA catheter for a multimodal approach from a single device. The key electrophysiological observation is the differential response between energy modalities at the same anatomic site: PFA achieved immediate and durable tachycardia termination, whereas RF produced only slowing, highlighting the potential superiority of PFA in thin-walled trabeculated structures. Whether this reflects an intrinsic advantage of PFA at this site, an effect of RF preconditioning, or both cannot be determined from a single case. These findings warrant evaluation in larger series of FATs arising from challenging anatomic substrates.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Claude (Anthropic) to assist with English language editing and manuscript formatting. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Ethics Statement: Written informed consent was obtained from the patient's legal guardian and from the patient himself for the publication of this case report. The patient and guardian were specifically informed of the off-label nature of PFA delivery via the Tactiflex DUO catheter for the indication of FAT (current regulatory approval is primarily for atrial fibrillation ablation), the clinical rationale for its use—including the insufficient response to RF at the same site during the first procedure and the potential advantages of PFA in thin-walled structures—and the available alternatives. Informed consent covered both the on-label and off-label aspects of the procedure. Identifying data have been anonymized. The procedure was performed in accordance with the principles of the Declaration of Helsinki and applicable local regulations.

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