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Integrated Pulsed Field Ablation Improves Procedural Efficiency Compared With Radiofrequency for Pulmonary Vein Isolation: A Multicenter Real-World Analysis

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Research Article

Keywords: atrial fibrillation, efficiency, pulsed field ablation, radiofrequency ablation

Posted Date: November 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11244630/v1

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Additional Declarations: Competing interest reported. This study was funded by Jonhson & Jonhson MedTech, Spain. Mosquera Garrote, Gómez Bodas, and Torres Costales are employees of Jonhson &

Jonhson MedTech. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Integrated Pulsed Field Ablation Improves Procedural Efficiency Compared With Radiofrequency for Pulmonary Vein Isolation: A Multicenter Real-World Analysis

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Funding support and author disclosures
This study was funded by Jonhson & Jonhson MedTech, Spain. Mosquera Garrote, Gómez Bodas, and Torres Costales are employees of Jonhson & Jonhson MedTech. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Summary tweet and hashtags: Integrated pulsed field ablation significantly reduced procedure time vs radiofrequency ablation for pulmonary vein isolation while maintaining acute success in a 503-patient multicenter study. PFA may improve EP lab efficiency and workflow. #AtrialFibrillation #PFA #Electrophysiology

Running title: Pulsed Field Ablation Improves PVI Efficiency

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Word count: 5685 words (including text, references and figure legends).

ABSTRACT

Background*:* Integrated pulsed field ablation (PFA) platforms combine nonthermal lesion delivery with electroanatomic mapping and may improve procedural workflow during atrial fibrillation (AF). Real-world comparisons with contemporary radiofrequency (RF) ablation remain limited.

Objectives*:* To compare procedural efficiency between integrated PFA and conventional RF ablation for pulmonary vein isolation (PVI), while maintaining acute procedural efficacy.

Methods*:* In this prospective, multicenter, nonrandomized study across 6 tertiary centers, consecutive patients undergoing first-time PVI for paroxysmal or persistent AF were included. Procedures were performed using integrated PFA (Varipulse™) or RF (SmartTouch SF™ or QDOT Micro™) ablation at operator discretion. The primary endpoint was total procedure time. Secondary endpoints included ablation and mapping duration, first-pass isolation (FPI), fluoroscopy time, additional lesions requirements, anesthesia strategy, and learning curve analysis.

Result*:* A total of 503 procedures (203 PFA, 300 RF) were analyzed. Acute PVI was achieved in 100% of cases. Procedure time was shorter with PFA than RF (93.3 vs 115.3 minutes; difference –22.1 minutes; $p < 0.0001$). PFA reduced ablation (–17.0 minutes; $p < 0.0001$) and mapping time ($p = 0.0005$) and achieved higher FPI rates (93.1% vs 85.8%; $p < 0.0001$). Additional lesions beyond PVI were less frequent with PFA (1.97% vs 19.33%, $p < 0.0001$). Fluoroscopy time was modestly higher in the PFA group (+2.6 minutes; $p = 0.0004$). Ablation duration decreased significantly within the first 15 cases.

Conclusions*:* Integrated PFA significantly improved procedural efficiency compared with RF ablation while maintaining acute PVI success, supporting its potential to enhance electrophysiology laboratory workflow.

Keywords: atrial fibrillation; efficiency; pulsed field ablation; radiofrequency ablation.

Condensed abstract: In a prospective multicenter study of 503 patients undergoing pulmonary vein isolation (PVI) for atrial fibrillation (AF), integrated pulsed field ablation (PFA) was compared with contemporary radiofrequency (RF) ablation. PFA significantly reduced total procedure time (93.3 vs 115.3 minutes; $p < 0.0001$), driven by shorter ablation and mapping durations, while maintaining 100% acute procedural success. First-pass isolation rates were higher and additional lesion requirements were lower with PFA. Fluoroscopy time was modestly increased. Procedural efficiency improved rapidly during early operator experience. Integrated PFA enhances electrophysiology laboratory workflow without compromising acute efficacy.

Abbreviations list:

AF: atrial fibrillation

EP: electrophysiology

FPI: first-pass isolation

PFA: pulsed field ablation

PVI: pulmonary vein isolation

RF: radiofrequency

INTRODUCTION

Pulsed field ablation (PFA) is an innovative modality for treating atrial fibrillation (AF) that induces selective cell death in cardiac tissue through high-intensity electrical pulses. Unlike conventional thermal ablation techniques such as radiofrequency (RF) or cryoablation, PFA creates highly selective myocardial lesions through irreversible electroporation, avoiding damage to adjacent sensitive structures, including peripheral nerves or the esophagus.[1-5] One of the main advantages of this technology is the potential for shorter procedural duration, as clinical series have reported reduced ablation times compared with traditional thermal techniques.[6,7] In the first randomized trial comparing PFA with thermal ablation in paroxysmal AF, PFA demonstrated non-inferior efficacy and safety to RF ablation while allowing faster procedures, although with greater fluoroscopy use.[8] More recently, the introduction of the Varipulse™ catheter has enabled integration of PFA withing a three-dimensional electronic mapping system.[9,10] This integrated platform combines mapping and ablation capabilities, enabling real-time catheter visualization and potentially facilitating fluoroscopy-minimization strategies.[10-12] A key hypothesis underlying integrated PFA technology is that workflow simplification may improve electrophysiology (EP) lab efficiency without compromising clinical efficacy. However, despite growing adoption of PFA systems, real-world data comparing procedural efficiency between integrated PFA platforms and contemporary RF ablation strategies remain limited.[13-16]

In this context, the present study was designed to compare the efficiency of integrated PFA ablation using Varipulse™ versus conventional RF ablation for pulmonary vein isolation (PVI) in patients with AF. The primary objective was to evaluate reduction in total procedure ('skin-to-skin') time while maintaining non-inferior acute efficacy (in terms of PVI) and a similar fluoroscopy time. Additional secondary objective was to assess differences between integrated PFA versus RF in several procedural metrics, such as total fluoroscopy time, number of

mapping points acquired, need for additional lesion sets beyond pulmonary vein isolation, anesthesia strategy used during the procedure, and characterization of the learning curve associated with adoption of the integrated pulsed field ablation technology.

METHODS

Study design and population

This study is a prospective observational, non-randomized, multicenter study conducted across six tertiary hospitals in Spain. Consecutive patients undergoing first-time PVI for paroxysmal or persistent AF were included. Procedures were performed using either RF ablation or integrated PFA according to operator's discretion and local clinical practice. Cases were divided into an RF group (SmartTouch SF™, Biosense Webster, Inc.; or QDOT Micro™ catheter, Biosense Webster, Inc., CA, USA) and a PFA group (VP group; Varipulse™ Biosense Webster, Inc.) integrated within the CARTO™ electroanatomic mapping system. All the procedural variables included in the study were collected using the CARTODAY application, and only procedures performed at centers with approved CARTODAY consent were included. Non-patient information was collected to analyze primary and secondary objectives based on the day-to-day usual clinical practice. Data reflected routine clinical practice without protocol-mandated procedural modifications, consistent with previously reported real-world PFA evaluations.[12,13]

Eligible participants were adults ≥18 years of age with paroxysmal or persistent AF and a clinical indication for first-time PVI. Patients were excluded if they had undergone a previous PVI or catheter ablation procedure, presented any contraindication to an ablation procedure or anticoagulation therapy, had ischemic heart disease or severe valvular disease, or carried an implanted cardiac device or known bradyarrhythmia requiring pacemaker implantation.

Additional exclusion criteria included the presence of contraindications to any of the study devices according to the respective instructions for use. The use of the Varipulse™ Platform is contraindicated in patients with active systemic infection or sepsis, the presence of intracardiac thrombus or myxoma, or those who have undergone a ventriculotomy or atriotomy within the preceding eight weeks, as well as in patients with prosthetic valves that could be damaged or cause catheter entrapment; furthermore, the device must not be used in the coronary vasculature, via a retrograde transaortic approach, or in the presence of interatrial baffles or patches that could be compromised during transseptal access, as specified in the FDA Summary of Safety and Effectiveness Data.[17]

Procedural protocol and endpoints

All procedures were performed under sedation or general anesthesia protocol according to operator preference. Following transseptal puncture, electroanatomic mapping and voltage mapping of the left atrium were completed using a high-density mapping catheter (LASSO™, PENTARAY™, or OCTARAY™; Biosense Webster, Inc., CA, USA) or Varipulse™ catheter. Subsequently, RF ablation was performed point-by-point according to the CLOSE protocol[18] using SmartTouch SF™ or QDOT Micro™ catheters. Integrated PFA procedures were performed using the Varipulse™ catheter according to the inspIRE study published protocol.[11] For PVI, maximum energy setting to apply at least twelve applications per pulmonary vein (translating to 48 applications per subject or 36 applications if right/left common veins were present) were performed. Acute procedural success was determined by confirmation of entrance block, without a waiting period, consistent with previous PFA studies.[8,11]

The primary endpoint of the study was total procedure ('skin-to-skin') time, defined as the interval from femoral venous puncture to catheter removal. Secondary endpoints included ablation duration, electroanatomic mapping time, and left atrial dwell time, as well as

procedural effectiveness assessed by FPI rate and confirmation of acute pulmonary vein isolation. Additional secondary endpoints comprised several procedural metrics: (1) time the ablation catheter remains in the left atrium (dwell time), (2) time spent on electroanatomic mapping, (3) number of mapping points acquired, (4) sedation/anesthesia protocols used, (5) need for additional lesions beyond PVI (6) characterize the learning curve of the new Varipulse™ technology by analyzing the evolution of procedure duration as operator experience increases.

Statistical analysis

The primary analysis evaluated differences in procedural efficiency measured as 'skin-to-skin' time between PFA and VP groups. For an assumed level of confidence of 95% ($\alpha = 0.05$) for the primary variable and to detect a mean difference of 5% reduction in procedure times using Varipulse™ vs QDOT Micro™ and 31% vs SmartTouch SF™, with a power of 80% (β), it is estimated 133 patients in each group, assuming a 10% of sample size loses in the process.

Comparative analyses were performed using one-way analysis of variance (ANOVA) to assess differences among groups for key variables, including ablation time, mapping time, total fluoroscopy time, and 'skin-to-skin' time. Homogeneity of variances was assessed using Brown-Forsythe and Bartlett tests. When significant differences were detected ($p < 0.05$), Tukey's multiple comparison test was applied to identify specific group differences. Additionally, unpaired t-tests were conducted for targeted two-group comparisons, reporting 95% confidence intervals and effect sizes. All analyses were performed with a significance level of $\alpha = 0.05$.

RESULTS

A total of 503 pulmonary vein isolation procedures performed by 24 electrophysiologists across 6 centers and over 12 months were included in the analysis. They comprise 300 in the RF group and 203 in the Varipulse^{TM} group. The study population included 60.2% patients with paroxysmal AF and 39.8% with persistent AF. Complete acute pulmonary vein isolation was achieved in 100% of cases at the end of the procedure. Additional lesion delivery beyond pulmonary PVI was required significantly less frequently in the PFA group compared with the RP group (1.97% vs 19.33%, respectively). Study results are summarized in Table 1 and in Supplementary Table 1.

Primary endpoint

The primary endpoint of total procedure ('skin-to-skin') time was significantly shorter in the Varipulse™ group compared to the RF group, with mean procedure durations of 93.25 and 115.33 minutes, respectively (mean difference –22.09 minutes; $p < 0.0001$). Results are graphically depicted in Figure 1A. This reduction was consistent when performing a one-to-one comparison of Varipulse^{TM} with both SmartTouch SF™ (22.09 minutes reduction; 93.25 VP vs 115.34 STSF; $p < 0.0001$) and with QDOT Micro™ (22.05 reduction; 93.25 VP vs 115.30 QDOT; $p < 0.0001$). Results are graphically shown in Figure 1B. These differences are aligned with the primary objective of this study, demonstrating Varipulse™ superior efficiency in the electrophysiology lab related to a significant reduction of procedure times.

First pass isolation (FPI), determined by confirmation of entrance block, without a waiting period, was measured in this study. The overall success rate for FPI reached 88.77% with all the technologies. However, there were significant differences between VP and RF. FPI in the VP group reached 93.10% vs 85.83% in the RF group, with a mean difference of 7.27% ± 2.74% (95% CI -10.69% to -3.85%; $p < 0.0001$). Comparing the specific technologies of

ablation, the mean difference in VP vs STSF (93.10% vs 85.00%) was 8.10% ± 1.81% (95% CI 4.56% to 11.64%, p < 0.0001), and 3.10% ± 3.02% vs QDOT (95% CI -2.81% to 9.02%; p = 0.5596) (Figure 2 and Table 1).

Regarding fluoroscopy usage, a significant difference was also observed between the groups. The average fluoroscopy time in the RF group was 7.89 minutes vs 10.48 minutes in the VP group, with a mean difference of -2.58 ± 0.72 (95% confidence Interval -4.00 to -1.16, p = 0.0004). The mean difference between VP vs STSF was of 2.23 ± 0.75 (95.00% CI of diff. 0.76 to 3.71; p = 0.0086) and vs QDOT of 4.33 ± 1.25 (95.00% CI of diff. 1.90 to 6.80; p = 0.0017) There were no statistically significant differences between STSF vs QDOT (Figure 3 and Table 1).

Subgroup analysis of primary goal

There were significant differences between the groups regarding the type of AF treated (paroxysmal AF 77.34% in the VP group vs. 48.67% in the RF group, p<0.0001). To determine whether any differences remained when comparing the same AF type, a subanalysis of paroxysmal and persistent AF was performed. For paroxysmal AF (PAF), the mean 'skin-to-skin' time in the VP group was 92.69 minutes versus 113.7 minutes in the RF group, with a mean difference of –21.03 minutes (95% CI −30.55 to −11.50; p < 0.0001). The sample size for this subanalysis was 156 patients in the VP group and 146 in the RF group. Among patients with persistent AF (PersAF), the VP group had a mean 'skin-to-skin' time of 95.13 minutes versus 116.9 minutes in the RF group, with a mean difference of –21.73 minutes (95% CI −35.64 to −7.8; p = 0.0004).

Regarding FPI success, in the comparative analysis of both technologies in PAF, the VP group achieved FPI in 94.59% of cases compared with 87.84% in the RF group, yielding a mean difference of 6.7% (95% CI 1.09% to 12.39%; p = 0.01). In the PersAF analysis, the VP group

achieved FPI in 88.04% of cases versus 83.93% in the RF group, with no statistically significant difference (95% CI −4.1 to 12.37; p = 0.57). Fluoroscopy time was also analyzed for both AF types. In PAF, the VP group had a mean fluoroscopy time of 9.6 minutes versus 6.67 minutes in the RF group, with a mean difference of 2.9 minutes (95% CI 0.63 to 5.29; p = 0.006). In PersAF, the mean fluoroscopy time in the VP group was 13.34 minutes compared with 9.04 minutes in the RF group, with a mean difference of 4.29 minutes (95% CI 0.88 to 7.69; p = 0.0068). Figure 4 shows the results of the subgroup analysis.

To evaluate the user dependence of fluoroscopy time and to compare the two technologies, we conducted a per-operator analysis across five operators (i.e., to assess fluoroscopy time from a more user-dependent perspective). This analysis revealed an operator-related pattern: three of the five operators consistently reported shorter fluoroscopy times for the VP group compared with the RF group. Results are presented in Supplementary Figure 1. 1.

Secondary endpoints

Beyond the significant differences between VP and RF in the analysis of key procedural times, notable variations were also observed in mapping and ablation durations. Secondary analysis demonstrates shorter mapping time in the VP group (10.56 vs 13.12 minutes in the RF group; Table 1), yielding a mean difference of 2.56 ± 0.73 (95% CI 1.13 to 3.99; p = 0.0005). The greatest difference was found in ablation time (32.90 minutes in the VP group vs 49.93 minutes in the RF group; mean difference of 17.03 ± 1.52; 95% CI 14.05 to 20.00; p < 0.0001) (Table 1).

Regarding differences between sedation with propofol and general anesthesia, several outcomes were relevant to EP lab efficiency. Among all cases, 125 were performed under general anesthesia and 362 under propofol sedation. Information on the sedation/anesthesia type was missing in 16 cases. Regardless of the technology used, the mean ‘skin-to-skin’ time

was significantly reduced in the propofol sedation group with 103.6 minutes versus 113.5 minutes in the general anesthesia group (p = 0.0048) (Fig. 5A). In a subgroup analysis, a statistically significant increase was observed for RF versus VP procedures in both types of sedation (Fig. 5B). Additionally, there was a statistically significant increase in 'skin-to-skin' time in the RF group with general anesthesia versus propofol sedation, consistent with our prior findings (Fig. 5). Interestingly, this pattern did not appear with the VP group, as the differences between both types of sedation were statistically non-significant (Fig. 5B).

Learning curve analysis with up to five physicians demonstrated a significant reduction in ablation duration during the first 15 consecutive PFA (Varipulse^{TM}) cases per operator (p = 0.0269) over this period, with stabilization of procedural metrics observed after approximately seven cases. There was a non-significant decrease in the 'skin-to-skin' time (p = 0.7056), fluoroscopy time (p = 0.0967), and a non-significant increase in FPI (%) (p = 0.3908). Figure 6 shows these results.

DISCUSSION

In this prospective, multicenter, real-world analysis, integrated PFA using the Varipulse™ platform was associated with a significant reduction in total procedure time compared with contemporary RF ablation, while maintaining complete acute PVI success and achieving higher first-pass isolation rates. These findings provide important mechanistic and operational insights into how integrated PFA technology may reshape procedural workflow and efficiency in modern electrophysiology laboratories.

Procedural efficiency with preserved acute effectiveness

The principal finding of this study is a consistent reduction of approximately 22 minutes in total 'skin-to-skin' procedure time with PFA compared with RF ablation. Importantly, this effect persisted across atrial fibrillation subtypes, suggesting that efficiency gains were not solely attributable to differences in case selection but rather reflected intrinsic procedural characteristics of the ablation modality. From a mechanistic perspective, the observed reduction was primarily driven by a marked reduction in ablation time and reduced mapping time, consistent with the non-thermal, rapid lesion deployment characteristics of PFA.[1,2,8,19] Unlike point-by-point RF ablation, PFA enables circumferential lesion sets with fewer applications and without the need for lesion contiguity validation or contact-force optimization.[8,11,20] This likely explains both the reduced ablation time and the higher FPI rates observed in the PFA cohort. Acute PVI was achieved in 100% of cases in both groups, reinforcing the non-inferior acute efficacy profile of PFA reported in randomized trials such as ADVENT.[6,8] Notably, FPI observed in the present study was significantly higher in the PFA group, particularly compared with conventional irrigated RF (SmartTouch SF™). While the difference versus QDOT Micro™ did not reach statistical significance, the numerical trend favors PFA and suggests that although high-power short-duration RF may approximate procedural efficiency gains, integrated PFA maintains a workflow advantage.

Fluoroscopy time was modestly higher in the PFA group. However, the absolute increase was limited and occurred during the early adoption phase of this technology. Importantly, the modest fluoroscopy increment did not offset the substantial overall time savings. Given the integration of Varipulse™ within a 3D mapping system, emerging zero-fluoroscopy experiences and the seemingly present operator-related bias, it is reasonable to anticipate further reductions as operator familiarity increases. Previous reports have demonstrated feasibility of fluoroscopy-minimized or zero-fluoroscopy workflows using integrated PFA systems, suggesting that radiation exposure may decrease with increasing operator experience

and workflow optimization.[10,12,21,22] Taken together, the primary endpoint supports the hypothesis that integrated PFA improves laboratory efficiency without compromising acute procedural success.

Workflow simplification and procedural standardization

Secondary analyses provide insight into mechanisms underlying efficiency improvements. Mapping time was significantly shorter in the PFA group despite acquisition of substantially fewer mapping points, reflecting the dual mapping-ablation functionality of integrated circular PFA catheters. This represents a conceptual shift from extensive pre-ablation mapping toward streamlined anatomical workflows in straightforward PVI procedures. For EP laboratories, this may translate into streamlined workflows and reduced procedural complexity. Similar workflow simplification has been suggested in early multicenter experiences with integrated PFA platforms.[11,13,23]

One of the most striking findings was the lower incidence of additional lesions beyond PVI in the PFA group. Although differences in AF substrate distribution may partially contribute, these findings suggest more consistent and transmural circumferential isolation and lesion durability during index procedures. Reduced need for adjunctive ablation likely contributes both to shorter procedural duration and improved workflow reproducibility. Sedation strategy provided further insight. Procedures performed under propofol sedation were significantly shorter than those under general anesthesia overall. Interestingly, this difference was driven primarily by RF cases and was not observed in PFA procedures. This suggests that PFA may be less sensitive to anesthesia-related workflow variability, potentially due to shorter lesion delivery phases and reduced need for prolonged catheter stability. For high-volume centers, this finding has implications for scheduling efficiency and resource allocation.

The learning curve analysis demonstrated a significant reduction in ablation duration within the first fifteen cases per operator, with stabilization of procedural metrics occurring after approximately seven procedures. Although reductions in total procedure and fluoroscopy time did not reach statistical significance, these findings suggest rapid integration of the technology into clinical practice, consistent with prior early adoption studies of PFA systems.[12,24] From an implementation standpoint, a relatively short learning curve may facilitate dissemination across centers and lower barriers to implementation compared with technologies requiring extensive operator adaptation.

Clinical and organizational implications

Efficiency has become increasingly relevant in contemporary EP practice due to the sustained pressure on laboratory capacity placed by the rising of AF prevalence, expanding indications for catheter ablation, and growing procedural volumes.[25,26] A reproducible 20-minute reduction per case may translate into increased daily laboratory throughput, reduced overtime utilization, and therefore, improved scheduling flexibility. Additionally, shorter procedures may reduce operator fatigue and cumulative occupational strain.[27,28] Beyond procedural metrics, improved workflow efficiency may also contribute to reduced waiting times and optimized allocation of healthcare resources.[29,30] The findings of this study extend randomized efficacy data by focusing specifically on workflow metrics in a multicenter, real-world environment. This pragmatic perspective is particularly relevant for healthcare systems seeking both clinical innovation and operational sustainability.

Cost-effectiveness and health system impact

Although formal economic modeling was beyond the scope of this study, the observed procedural efficiency gains have potential cost-effectiveness implications. Reduced laboratory occupancy time, fewer adjunctive lesions, and decreased variability related to anesthesia

workflow could partially offset higher upfront device costs.[19,31] In high-volume centers, incremental throughput gains could translate into measurable institutional revenue increases or reduced waiting lists. Furthermore, if higher FPI rates translate into improved durability, an aspect requiring longer-term follow-up, downstream reductions in repeat procedures could further enhance economic value. Future prospective cost-effectiveness analyses incorporating device cost, lab time valuation, anesthesia resources, complication rates, and long-term arrhythmia recurrence will be essential to fully define the economic positioning of integrated PFA platforms within AF ablation strategies.

Limitations

This study has several limitations that should be acknowledged. Treatment allocation to PFA or RF was non-randomized and left to operator discretion, introducing potential selection bias. Differences in AF subtype distribution between groups may influenced procedural characteristics despite subgroup analyses. On the other hand, the study focused exclusively on acute procedural efficiency metrics and did not evaluate long-term arrhythmia recurrence, durability of PVI, or complication rates. Fluoroscopy use was modestly higher in the PFA group, potentially reflecting early adoption dynamics and lack of standardized fluoroscopy-minimization protocols, rather than intrinsic technological requirements. In addition, inclusion of two RF technologies introduced heterogeneity within the comparator group. Finally, as a multicenter real-world study involving multiple operators, inter-operator variability may influence procedural metrics, although this also enhances generalizability of the findings.

CONCLUSIONS

In a multicenter real-world setting, integrated Varipulse™ PFA significantly reduced total procedure time compared with contemporary RF ablation while maintaining acute PVI success

and improving first-pass isolation rates. Efficiency gains were primary driven by shorter ablation duration, streamlined mapping, and reduced need for additional lesion sets. The learning curve appears short, supporting scalable implementation. These findings suggest that integrated PFA may represent not only a technological advance in AF ablation but also a meaningful operational evolution for modern electrophysiology laboratories.

CLINICAL PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE

In patients undergoing pulmonary vein isolation for atrial fibrillation, integrated pulsed field ablation (PFA) with the Varipulse™ platform significantly reduces total procedure time compared with contemporary radiofrequency ablation while maintaining acute procedural success. Efficiency gains are primary driven by higher first-pass isolation rates, shorter ablation duration, streamlined mapping, and fewer additional lesion sets requirements. These findings suggest that integrated PFA may enhance procedural standardization and optimize electrophysiology laboratory workflow without compromising efficacy.

TRANSLATIONAL OUTLOOK

Future studies should evaluate whether the procedural efficiency advantages observed with integrated PFA translate into improved long-term arrhythmia-free survival, reduced need for repeat ablation, and enhanced cost-effectiveness at the health system level. Prospective randomized trials incorporating standardized fluoroscopy-minimization protocols and formal economic analyses will be essential to define the optimal role of integrated PFA within contemporary atrial fibrillation ablation strategies.

ACKNOWLEDGEMENTS

The authors would like to thank all patients and healthcare professionals who contributed to this study.

REFERENCES

1. Maizels L, Kalman JM. Pulsed-field ablation: a revolution in atrial fibrillation therapy. *Nat Rev Cardiol.* 2024;21:519–520.
2. Carta-Bergaz A, Ríos-Muñoz G R, Ávila P et al. Pulsed Field Ablation of Atrial Fibrillation: A Novel Technology for Safer and Faster Ablation. *Biomedicines*. 2024;12(10):2232.
3. Reddy VY, Neuzil P, Koruth JS, et al. Pulsed Field Ablation for Pulmonary Vein Isolation in Atrial Fibrillation. *J Am Coll Cardiol.* 2019;74(3):315-326.
4. Schlögl S, Schlögl KS, Bengel P, et al. Impact of open-irrigated radiofrequency catheter with contact force measurement on the efficacy and safety of atrial fibrillation ablation: a single-center direct comparison. *J Interv Card Electrophysiol*. 2022;65(3):685-693.
5. Lemoine MD, Fink T, Mencke C, et al. Pulsed-field ablation-based pulmonary vein isolation: acute safety, efficacy and short-term follow-up in a multi-center real world scenario. *Clin Res Cardiol*. 2023;112(6):795-806.
6. Boersma LVA, Széplaki G, Dello Russo A, et al. Real-world experience with the pentaspline pulsed field ablation system: one-year outcomes of the FARADISE registry. *Europace.* 2025;27(9):euaf182.

7. Yang M, Wang PY, Hao YL, et al. A real-world case-control study on the efficacy and safety of pulsed field ablation for atrial fibrillation. *Eur J Med Res*. 2023;28(1):519.
8. Reddy VY, Gerstenfeld EP, Natale A, et al. Pulsed Field or Conventional Thermal Ablation for Paroxysmal Atrial Fibrillation. *N Engl J Med*. 2023;389(18):1660-1671.
9. Nair DG, Gomez T, De Potter T. VARIPULSE: A step-by-step guide to pulmonary vein isolation. *J Cardiovasc Electrophysiol*. 2024;35(9):1817-1827.
10. Simeon E, Roeun S, Miled M, et al. When low is not low enough: zero-fluoroscopy atrial fibrillation ablation using the VARIPULSE™ pulsed field system-a prospective single-center study. *J Interv Card Electrophysiol*. 2026;69(2):249-257.
11. Duytschaever M, De Potter T, Grimaldi M, et al. Paroxysmal Atrial Fibrillation Ablation Using a Novel Variable-Loop Biphasic Pulsed Field Ablation Catheter Integrated With a 3-Dimensional Mapping System: 1-Year Outcomes of the Multicenter inspIRE Study. *Circ Arrhythm Electrophysiol*. 2023;16(3):e011780.
12. Andria N, Abuiznait Z, Saad M, et al. Single-Center Real World Experience with the VARIPULSE Platform for Pulsed Field Ablation of Atrial Fibrillation, Atrial Flutter, and Redo Procedures. *J Clin Med*. 2025;15(1):28.
13. Almorad A, Sebag FA, Brix Kronborg M et al. Acute safety, effectiveness and procedural workflow for novel pulsed field ablation variable loop circular catheter in AF procedures: A prospective, multicentre, post-market clinical trial. *Eur Heart J*. 2025;46(1):ehaf784-796
14. Sawada M, Sato H, Nagashima K et al. First Multicenter Japanese Registry on Tissue Proximity–Guided Pulsed Field Ablation: Procedural Safety and Mid–Term Outcomes. *Heart Rhythm O2*. 2025;7(2):221-231.

15. Zylla MM, Mages C, Rahm AK, et al. Comparative evaluation of 2 pulsed field ablation systems for atrial fibrillation: Insights from real-world clinical implementation and short-term outcomes. *Heart Rhythm*. 2025;22(9):2201-2208.
16. Martins Esteves I, de Pontes VB, Trevisan T, et al. Pulsed-Field Ablation Versus Radiofrequency Ablation for Paroxysmal Atrial Fibrillation: A Systematic Review and Meta-Analysis. *J Arrhythm*. 2025;41(4):e70158.
17. FDA Summary of Safety and Effectiveness Data on VARIPULSE™. 2025. Available at: https://www.fda.gov/medical-devices/recently-approved-devices/varipulse-platform-varipulse-catheter-trupulse-generator-sterile-interface-cable-ngen-pump-p240006
18. Jais P, Neuzil P, Scherr D, et al. Pulsed field vs radiofrequency ablation for paroxysmal atrial fibrillation: the BEAT PAROX-AF trial. *Eur Heart J*. 2026;ehaf1115.
19. Calvert P, Mills MT, Xydis P, et al. Cost, efficiency, and outcomes of pulsed field ablation vs thermal ablation for atrial fibrillation: A real-world study. *Heart Rhythm*. 2024;21(9):1537-1544.
20. Nakagawa H, Ikeda A, Yokoyama K, et al. Improvement in Lesion Formation with Radiofrequency Energy and Utilization of Alternate Energy Sources (Cryoablation and Pulsed Field Ablation) for Ventricular Arrhythmia Ablation. *Card Electrophysiol Clin*. 2022;14(4):757-767.
21. Pérez-Pinzón J, Villarreal D, Ma M, et al. Learning curve and procedural efficiency of zero-fluoroscopy pulsed-field ablation for atrial fibrillation. *Heart Rhythm*. 2025;S1547-5271(25):02917-0.
22. Borlich M, Groschke S, Wietgrefe J, et al. Near-zero fluoroscopy workflow for pulmonary vein isolation in atrial fibrillation using a variable loop, 3D-integrated

circular PFA catheter (Varipulse™): initial single-center experience with the first 35 patients. *J Interv Card Electrophysiol*. 2025;68(4):877-884.

23. Jewell C, Garabelli P, Davis L, et al. Mapping workflow trends in pulsed-field ablation procedures: an international glimpse. *Europace*. 2025;27(Suppl 1):euaf085.148.
24. Molon G, Nardi S, Mitacchione G, et al. Acute outcomes and learning curve from the initial patients treated with the PulseSelect system: a real-world multicenter experience of pulsed field ablation. *J Interv Card Electrophysiol*. 2025;68(7):1475-1485.
25. Kattel S, Tan Z, Lin Z, et al. Procedural volume and outcomes with atrial fibrillation ablation: A report from the NCDR AFib Ablation Registry. *Heart Rhythm*. 2025;22(1):37-48.
26. Liang M, Zhang J, Li G, Wang P. Global research progress on radiofrequency ablation in cardiology: A bibliometric analysis (2004-2023). *Medicine (Baltimore)*. 2024;103(23):e38498.
27. Kowalski M, Su WW, Holbrook R, et al. Impact of Cryoballoon Ablation on Electrophysiology Lab Efficiency During the Treatment of Patients With Persistent Atrial Fibrillation: A Subanalysis of the STOP Persistent AF Study. *J Invasive Cardiol*. 2021;33(7):E522-E530.
28. Tonchev IR, Nam MCY, Gorelik A, et al. Relationship between procedural volume and complication rates for catheter ablation of atrial fibrillation: a systematic review and meta-analysis. *Europace*. 2021;23(7):1024-1032.
29. Berte B, Kobza R, Toggweiler S, et al. Improved Procedural Efficiency of Atrial Fibrillation Ablation Using a Dedicated Ablation Protocol and Lean Management. *JACC Clin Electrophysiol*. 2021;7(3):321-332.

30. Qeska D, Singh SM, Qiu F, et al. Variation and clinical consequences of wait-times for atrial fibrillation ablation: population level study in Ontario, Canada. *Europace*. 2023;25(5):euad074.
31. Soleimani H, Dastjerdi P, Mohammadi NSH, et al. Cost Comparison of Pulsed Field Ablation and Conventional Thermal Ablation for Atrial Fibrillation: A Systematic Review. *Pacing Clin Electrophysiol*. 2026;49(2):113-123.

FIGURE LEGENDS

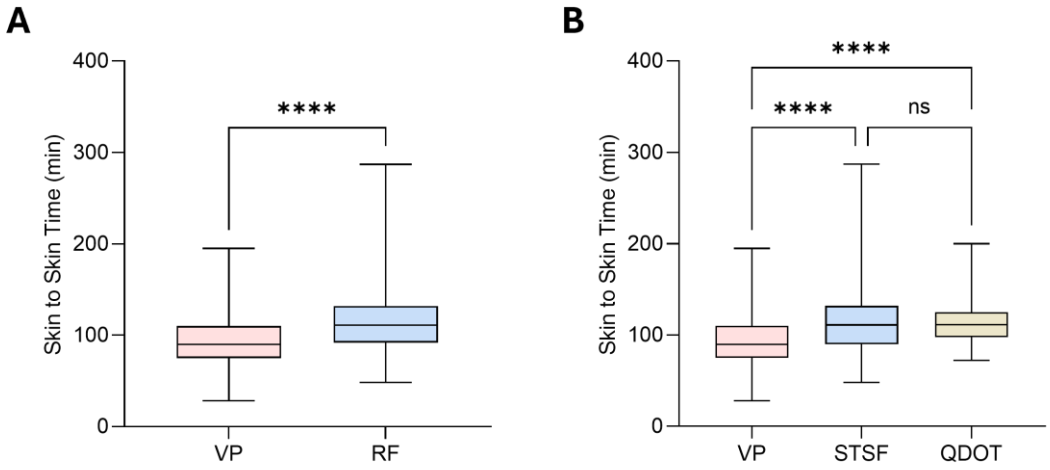


Figure 1. 'Skin-to-skin' time analysis. A) Mean difference VP vs RF: –22.09 ± 2.92 minutes; 95% CI –15.22 to –27.9; p < 0.0001 (P value summary ****). B) Mean difference VP vs. STSF: –22.09 minutes; 95% CI –29.23 to –14.96); p < 0.0001 (P value summary ****). Mean difference VP vs. QDOT: –22.05; 95% CI –33.97 to –10.13; p < 0.0001 (P value summary ****). Mean difference STSF vs. QDOT: 0.04; 95% CI –11.66 to 11.74; p > 0.9999 (P value summary ns). CI, confidence interval; ns, non-statistically significant; QDOT, QDOT Micro™; RF, radiofrequency group; STSF, SmartTouch SF™; VP, Varipulse™ group.

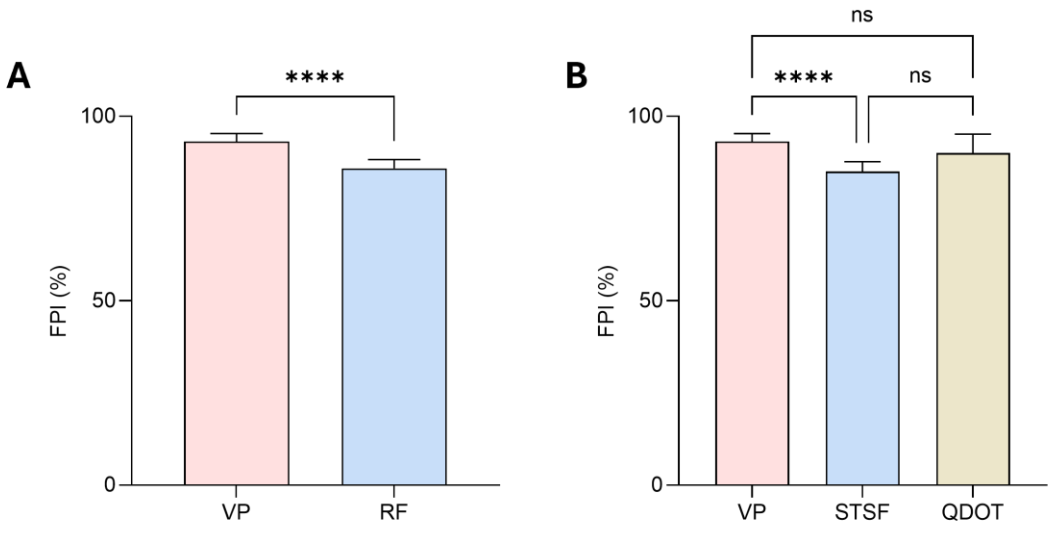


Figure 2. First pass isolation (FPI) analysis. A) Mean difference VP vs RF: 7.27% ± 2.74%; 95% CI –10.69% to –3.85%; p < 0.0001 (P value summary ****). B) Mean difference VP vs. STSF: 8.10% ± 1.81%; 95% CI 4.56% to 11.64%; p < 0.0001 (P value summary ****). Mean difference VP vs. QDOT: 3.10% ± 3.02%; 95% CI –2.81% to 9.02% p = 0.5596 (P value summary ns). Mean difference STSF vs. QDOT: –5.00% ± 2.96%; 95% CI –10.80% to 0.80%; p = 0.2109 (P value summary ns). CI, confidence interval; ns, non-statistically significant; QDOT, QDOT Micro™; RF, radiofrequency group; STSF, SmartTouch SF™; VP, Varipulse™ group.

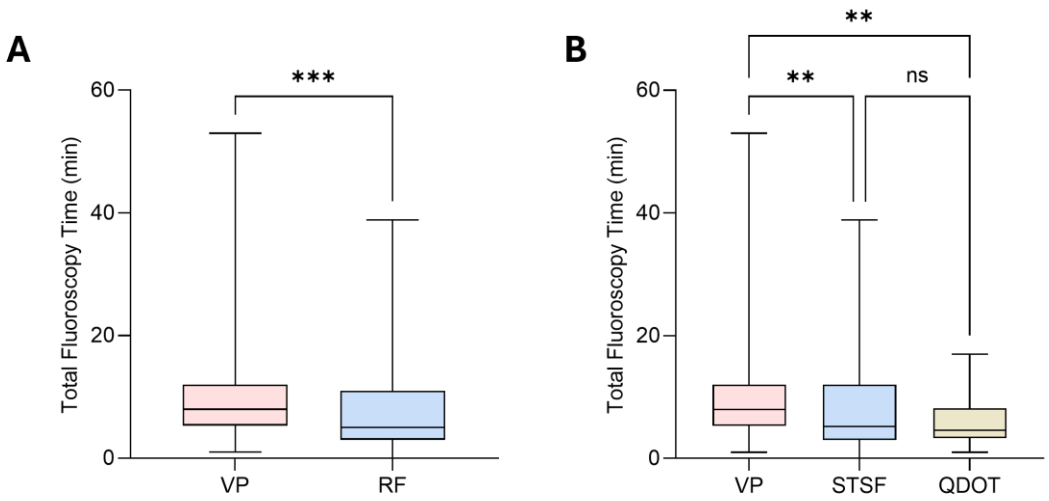


Figure 3: Fluoroscopy time analysis. A) Difference between means fluoroscopy times of RF and VP: –2.58 ± 0.72; 95% CI –4.00 to -1.16; p = 0.0004 (P value summary ***). B) Mean difference VP vs. STSF: 2.23 ± 0.75; 95% CI 0.76 to 3.71; p = 0.0086 (P value summary **). Mean difference VP vs. QDOT: 4.33 ± 1.25; 95% CI 1.90 to 6.80; p = 0.0017 (P value summary **). Mean difference STSF vs. QDOT: 2.10 ± 1.23; 95% CI –0.31 to 4.51; p = 0.2043 (P value summary ns). CI, confidence interval; ns, non-statistically significant; QDOT, QDOT Micro™; RF, radiofrequency group; STSF, SmartTouch SF™; VP, Varipulse™ group.

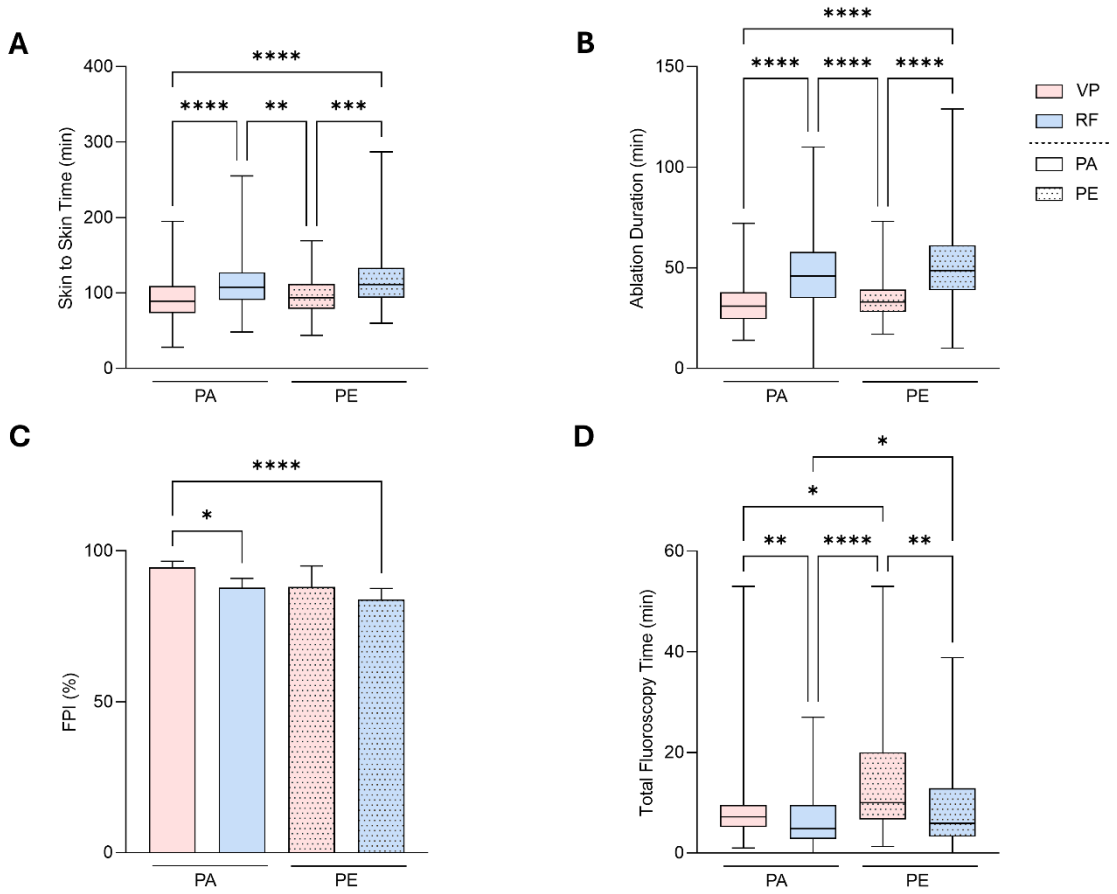


Figure 4: Primary outcomes of a subgroup analysis based on type of AF: paroxysmal (PA) or persistent (PE) atrial fibrillation. A) Difference in 'skin-to-skin' time mean (VP vs RF) in the PA group: –21.03 minutes; 95% CI interval -30.55 to -11.50; p value <0.0001 (P value summary ****). Difference between means (VP vs RF) in the PE group: –21.73 minutes; 95% CI –35.64 to –7.8; p = 0.0004 (P value summary ***). B) Differences in ablation time mean between VP vs RF in PA group: –16.34 minutes; 95% CI –21.28 to –11.40; p < 0.0001 (P value summary ****). Difference between VP vs RF in mean ablation time in the PE: –16.14 minutes; 95% CI –23.36 to –8.92; p < 0.0001 (P value summary ****). C) Mean difference in FPI success between VP vs RF in PA: 6.7%; 95% CI 1.09 to 12.39; p = 0.0118 (P value summary *). D) Mean difference in total fluoroscopy time between VP vs RF in the PA group: 2.96 minutes; 95% CI 0.63 to 5.29; p = 0.0061 (P value summary **). Mean difference in total

fluoroscopy time between VP vs RF in the PE group: 13.34 minutes; 95% CI 0.88 to 7.69; p = 0.0068 (P value summary **). AF, atrial fibrillation; CI, confidence interval; FPI, first-pass isolation; PA, paroxysmal AF; PE, persistent AF; RF, radiofrequency group: VP, Varipulse^{TM} group.

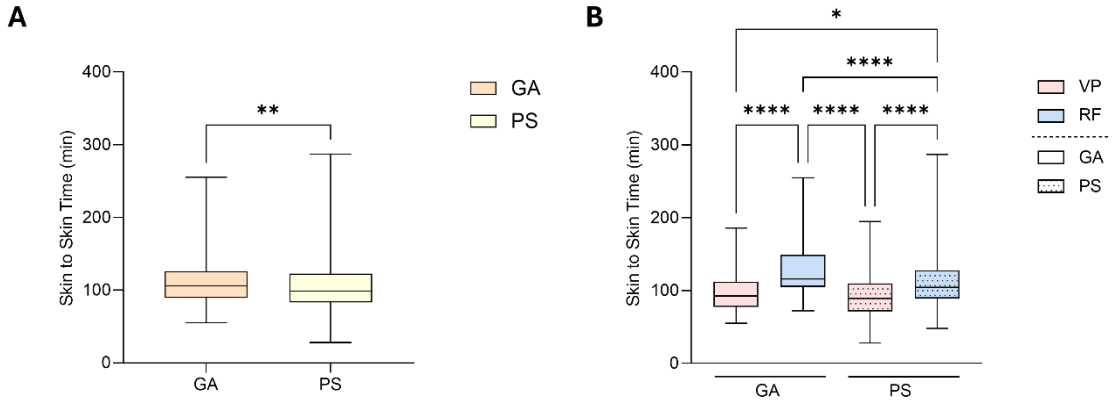
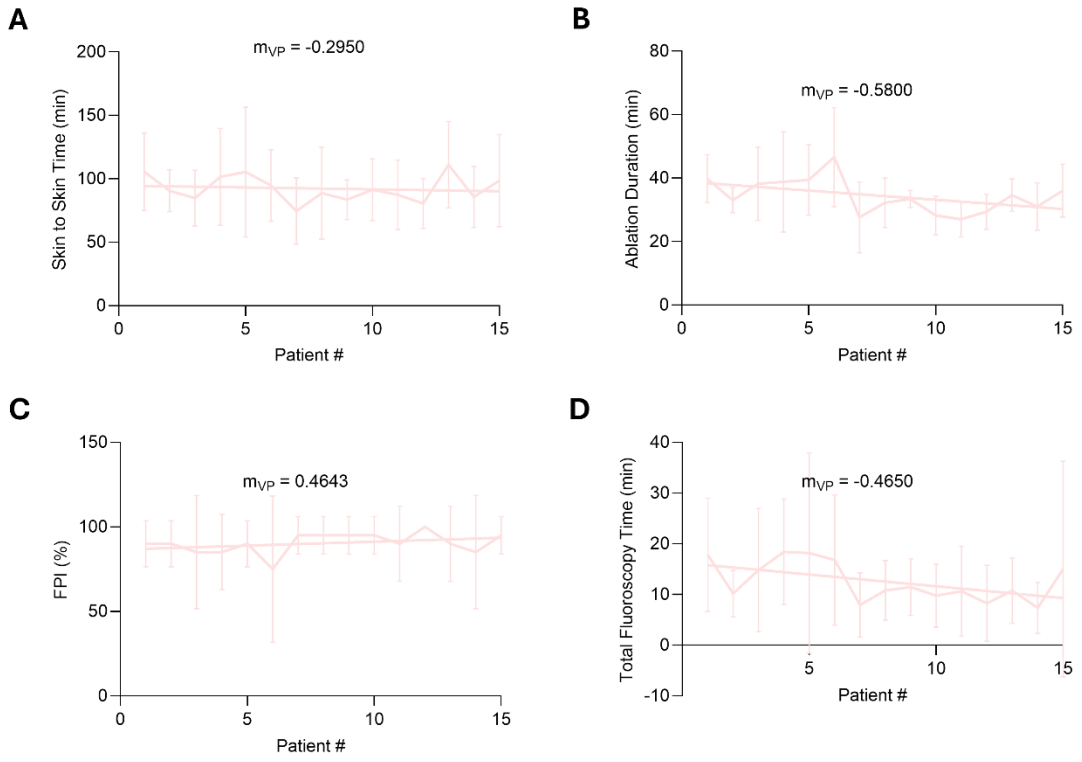


Figure 5. General anesthesia (GA) vs propofol sedation (PS) 'skin to skin' time analysis. A) Difference between means (GA vs PS): –9.90 ± 3.49 minutes; 95% CI –16.77 to –3.03; p = 0.0048 (P value summary **). B) Mean difference VP-GA vs. RF-GA: –33.79 ± 5.68 minutes; 95% CI –48.42 to –19.15); p < 0.0001 (P value summary ****). Mean difference VP-GA vs. VP-PS: –4.29 ± 4.86 minutes; 95% CI –8.24 to 16.83; p = 0.8136 (P value summary ns). Mean difference VP-GA vs. RF-PS: –14.00 ± 4.55 minutes; 95% CI –25.73 to –2.27); p = 0.0118 (P value summary *). Mean difference VP-PS vs. RF-GA: 38.08 ± 4.83 minutes; 95% CI –25.61 to 50.55); p < 0.0001 (P value summary ****). Mean difference VP-PS vs. RF-PS: –18.29 ± 3.44 minutes; 95% CI –27.17 to –9.42); p < 0.0001 (P value summary ****). Mean difference RF-GA vs. RF-PS: 19.79 ± 4.52 minutes; 95% CI 8.13 to 31.44; p <0.0001 (P value summary ****). CI, confidence interval; GA, general anesthesia; PS, propofol sedation; RF, radiofrequency group; VP, Varipulse^{TM} group.



577

578 **Figure 6. Learning curve analysis for 15 cases with the same electrophysiologists (n = 5)**
579 **for VP procedure.** A) Learning curve analysis for 'skin-to-skin' time, the slope was non-
580 significantly non-zero: –0.2950 (p = 0.7056). B) Learning curve analysis for ablation duration,
581 the slope was significantly non-zero: 0.5800 (p = 0.0269). C) Learning curve analysis for FPI
582 (%), the slope was non-significantly non-zero: 0.4643 (p = 0.3908). D) Learning curve analysis
583 for total fluoroscopy time, the slope was non-significantly non-zero: –0.4650 (p = 0.0967). FPI,
584 first-pass isolation; VP, Varipulse^{TM} group.

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587 # TABLES

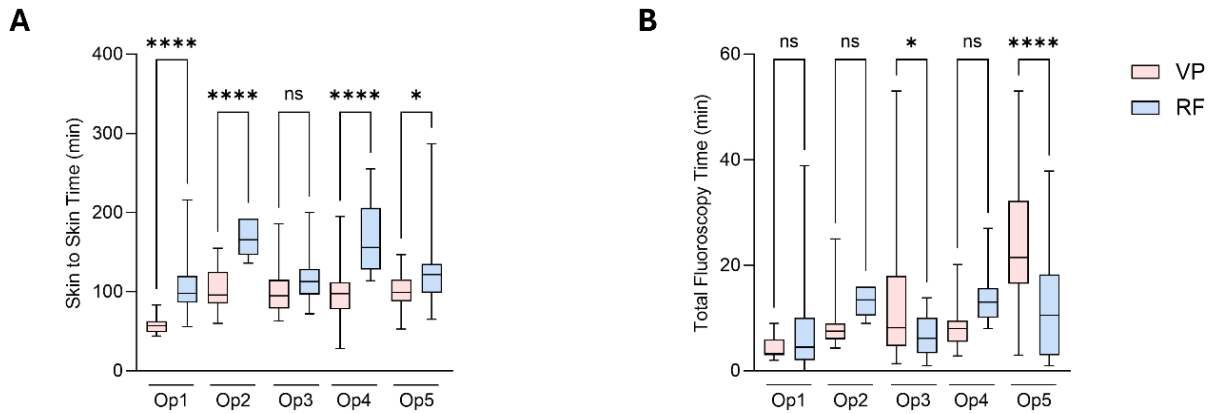
588 **Table 1.** Summary of study results.

Variable	VP Group	RF Group	Mean Difference	p value
'Skin-to-skin' time (minutes; average)	93.25	115.33	–22.08	<0.0001
First-pass isolation (%)	93.10%	85.83%	7.27%	<0.0001
Mapping time (minutes; average)	10.56	13.12	–2.56	0.0005
Ablation time (minutes; average)	32.90	49.93	–17.03	<0.0001
Fluoroscopy time (minutes; average)	10.48	7.89	2.59	0.0004
< 5 mins fluoroscopy (%)	21.67%	44.66%	–22.99%	<0.0001
General Anesthesia vs Sedation with Propofol (%)	21.80%	30.96%	–9.16%	0.0261
Paroxysmal AF vs Persistent AF (%)	77.34%	48.67%	28.67%	<0.0001
Mapping points average	1888	8754	–6866	<0.0001

589 AF, atrial fibrillation; RF radiofrequency group; VP, Varipulse^{TM} group.

590

SUPPLEMENTARY MATERIAL



Supplementary figure 1. Per-operator subanalysis. A) Per-operator (n = 5) subanalysis of 'skin-to-skin' time (min). Difference between means (Op1) –47.26 ± 7.96; 95% CI –67.84 to –26.69; p < 0.0001 (P value summary ****). Difference between means (Op2) –63.45 ± 13.53; 95% CI –98.44 to –28.45; p < 0.0001 (P value summary ****). Difference between means (Op3) –15.50 ± 9.06; 95% CI –38.92 to 7.93; p = 0.3699 (P value summary ns). Difference between means (Op4) –69.69 ± 10.10; 95% CI –95.82 to –43.56; p < 0.0001 (P value summary ****). Difference between means (Op5) –22.64 ± 7.72; 95% CI –42.61 to –2.67; p = 0.0181 (P value summary *). B) Per-operator (n = 5) subanalysis of total fluoroscopy time (min). Difference between means (Op1) –3.10 ± 2.02; 95% CI –8.33 to 2.13¸p = 0.4899 (P value summary ns). Difference between means (Op2) –5.00 ± 3.44; 95% CI –13.90 to 3.89; p = 0.5477 (P value summary ns). Difference between means (Op3) 7.13 ± 2.30; 95% CI 1.17 to 13.08; p = 0.0107 (P value summary *). Difference between means (Op4) –4.92 ± 2.57; 95% CI –11.56 to 1.72; p = 0.2519 (P value summary ns). Difference between means (Op5) 12.68 ± 1.96; 95% CI 7.60 to 17.75; p < 0.0001 (P value summary ****). CI, confidence interval; Op, operator.

609

610 **Supplementary Table 1**. Analysis of the additional ablations performed with VP and RF.

Additional Ablations	VP	% Total Ablations VP	RF	% Total Ablations RF	Mean Difference	p value
Carina Line	8	3,94%	160	53,33%	-49,39%	<0.0001
CTI	0	0,00%	80	26,67%	-26,67%	<0.0001
Mitral Line	0	0,00%	10	3,33%	-3,33%	0.007
Posterior Isolation	4	1,97%	13	4.33%	-2,36%	0.2091
SVC Isolation	0	0,00%	2	0,67%	-0,67%	0.5176
Fibrosis	0	0,00%	5	1,67%	-1,67%	0.0848
Roof Line	0	0,00%	12	4,00%	-4,00%	0.0022
Vein of Marshall EtOH ablation	0	0,00%	14	4,67%	-4,67%	0.0012
CS Isolation	0	0,00%	2	0,67%	-0,67%	0.5176
Total Additional Ablations (excluding Carina Line and CTI)	4	1,97%	58	19,33%	-17,36%	<0.0001

611 CTI, cavotricuspid isthmus; RF radiofrequency group; SVC, superior vena cava; VP,
612 Varipulse^{TM} group.

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