Journal of Interventional Cardiac Electrophysiology

A Standardized Stepwise Zero-Fluoroscopy Approach with Transesophageal Echocardiography Guidance for Atrial Fibrillation Ablation

--Manuscript Draft--

Manuscript Number:	
Full Title:	A Standardized Stepwise Zero-Fluoroscopy Approach with Transesophageal Echocardiography Guidance for Atrial Fibrillation Ablation
Article Type:	Original Research
Section/Category:	Catheter Ablation
Keywords:	Keywords: Atrial Fibrillation; Catheter Ablation; Fluoroscopy; Transesophageal Echocardiography; Radiological Dose; No X-ray.
Corresponding Author:	Antonio Berruezo, MD, Ph.D. Centro Médico Teknon: Centro Medico Teknon Barcelona, SPAIN
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Centro Médico Teknon: Centro Medico Teknon
Corresponding Author's Secondary Institution:	
First Author:	Giulio Falasconi
First Author Secondary Information:	
Order of Authors:	Giulio Falasconi
	Diego Penela
	David Soto-Iglesias
	Beatriz Jáuregui
	Alfredo Chauca
	Rodolfo San Antonio
	Augusto Ordoñez
	Cheryl Teres
	Jose Miguel Carreño
	Claudia Scherer
	Daniel Viveros
	Marina Huguet
	Jose Torres
	Pedro Vergara
	Giuliana Maldonado
	Alejandro Panaro
	Oscar Cámara
	Antonio Berruezo, MD, Ph.D.
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	Purpose . There is growing interest in performing fluoroless radiofrequency ablation

	(RFA) for atrial fibrillation (AF) due to the increasing awareness of risk associated with radiation exposure of patients and professional staff. The present study aimed to evaluate the feasibility, safety and efficacy of a stepwise transesophageal echocardiography (TEE)-guided zero-fluoroscopy approach (ZFA) for RFA. Methods. Consecutive patients (n=111) referred for AF-ablation were prospectively enrolled with intention to RFA with ZFA. Procedural outcomes were compared with historical controls (HCs) after 1:1 propensity-score matching. ZFA success was considered when no Xray were utilized to perform the whole procedure. Results. ZFA success was achieved in 80 (72%) procedures. BMI>35 kg/m 2 resulted the only independent predictor of ZFA failure (OR=6.10, 95%CI 1.15-46.49, p=0.04). Total procedural time was lower in ZFA group compared to HCs (47.0 vs 55.0 minutes, p<0.001). In comparison to HCs, a significant reduction in radiation exposure was observed in ZFA group: fluoroscopy time (3 vs 63 seconds, p<0.001), total emitted fluoroscopy dose (0.2 vs 6.0 mGy, p<0.001), dose-area product (0.04 vs 1.4 Gy*cm 2 , p<0.001), and effective dose (0.8 vs 27.2 mSv*100, p<0.001). Complete pulmonary vein isolation was achieved in all procedures. No difference was observed between the groups in in-hospital complication rate (0.9% vs. 1.8%, p=0.99). Conclusion. This is the largest study proving procedural feasibility, safety and efficacy of TEE-guided AF-ablation with a complete or near-complete avoidance of radiological exposure, without using intracardiac echocardiography.

A Standardized Stepwise Zero-Fluoroscopy Approach with Transesophageal Echocardiography Guidance for Atrial Fibrillation Ablation

Short Title: Zero Xray TEE-guided AF-ablation

Giulio Falasconi, MD,[a,b] Diego Penela, MD, PhD,[a] David Soto-Iglesias, MSc, PhD,[a] Beatriz Jáuregui, MD,[a] Alfredo Chauca, MD[a] Rodolfo San Antonio, MD,[a] Augusto Ordoñez, MD,[a] Cheryl Teres, MD,[a] Jose Miguel Carreño, MD,[a] Claudia Scherer, MD,[a] Daniel Viveros, MD,[a] Marina Huguet, MD, PhD,[a] Jose Torres, MD,[a] Pedro Vergara, MD,[a] Giuliana Maldonado, MD,[a] Alejandro Panaro, MD,[a] Oscar Cámara, MSc, PhD,[c] Antonio Berruezo, MD, PhD[a]

[a] Heart Institute, Teknon Medical Centre, Barcelona, Spain

[b] Vita-Salute University, San Raffaele, Milan, Italy

[c] Pompeu Fabra University, Barcelona, Spain

*Corresponding author:

Antonio Berruezo MD, PhD

Head of Arrhythmia Department, Teknon Medical Centre,

Calle Villana 12 (08022), Barcelona, Spain.

E-mail address: antonio.berruezo@quironsalud.es

Words count: 3588

STRUCTURED ABSTRACT

Purpose. There is growing interest in performing fluoroless radiofrequency ablation (RFA) for atrial fibrillation (AF) due to the increasing awareness of risk associated with radiation exposure of patients and professional staff. The present study aimed to evaluate the feasibility, safety and efficacy of a stepwise transesophageal echocardiography (TEE)-guided zero-fluoroscopy approach (ZFA) for RFA.

Methods. Consecutive patients (n=111) referred for AF-ablation were prospectively enrolled with intention to RFA with ZFA. Procedural outcomes were compared with historical controls (HCs) after 1:1 propensity-score matching. ZFA success was considered when no Xray were utilized to perform the whole procedure.

Results. ZFA success was achieved in 80 (72%) procedures. BMI>35 kg/m^2 resulted the only independent predictor of ZFA failure (OR=6.10, 95%CI 1.15-46.49, p=0.04). Total procedural time was lower in ZFA group compared to HCs (47.0 vs 55.0 minutes, p<0.001). In comparison to HCs, a significant reduction in radiation exposure was observed in ZFA group: fluoroscopy time (3 vs 63 seconds, p<0.001), total emitted fluoroscopy dose (0.2 vs 6.0 mGy, p<0.001), dose-area product (0.04 vs 1.4 Gy*cm^2, p<0.001), and effective dose (0.8 vs 27.2 mSv*100, p<0.001). Complete pulmonary vein isolation was achieved in all procedures. No difference was observed between the groups in in-hospital complication rate (0.9% vs. 1.8%, p=0.99).

Conclusion. This is the largest study proving procedural feasibility, safety and efficacy of TEE-guided AF-ablation with a complete or near-complete avoidance of radiological exposure, without using intracardiac echocardiography.

Keywords: Atrial Fibrillation; Catheter Ablation; Fluoroscopy; Transesophageal Echocardiography; Radiological Dose; No X-ray.

DECLARATIONS

Funding: none.

Conflict of interest: Dr. Berruezo is stockholder of ADAS 3D Medical. Dr. Soto-Iglesias is an employee of Biosense Webster. The other authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Authors' Contributions: All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Giulio Falasconi, Diego Penela and David Soto-Iglesias. The first draft of the manuscript was written by Giulio Falasconi and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics Approval: This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the local Ethics Committee.

INTRODUCTION

Atrial fibrillation (AF) is the most frequent cardiac arrhythmia in adult people and radiofrequency ablation (RFA) is an established and widely performed treatment for AF[1]. Recently, the awareness of risk associated with radiation exposure of patients and professional staff has significantly increased. Several studies have demonstrated the direct relationship between the radiation dose from medical imaging and the lifelong risk of both deterministic and stochastic side effects[2].

Large studies already reported excellent outcomes in right-sided ablations in patients presenting with supraventricular tachycardias[3]. However, concerns regarding transseptal access have limited the use of fluoroless approaches for left atrium (LA) ablations.

There is growing evidence that the combined use of 3D EAM and intracardiac echocardiography (ICE) to guide transseptal puncture (TSP) allows reduction or even elimination of fluoroscopy[4] with the downside of the need for an additional catheter and venous puncture. Nevertheless, due to the non-ubiquitous use of ICE, the need for trained cardiologists, and the increase of procedural cost, TSP remains largely fluoroscopy-dependent in most centers. In this context, fluoroless or near-fluoroless approach for pulmonary veins isolation (PVI) without ICE is limited to case series and/or selected patient settings[5].

We report a single center experience evaluating the feasibility, safety and efficacy of a standardized stepwise transesophageal echocardiography (TEE)-guided approach to achieve zero or near-zero Xray AF-ablation.

METHODS

Patient sample

We conducted a single-center, experimental, and prospective study. Consecutive unselected patients who underwent first- or redo- RFA with intention for zero-fluoroscopy approach (ZFA) were prospectively enrolled between January 2021 and April 2021. All patients had symptomatic paroxysmal or persistent AF with indication for ablation in accordance with ESC guidelines[6]. The only exclusion criterion was the presence of Cardiac Implantable Electronic Device (CIED).

Procedural outcomes obtained in the prospective group were compared with those obtained in a historical control cohort (a group of consecutive patients that met the same inclusion and exclusion criteria and underwent RFA for AF in the same center without intention for ZFA from May 2020 to December 2020). In this control arm the same procedural workflow was followed except for a less restrictive use of fluoroscopy that was used to guide the TSP and to localize the catheter, although in compliance with the recommendation to keep the radiation as low as reasonably achievable.

Written informed consent was obtained from all patients. The study complied with the Declaration of Helsinki and was approved by the Institutional Ethics Committee.

Pre-procedural Preparation

The same pre-procedural preparation was followed for both groups (ZFA and HCs).

All procedures were performed using CARTO3 mapping system (Biosense Webster, Johnson & Johnson Medical S.p.A., CA, USA). A multi-detector cardiac tomography (MDCT) study was obtained within 7 days prior to the procedure in all patients without contraindications. MDCT-derived data were used to calculate the left atrial wall thickness (LAWT) in order to tailor the RF energy delivery (ablation index) adapted to the local LAWT[7]. All procedures were performed under general anesthesia and utilizing high-frequency low-tidal volume (HFLTV) ventilation protocol[8] (*Supplemental Table 1*). Intraprocedural TEE-guidance was performed by cardiologists experienced in cardiac imaging. All procedures were performed with single catheter technique[9], using a 3.5-mm tip ThermoCool SmartTouch (Biosense Webster, Johnson & Johnson Medical S.p.A., CA, USA) irrigated catheter. During all procedures fluoroscopy was available to ensure patient safety; in case of necessity, all operators used a frame rate setting of 7.5 frames per second.

Zero-Fluoroscopy Stepwise Approach

Vascular access and TEE-guided transseptal puncture

Single percutaneous access of right femoral vein was obtained using Seldinger technique. A long-guidewire was inserted via the needle and advanced until the correct positioning in the superior vena cava, as confirmed by TEE (bicaval view). Difficulties in advancing the guide and navigating the veins were overcome by pulling back the guidewire and slightly rotating it. The PREFACE® Guiding Sheath (Johnson & Johnson Medical S.p.A., CA, USA) was introduced over the guidewire and advanced in the superior vena cava, visualized by TEE (bicaval view).

A HeartSpan® Transseptal Needle (Johnson & Johnson Medical S.p.A., CA, USA) was connected to the pressure line and then advanced until needle arrow was 2-3 cm from the sheath dilator distal

extremity. The needle and the sheath were pulled back caudally under TEE monitoring (bicaval view) with the needle arrow pointing at 5 o'clock. When a central position within the fossa ovalis was reached and tenting was obtained, TEE-guidance moved to the short axis view in order to check the antero-posteriority; the position of the tenting is therefore optimized by rotating the needle arrow clockwise or counterclockwise. The needle was then pushed out under TEE monitoring (short axis view) until fossa ovalis was crossed, with a visible release of the tenting. Before advancing the dilator and the sheath, the correctness of the puncture was confirmed by the check of the left atrial pressure trace and the injection of saline solution into LA through the needle, visible on TEE as "echocardiographic bubbles". The dilator and the sheath were then advanced under TEE guidance and thereafter dilator and needle were pulled out. A double track image of the sheath became visible in this moment on TEE.

Catheter insertion through the sheath was recognized by a hyperechoic image filling the double track image; at the same time catheter entrance in LA was also checked using CARTO system because of the change from black to gray of the double basal line of the representation of the ablation catheter. Then, ablation catheter was positioned within right upper pulmonary vein (PV) by posterior rotation under the guidance of TEE-imaging and CARTO.

Procedural steps of TEE-guided transseptal puncture are illustrated in *Figure 1, Supplemental Video 1, Supplemental Video 2.*

Electroanatomical mapping and Isolation of pulmonary veins

CARTO3 fast anatomical map (FAM) was created using the ablation catheter, utilizing at the same time TEE-guidance when necessary. Image integration of the 3D FAM and the preprocedural MDCT-derived maps with LAWT information was performed using CartoMerge software.

At this point, TEE probe was withdrawn and esophageal temperature probe was positioned under minimal fluoroscopic guidance.

Regarding first-ablation procedures, PVI was performed point-by-point, with a maximal interlesion distance of 6 mm and with ablation index adapted to the LAWT according to standard pre-defined local protocol (*Supplemental Table 1*). PVI phase within redo-ablation procedures using a single catheter was previously described elsewhere[7].

Procedural steps of electroanatomical mapping and PVI are summarized in *Figure 2*, *Supplemental Video 3*.

Procedural Outcomes and Radiological Exposure

Efficacy outcome was defined as PVI with bidirectional block at the end of the procedure. Safety outcome was defined as absence of reported procedural-related adverse events. We defined as procedure-related adverse events the following: procedure-related death, ischemic or hemorrhagic stroke, procedure-related major bleeding, esophageal injury, cardiac tamponade, cardiac effusion, or vascular complication.

For each procedure, the following parameters about radiological exposure were recorded: total fluoroscopy time (FT), total emitted fluoroscopy dose (FD) and dose area product (DAP), which corresponds to the product of the intensity of the radiation beam (air kerma) and the area of the beam. Effective dose (ED) was also calculated utilizing the accepted formula: mSv = DAP (Gy*cm2) x 0.20[10].

Consistent with previous studies[10], ZFA success was defined when within a ZFA procedure no Xray were utilized to perform the whole procedure, with the only exception of a minimal fluoroscopic guidance to permit the correct positioning of esophageal temperature probe.

Statistical analysis

Continuous variables were presented as mean ± standard deviation or median (interquartile range) as appropriate, while categorical variables as frequency distribution and percentage. Mann-Whitney

test and Fisher's exact test were used to compare continuous and categorical variables, respectively. To balance patients' baseline clinical characteristics, a 1:1 matched analysis was performed between ZFA group and historical controls (HCs). Within ZFA group, logistic regression models were performed to identify factors associated with ZFA failure.

A level of $p<0.05$ was chosen for statistical significance. Data were analyzed with R version 3.6.2 software (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Patient population and characteristics

Figure 3 illustrates the flow diagram of the study design. Between May 2020 and April 2021, a total of 351 consecutive AF ablation procedures were performed. 24 patients were CIED-carriers and excluded from the analysis. Between January 2021 and April 2021, a total of 111 patients were prospectively enrolled in the study and underwent RFA for AF with ZFA. The historical cohort was composed of 216 patients, who underwent AF-ablation between May 2020 and December 2020. Before matching, hypertension was significantly more frequent in HCs *(Supplementary Table 2).* After propensity-score matching, the final cohort included two groups (ZFA vs. HCs) of 111 patients each with no differences in baseline characteristics (*Table 1*).

The age of the patients was 62.5 years (56.0-71.0), 141(63.5%) were male. 156 (70.3%) patients had paroxysmal AF, 66 (29.7%) persistent, 174 (78.4%) underwent first-ablation, and 48 (21.6%) redo-procedure.

Procedural and Ionizing Radiation data

Peri-procedural and ionizing radiation data are reported in *Table 2*.

Total procedural time was lower in ZFA group compared to HCs (47.0 minutes [41.0-54.0] vs. 55.0 minutes [48.8-67.0], $p<0.001$). The time required to perform transseptal puncture was higher in

ZFA group (183 seconds [124-241] vs. 123 seconds [63-182], p<0.001). No differences between groups was observed in RF time and number of ablation points.

All the recorded parameters about radiological exposure were significantly reduced in ZFA group compared to HCs. In detail, ZFA obtained significantly lower total FT (3 seconds [1-12] vs. 63 seconds [43-81], p<0.001), total emitted FD (0.2 mGy [0.05-0.6] vs. 6.0 mGy [3.5-8.2], p<0.001), DAP (0.04 Gy*cm^2 [0.01-0.1] vs. 1.4 Gy*cm^2 [0.8-1.9], p<0.001), and ED (0.8 mSv*100 [0.2-3.0] vs. 27.2 mSv*100 [16.4-37.7], p<0.001). Procedural time, transseptal time, FT, and DAP comparison between ZFA group and HCs are shown in *Figure 4*.

Complete PVI was achieved in all procedures. No statistically significant differences regarding complications were found between ZFA group and HCs (0.9% vs. 1.8% respectively, p=0.99). In ZFA group, complication occurred in one patient, reporting inguinal hematoma however not requiring vascular surgery.

A significant reduction of radiological exposure for ZFA group with respect of HCs was confirmed in all the analyzed subgroups of the cohort: first-ablation procedure, redo procedure, paroxysmal AF, and persistent AF subgroups (*Supplemental Table 3, Supplemental Figure 1*).

Zero-Fluoroscopy Approach group

In the ZFA group, ZFA success was reached in 80 (72%) procedures. Fluoroscopy use was necessary during 31 (28%) procedures, because of the difficulty in long-guidewire advancing until the correct positioning in superior vena cava in 6 cases (5%), and to guide challenging TSP due to aneurismal/hypertrophic atrial septum or small fossa ovalis in 25 cases (23%). No differences in the monthly rate of ZFA success was found during the study period (p=0.87) (Supplemental Figure 2). ZFA success procedures compared to those with ZFA failure resulted in a significantly reduced radiological exposure (*Table 3).* BMI>35 kg/m^2 resulted the only independent predictor of ZFA failure, at the multivariate logistic regression analysis, (OR=6.10, 95%CI 1.15-46.49, p=0.04).

Univariate and multivariate logistic regression analysis for predictors of ZFA failure are shown in *Table 4.*

DISCUSSION

Main Findings

To our knowledge, this is the largest study reporting feasibility, procedural safety, and effectiveness of a standardized TEE-guided fluoroless approach for RFA of AF without the use of ICE. The main findings of this study are: (i) TEE-guided ZFA is a feasible approach leading to a significant reduction in radiological exposure; (ii) ZFA is safe with a low complication rate, not different from HCs group; (iii) procedural effectiveness is comparable to a fluoroscopy-guided procedure (historical cohort); (iv) ZFA has a high success rate already in the first few months and BMI> 35 kg/m^2 is the only independent predictor of ZFA failure; (v) a significant reduction of radiological exposure with the use of ZFA was observed in all analyzed subgroups: first-ablation procedure, redo procedure, paroxysmal AF, persistent AF.

Near-abolition of radiological exposure

The cornerstone of this study was minimizing radiation exposure, as recommended by the American College of Cardiology with “the ALARA statement”: keep the radiation “as low as reasonably achievable”[11]. Lickfett et al.[2] estimated that a 60 minutes exposure to X-ray within AF-ablation procedure resulted in a lifetime risk of fatal malignancies in 0.07% of women and 0.1% of men. NO-PARTY trial[12] was the first multicenter randomized trial comparing the effect of minimal-fluoroscopy versus conventional ablation of supraventricular tachycardia: it showed that the first dramatically reduced patients' exposure, the estimated risk of cancer incidence and mortality, and the estimated years of life affected and lost. Concerning the results of previous studies about minimal-fluoroscopy approach in left sided ablations, Pani et al.[10] showed a mean FT of 169.1 ± 72.1 seconds required to perform TSP. Cha et al.[4] reported a series of 30 ICE-

guided AF-ablation with a FT of 3.7 ± 9.6 minutes. Sommer et al.[13] recently described within a large cohort of 1000 ICE-guided procedures a FT of 0.9 ± 2.7 minutes and a DAP of 3.45 ± 9.08 Gy*cm^2.

In the present study we reported an experience of the first four months of transition from a pre-existing minimal-fluoroscopy approach for AF-ablation to a flourless one with the same EP laboratory setup, illustrating that near-zeroing of radiological exposure can be achieved safely by experienced operators. Within HCs, FT and DAP (63.0 seconds [43.2-81.0] and 1.4 Gy*cm^2 [0.8-1.9], respectively) were at least similar to those communicated in studies concerning minimal-fluoroscopy AF-ablation. The TEE-guided ZFA lead to a near-abolition of radiological exposure since the first few procedures, reporting median values of FT 3 seconds and DAP 0.04 Gy*cm^2. These low values were also due to the high ZFA success rate within the ZFA group (72%); Haegeli et al.[14] described a case series with 53% of complete fluoroless procedures, in which fluoroscopy was always used for challenging TSP. This difference can be also attributable to the use of the single catheter technique, which allows to halve the number of TSPs and therefore the incidence of difficulties in this phase. Moreover, ZFA success could be facilitated by using a HRLV ventilation protocol that minimizes the thorax movement and increase the catheter stability[8].

Within ZFA cohort, the only independent predictor of ZFA failure resulted in BMI>35 kg/m^2. This finding is in line with a previous observational study[15] concerning severely obese patients managed with AF-ablation, which showed a significant increase of procedural complications, primary driven by complicated vascular accesses and pericardial effusions. Consequently, procedural difficulties result in increased use of fluoroscopy to aid the procedure.

Finally, the sub-analysis of the present study confirmed that the near-abolition of radiological exposure is achievable and comparable within first-ablation procedure, redo procedure, paroxysmal AF, and persistent AF subgroups.

Transesophageal Echocardiography guidance

The use of TEE guidance during TSP phase has become essential in numerous EP labs for successful LA access, by allowing a precise choice of the puncture site, and increasing safety by minimizing the risk of complications[16]. Concerning AF-ablation, many studies described a systematic use of the fluoro-echo-guided TSP[4, 14], in which, however, this phase remained largely fluoro-dependent. At present, TEE-only guidance to achieve fluoroless TSP has been used only in paediatric population[17], while large studies in adult populations were only performed with ICE-guided TSP. The present is the first large series reporting a TEE-guided ZFA for AF-ablation in an adult cohort.

In the series of 1000 ICE-guided procedures, Sommer et al.[13] reported an overall complication rate of 2.0%. The complication rate of 0.9% described in our cohort is at least comparable with the results of ICE-guided fluoro-sparing procedures. To correctly interpret these results, it is worthy to bear in mind that a TEE-guided approach doesn't imply the need for a further vascular access, consequently minimizing the probability of vascular complications.

Developing a ZFA

A further strength of the described approach was that no additional equipment was required: to start with, it just needed facilities readily available in most EP labs performing AF-ablation.

ZFA doesn't require the use of ICE for the execution of minimal-fluoroscopic procedures; this allows to overcome several drawbacks such as the non-ubiquitous availability, the need for trained cardiologists and for a further venous access, and the increased costs per procedure.

Therefore, ZFA is the only described approach that allows to perform fluoroless AF-ablation with single catheter technique[9].

The simple changes made for the transition to ZFA allowed to reach a high success rate already in the first month of using the approach, without significant differences during the study period. Moreover, the absence of excessive changes in the workflow allowed to maintain high procedural efficiency and continue improving efficiency. In fact, ZFA group resulted in an increase in the time

required for TSP (183.0 vs. 123.0 seconds); however, a progressive reduction of the procedural time in respect to HCs (47.0 vs. 55.0 minutes) was appreciated, due to the continuation of the efficiency improvement. A trend towards a continuous reduction in procedure time was observed during the entire study period (*Supplemental Figure 3*).

Clinical Implications

This proof-of-concept study is a further step towards a paradigm shift that has already begun. At present, traditional EP labs are primarily designed around the use of an X-ray system. However, similarly to what already happened in many supraventricular arrhythmias not requiring access to LA[12], all trained operators should strive for a fluoroless AF-ablation approach given its safety and effectiveness. Fluoroscopy use should be limited to situations in which it becomes necessary for the patient's safety. From a pharma-economical perspective, it is proven that eventual additional costs of fluoro-sparing approaches are at least offset by the cost-savings of therapies for Xray-related diseases[12].

Study limitations.

The first limitation is that this is a single-centre, non-randomized study; we tried to overcome this limitation by matching baseline patients' characteristics between ZFA group and HCs, and finally no consistent differences were observed.

Second limitation is that even though the need for a MDCT might imply additional radiation exposure, the overall radiation dose administered is still reasonable, it is lower to what has been reported on recent prospective trials on conventional AF-ablation[18]. Although it not essential for performing the described ZFA protocol, whenever possible we prefer to obtain preprocedural CT-derived information because it allows to identify eventual alterations of interatrial septum, atrial

masses, atrial pouches, accessory pulmonary veins or appendage thrombi; finally, it allows to tailor ablation based on the local LAWT.

Third, all procedures were performed under general anesthesia, mechanical ventilation with HFLTV and with CARTO3 mapping system, thus the present results of our study should not be directly applied to other procedural settings.

Finally, no data about mid- and long-term outcomes were available for analysis. Short-term outcomes were compared with results obtained in a historic control. The goodness of the outcomes of ZFA should be confirmed and validated in a larger, long-term prospective randomized trial.

CONCLUSION

This proof-of-concept study proves the procedural feasibility of a TEE-guided RFA for AF with a complete or near-complete avoidance of radiological exposure. ZFA, using equipment readily available in most EP labs, allows maintaining procedural safety, efficacy and efficiency.

Acknoledgements: none.

REFERENCES

1. Calkins, H., G. Hindricks, R. Cappato, Y. H. Kim, E. B. Saad, L. Aguinaga, J. G. Akar, V. Badhwar, J. Brugada, J. Camm, P. S. Chen, S. A. Chen, M. K. Chung, J. C. Nielsen, A. B. Curtis, D. W. Davies, J. D. Day, A. d'Avila, Nmsn de Groot, L. Di Biase, M. Duytschaever, J. R. Edgerton, K. A. Ellenbogen, P. T. Ellinor, S. Ernst, G. Fenelon, E. P. Gerstenfeld, D. E. Haines, M. Haissaguerre, R. H. Helm, E. Hylek, W. M. Jackman, J. Jalife, J. M. Kalman, J. Kautzner, H. Kottkamp, K. H. Kuck, K. Kumagai, R. Lee, T. Lewalter, B. D. Lindsay, L. Macle, M. Mansour, F. E. Marchlinski, G. F. Michaud, H. Nakagawa, A. Natale, S. Nattel, K. Okumura, D. Packer, E. Pokushalov, M. R. Reynolds, P. Sanders, M. Scanavacca, R. Schilling, C. Tondo, H. M. Tsao, A. Verma, D. J. Wilber, and T. Yamane. "2017 Hrs/Ehra/Ecas/Aphrs/Solaece Expert Consensus Statement on Catheter and Surgical Ablation of Atrial Fibrillation: Executive Summary." Heart Rhythm 14, no. 10 (2017): e445-e94.

2. Lickfett, L., M. Mahesh, C. Vasamreddy, D. Bradley, V. Jayam, Z. Eldadah, T. Dickfeld, D. Kearney, D. Dalal, B. Luderitz, R. Berger, and H. Calkins. "Radiation Exposure During Catheter Ablation of Atrial Fibrillation." Circulation 110, no. 19 (2004): 3003-10.

3. Di Cori, A., G. Zucchelli, L. Segreti, V. Barletta, S. Viani, L. Paperini, V. Della Tommasina, T. Cellamaro, A. Vecchi, E. Soldati, and M. G. Bongiorni. "Predictors of Zero X Ray Procedures in Supraventricular Arrhythmias Ablation." Int J Cardiovasc Imaging 36, no. 9 (2020): 1599-607.

4. Cha, M. J., E. Lee, and S. Oh. "Zero-Fluoroscopy Catheter Ablation for Atrial Fibrillation: A Transitional Period Experience." J Arrhythm 36, no. 6 (2020): 1061-67.

5. Scaglione, M., E. Ebrille, D. Caponi, A. Battaglia, P. Di Donna, M. Anselmino, M. Peyracchia, P. Mazzucchi, N. Cerrato, F. Ferraris, D. Castagno, F. Lamberti, and F. Gaita. "Zero-Fluoroscopy Atrial Fibrillation Ablation in the Presence of a Patent Foramen Ovale: A Multicentre Experience." J Cardiovasc Med (Hagerstown) 21, no. 4 (2020): 292-98.

6. Hindricks, G., T. Potpara, N. Dagres, E. Arbelo, J. J. Bax, C. Blomstrom-Lundqvist, G. Boriani, M. Castella, G. A. Dan, P. E. Dilaveris, L. Fauchier, G. Filippatos, J. M. Kalman, M. La

Meir, D. A. Lane, J. P. Lebeau, M. Lettino, G. Y. H. Lip, F. J. Pinto, G. N. Thomas, M. Valgimigli, I. C. Van Gelder, B. P. Van Putte, C. L. Watkins, and E. S. C. Scientific Document Group. "2020 Esc Guidelines for the Diagnosis and Management of Atrial Fibrillation Developed in Collaboration with the European Association for Cardio-Thoracic Surgery (Eacts)." Eur Heart J 42, no. 5 (2021): 373-498.

7. Teres, C., D. Soto-Iglesias, D. Penela, B. Jauregui, A. Ordonez, A. Chauca, M. Huguet, C. Ramirez, G. Oller, A. Jornet, J. Palet, D. Santana, A. Panaro, G. Maldonado, G. de Leon, B. Gualis, G. Jimenez-Britez, A. Evangelista, J. Carballo, J. T. Ortiz-Perez, and A. Berruezo. "Left Atrial Wall Thickness of the Pulmonary Vein Reconnection Sites During Atrial Fibrillation Redo Procedures." Pacing Clin Electrophysiol (2021).

8. Gabriels, J., J. Donnelly, M. Khan, D. Anca, S. Beldner, J. Willner, L. M. Epstein, and A. Patel. "High-Frequency, Low Tidal Volume Ventilation to Improve Catheter Stability During Atrial Fibrillation Ablation." JACC Clin Electrophysiol 5, no. 10 (2019): 1224-26.

9. Pambrun, T., S. Combes, P. Sousa, M. L. Bloa, R. El Bouazzaoui, D. Grand-Larrieu, N. Thompson, R. Martin, N. Combes, S. Boveda, M. Haissaguerre, and J. P. Albenque. "Contact-Force Guided Single-Catheter Approach for Pulmonary Vein Isolation: Feasibility, Outcomes, and Cost-Effectiveness." Heart Rhythm 14, no. 3 (2017): 331-38.

10. Pani, A., B. Giuseppina, C. Bonanno, M. Grazia Bongiorni, N. Bottoni, R. Brambilla, S. Ceglia, P. Della Bella, G. Vito, D. Malaspina, E. Menardi, V. Napoli, M. S. Negroni, S. Ocello, D. Orsida, C. Pandozi, S. Pedretti, D. Penela, P. Pepi, L. Rossi, G. Rovaris, A. Scopinaro, A. Vincenti, G. Viola, V. Zaca, F. Zoppo, and P. Vergara. "Predictors of Zero X-Ray Ablation for Supraventricular Tachycardias in a Nationwide Multicenter Experience." Circ Arrhythm Electrophysiol 11, no. 3 (2018): e005592.

11. Limacher, M. C., P. S. Douglas, G. Germano, W. K. Laskey, B. D. Lindsay, M. H. McKetty, M. E. Moore, J. K. Park, F. M. Prigent, and M. N. Walsh. "Acc Expert Consensus Document.

Radiation Safety in the Practice of Cardiology. American College of Cardiology." J Am Coll Cardiol 31, no. 4 (1998): 892-913.

12. Casella, M., A. Dello Russo, G. Pelargonio, M. Del Greco, G. Zingarini, M. Piacenti, A. Di Cori, V. Casula, M. Marini, F. Pizzamiglio, M. Zucchetti, S. Riva, E. Russo, M. L. Narducci, E. Soldati, L. Panchetti, U. Startari, G. Bencardino, F. Perna, P. Santangeli, L. Di Biase, F. Cichocki, G. Fattore, M. Bongiorni, E. Picano, A. Natale, and C. Tondo. "Near Zero Fluoroscopic Exposure During Catheter Ablation of Supraventricular Arrhythmias: The No-Party Multicentre Randomized Trial." Europace 18, no. 10 (2016): 1565-72.

13. Sommer, P., L. Bertagnolli, S. Kircher, A. Arya, A. Bollmann, S. Richter, S. Rolf, and G. Hindricks. "Safety Profile of near-Zero Fluoroscopy Atrial Fibrillation Ablation with Non-Fluoroscopic Catheter Visualization: Experience from 1000 Consecutive Procedures." Europace 20, no. 12 (2018): 1952-58.

14. Haegeli, L. M., L. Stutz, M. Mohsen, T. Wolber, C. Brunckhorst, C. J. On, and F. Duru. "Feasibility of Zero or near Zero Fluoroscopy During Catheter Ablation Procedures." Cardiol J 26, no. 3 (2019): 226-32.

15. Shoemaker, M. B., R. Muhammad, M. Farrell, B. Parvez, B. W. White, M. Streur, T. Stubblefield, J. Rytlewski, S. Parvathaneni, R. Nagarakanti, D. M. Roden, P. Saavedra, C. Ellis, S. P. Whalen, and D. Darbar. "Relation of Morbid Obesity and Female Gender to Risk of Procedural Complications in Patients Undergoing Atrial Fibrillation Ablation." Am J Cardiol 111, no. 3 (2013): 368-73.

16. Russo, G., M. Taramasso, and F. Maisano. "Transseptal Puncture: Procedural Guidance, Challenging Situations and Complications Management." EuroIntervention (2021).

17. Clark, J., J. R. Bockoven, J. Lane, C. R. Patel, and G. Smith. "Use of Three-Dimensional Catheter Guidance and Trans-Esophageal Echocardiography to Eliminate Fluoroscopy in Catheter Ablation of Left-Sided Accessory Pathways." Pacing Clin Electrophysiol 31, no. 3 (2008): 283-9.

18. Sciahbasi, A., G. Ferrante, D. Fischetti, D. J. Miklin, A. Sarandrea, V. Schirripa, F. Guarracini, A. Arya, G. Loreni, A. Bruni, S. Rigattieri, M. Marini, S. Vagnarelli, G. Scevola, B. Reimers, G. Hindricks, and M. Cohen. "Radiation Dose among Different Cardiac and Vascular Invasive Procedures: The Rodeo Study." Int J Cardiol 240 (2017): 92-96.

FIGURE AND TABLE LEGEND

Figure 1. ZFA stepwise TEE-guided transseptal puncture. (A) TEE bicaval view showing guiding sheath localized in the superior vena cava. (B) Simultaneous visualization of TEE bicaval and SAX view during the pull-back phase of TSP through utilizing XPlane modality. (C) TEE imaging showing the double track image of the sheath positioned in LA. (D) TEE imaging showing the hyperechoic image of the ablation catheter filling the double track image. (E) TEE imaging visualizing the ablation catheter advanced in LA. AoV: aortic valve; FO: fossa ovalis; IVC: inferior vena cava; LA: left atrium; RA: right atrium; RV: right ventricle; SAX: short axis; SVC: superior vena cava; TV: Tricuspid Valve; TEE: Transesophageal Echocardiography.

Figure 2. ZFA electroanatomical mapping and PVI. (A) TEE imaging and CARTO 3 navigation system with MDCT-derived LAWT map showing ablation catheter within RUPV. (B) FAM reconstruction and electrograms-guided mitral annulus tagging. (C) TEE XPlane simultaneous visualization of 2ch and 3ch view during FAM reconstruction of the mitral annulus. (D) Complete FAM. (E) Visitag system use during PVI. (F) Complete PVI. 4ch: 4 chambers; 2ch: 2 chambers; FAM: Fast Anatomical Map; LA: Left Atrium; LAWT: Left Atrial Wall Thickness; LV: Left Ventricle; MV: Mitral Valve; PVI: Pulmonary Veins Isolation; RUPV: right upper pulmonary vein; TEE: Transesophageal Echocardiography.

Figure 3. Flow Diagram of the Study Design. AF: Atrial Fibrillation; CIED: Cardiac Implantable Electronic Device; RFA: Radiofrequency Ablation; ZFA: Zero-Fluoroscopy Approach.

Figure 4. Procedural time, Transseptal time, Fluoroscopic time, and DAP comparison between ZFA group and HCs. DAP: Dose Area Product; ZFA: Zero-Fluoroscopy Approach.

Table 1. Patients' Baseline Characteristics after Propensity Score-Matching.

Table 2. Peri-procedural data and Ionizing Radiation data.

Table 3. Patients'Baseline Characteristics, Procedural data and Ionizing Radiation data of ZFA group according to ZFA success.

Table 4. Predictors of ZFA failure at univariate and multivariate logistic regression analysis.

Figure 1

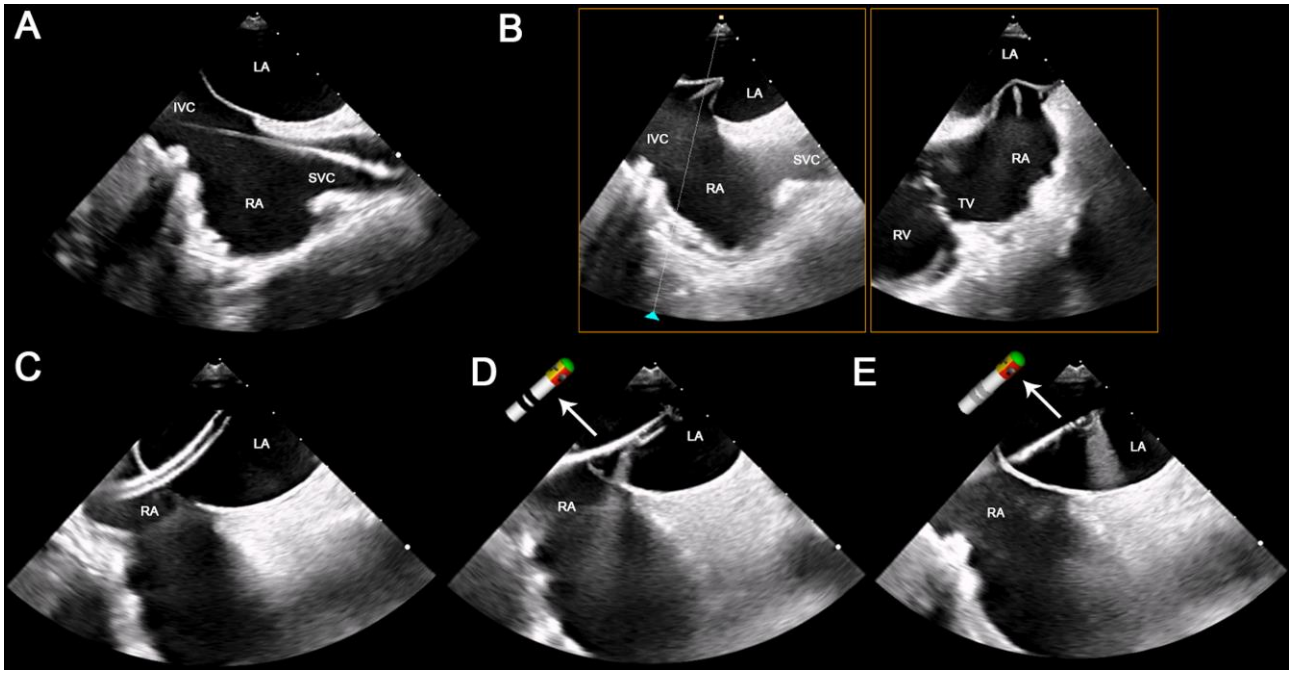


Figure 2

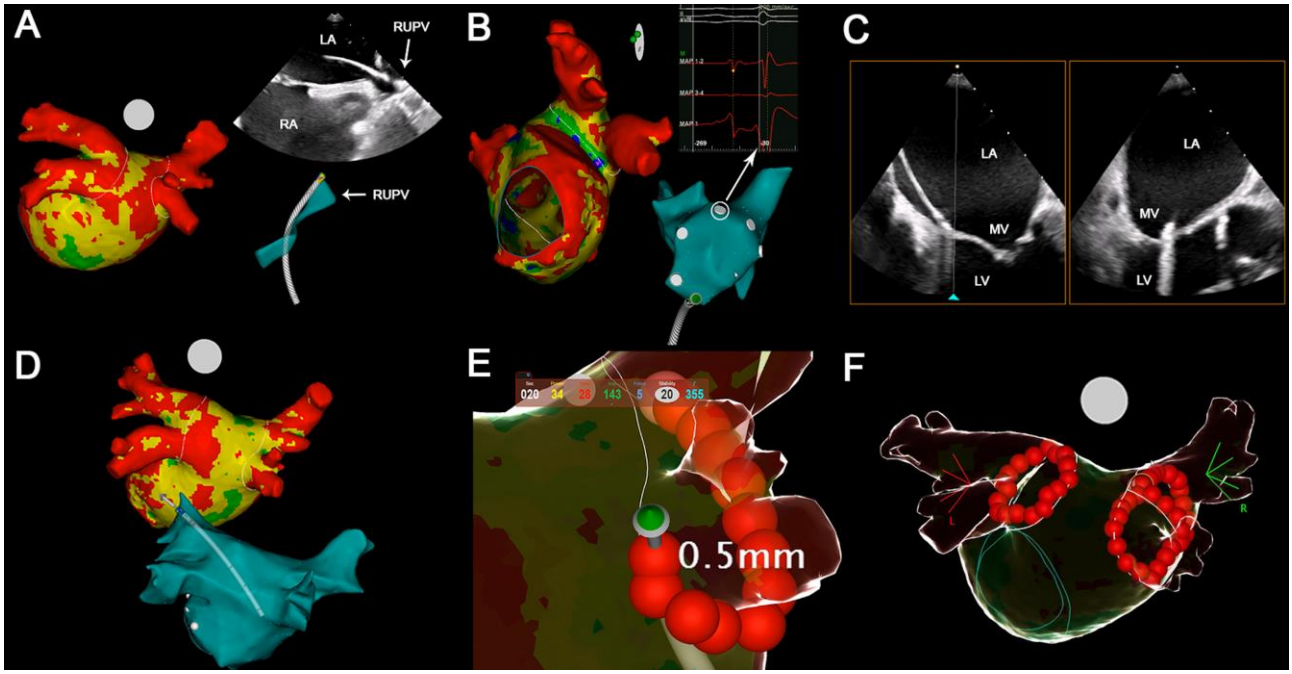


Figure 3

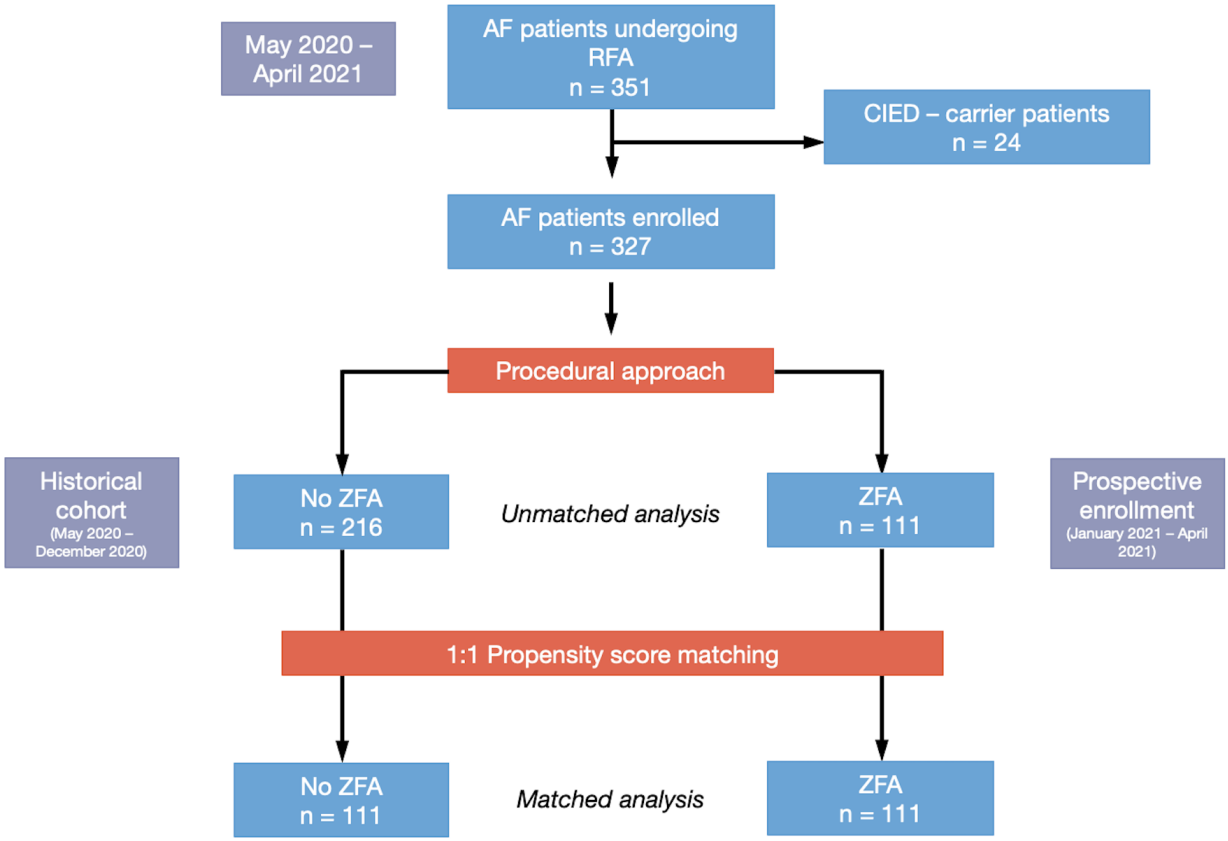

May 2020 – April 2021
AF patients undergoing RFA n = 351
CIED – carrier patients n = 24
AF patients enrolled n = 327
Procedural approach
Historical cohort (May 2020 – December 2020)
No ZFA n = 216
Unmatched analysis
ZFA n = 111
Prospective enrollment (January 2021 – April 2021)
1:1 Propensity score matching
No ZFA n = 111
Matched analysis
ZFA n = 111

Figure 4

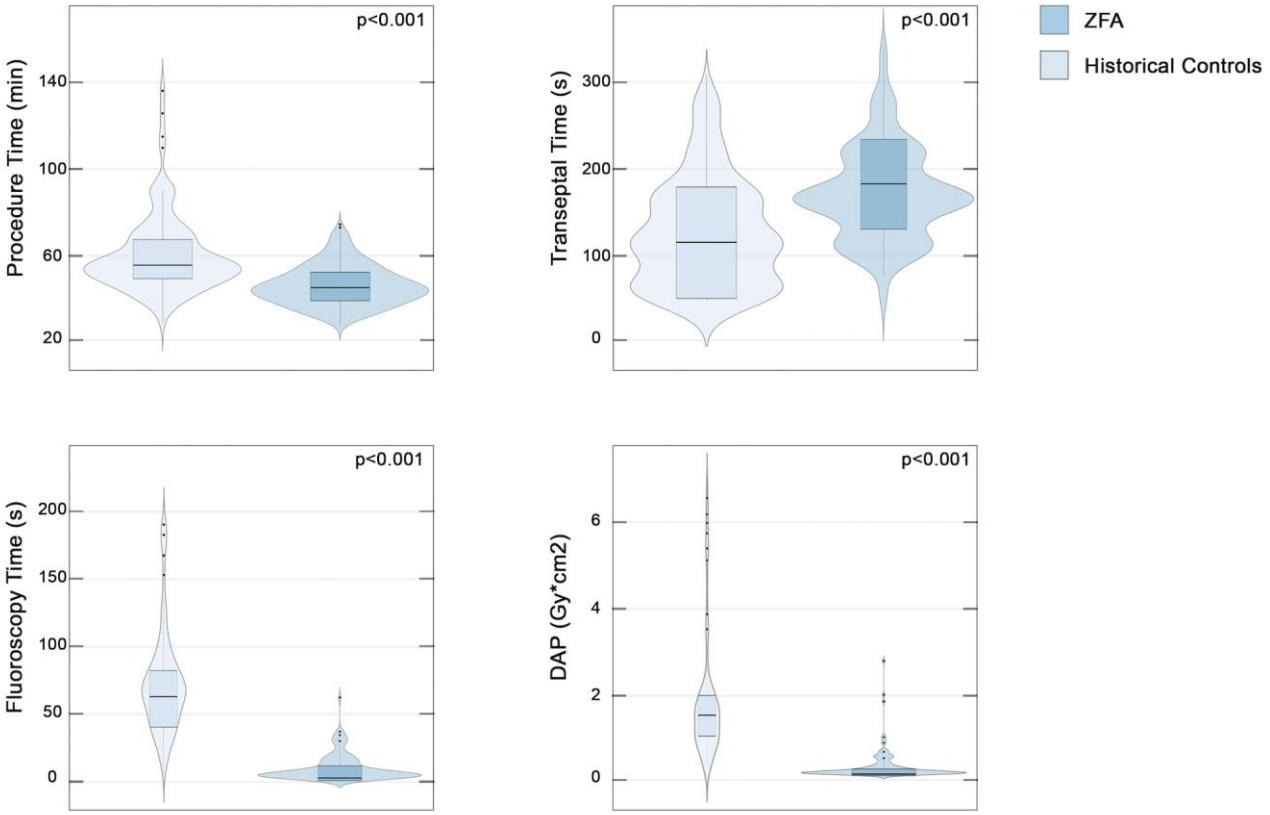

p<0.001
Procedure Time (min)
140
100
60
20
p<0.001
Transeptal Time (s)
300
200
100
0
ZFA
Historical Controls
p<0.001
Fluoroscopy Time (s)
200
150
100
50
0
p<0.001
DAP (Gy*cm2)
6
4
2
0

Table 1. Patients' Baseline Characteristics after Propensity Score-Matching.

	Historical controls (N=111)	ZFA group (N=111)	Total patients (N=222)	p value
Age (years)	64.0 (56.0-71.5)	62.0 (56.0-71.0)	62.5 (56.0-71.0)	0.84
Male	71 (64.0)	70 (63.1)	141 (63.5)	0.99
Height (cm)	170.0 (163.0-178.0)	172.0 (163.0-177.0)	170.0 (163.0-178.0)	0.81
Weight (kg)	78.0 (68.0-88.0)	76.0 (70.0-86.2)	77.0 (68.5-87.5)	0.59
BMI (kg/m^2)	26.5 (23.3-29.6)	25.9 (24.2-29.1)	26.2 (23.9-29.4)	0.58
Hypertension	44 (39.6)	35 (31.5)	79 (35.6)	0.26
Dyslipidemia	19 (17.1)	17 (15.3)	36 (16.2)	0.86
Smoke History	6 (5.4)	9 (8.1)	15 (6.8)	0.59
Type 2 diabetes	8 (7.2)	8 (7.2)	16 (7.2)	0.99
CAD History	7 (6.3)	5 (4.5)	12 (5.4)	0.77
Previous AF ablation	24 (21.6)	24 (21.6)	48 (21.6)	0.99
LVEF (%)	58.0 (56.0-61.0)	58.0 (57.0-61.0)	58.0 (56.2-61.0)	0.91
LA diameter (mm)	40.0 (35.0-43.0)	39.0 (34.0-43.0)	40.0 (35.0-43.0)	0.49
Paroxysmal AF	75 (67.6)	81 (73.0)	156 (70.3)	0.46
CHA_2DS_2-VASc score	1.8±1.5	1.8±1.6	1.8±1.5	0.99
HAS-BLED score	0.8±0.9	0.8±1.0	0.8±1.0	0.95
Four Independent Ostia	86 (77.5)	79 (71.2)	165 (74.3)	0.36
Common left ostium	23 (20.7)	31 (27.9)	54 (24.3)	0.27
Common right ostium	2 (1.8)	1 (0.9)	3 (1.4)	0.99

Results are reported as n (%) for categorical variables and median (interquartile range) or mean±standard deviation for continuous variables.

AF = Atrial Fibrillation; BMI = Body Mass Index; CAD = Coronary Artery Disease; LA = Left Atrium; LVEF = Left Ventricle Ejection Fraction; PVs = Pulmonary Veins; ZFA = Zero Fluoroscopy Approach.

Table 2. Peri-procedural data and Ionizing Radiation data

Table 2a. Peri-procedural data

	Historical controls (N=111)	ZFA group (N=111)	Total patients (N=222)	p value
First ablation procedure	87 (78.4)	87 (78.4)	174 (78.4)	0.99
Redo procedure	24 (21.6)	24 (21.6)	48 (21.6)	0.99
Ventilation rate (breaths/min)	47.0 (44.2-50.0)	47.0 (45.0-52.0)	47.0 (45.0-51.0)	0.13
Tidal volume (ml)	253.0 (251.0-285.5)	253.0 (251.0-258.0)	253.0 (251.0-281.0)	0.12
Procedural time (min)	55.0 (48.8-67.0)	47.0 (41.0-54.0)	50.0 (44.0-58.5)	**<0.001**
Transseptal time (s)	123.0 (63.0-182.0)	183.0 (124.0-241.0)	181.0 (122.0-184.0)	**<0.001**
FAM and merge time (min)	12.0 (11.0-15.0)	12.0 (11.0-13.8)	12.0 (11.0-14.0)	0.38
RF time (min)	14.3 (12.0-16.4)	13.2 (10.8-15.7)	13.9 (11.4-16.2)	0.17
Total Visitags	57.0 (44.0-63.2)	54.0 (48.0-64.0)	56.0 (46.0-64.0)	0.87
Complete PVs isolation	111 (100.0)	111 (100.0)	222 (100.0)	0.99
Acute procedural complication	2 (1.8)	1 (0.9)	3 (1.4)	0.99

Table 2b. Ionizing Radiation data

	Historical controls (N=111)	ZFA group (N=111)	Total patients (N=222)	p value
Fluoroscopy time (s)	63.0 (43.2-81.0)	3.0 (1.0-12.0)	26.0 (3.0-62.8)	**<0.001**
Fluoroscopy Dose (mGy)	6.0 (3.5-8.2)	0.2 (0.05-0.6)	1.6 (0.2-6.1)	**<0.001**
Dose Area Product (Gy*cm2)	1.4 (0.8-1.9)	0.04 (0.01-0.1)	0.4 (0.04-1.4)	**<0.001**
Effective dose (mSv*100)	27.2 (16.4-37.7)	0.8 (0.2-3.0)	9.0 (0.8-27.8)	**<0.001**

Results are reported as n (%) for categorical variables and median (interquartile range) or mean±standard deviation for continuous variables.

FAM = Fast Anatomical Mapping; RF = Radiofrequency ; PVs = Pulmonary Veins; ZFA = Zero Fluoroscopy Approach.

Table 3. Patients' Baseline Characteristics, Procedural data and Ionizing Radiation data of ZFA group according to ZFA success.

Table 3a.Peri-procedural data

	ZFA failure (N=31)	ZFA success (N=80)	Total ZFA patients (N=111)	p value
First ablation procedure	22 (71.0)	65 (81.2)	87 (78.4)	0.30
Procedural time (min)	47.0 (41.0-54.5)	47.0 (41.0-54.0)	47.0 (41.0-54.0)	0.92
Transseptal time (sec)	241.0 (183.5-244.0)	181.5 (123.0-184.0)	183.0 (124.0-241.0)	**<0.001**
FAM and merge time (min)	12.0 (10.0-13.0)	12.0 (11.0-14.0)	12.0 (11.0-13.8)	0.36
RF time (min)	12.3 (10.5-14.8)	13.4 (11.4-15.8)	13.2 (10.8-15.7)	0.27
Total Visitags	51.0 (45.5-56.2)	54.0 (50.0-66.0)	54.0 (48.0-64.0)	0.06
Complete PVs isolation	31 (100.0)	80 (100.0)	111 (100.0)	0.99
Acute procedural complication	0 (0.0)	1 (1.2)	1 (0.9)	0.99

Table 3b. Ionizing Radiation data

	ZFA failure (N=31)	ZFA success (N=80)	Total ZFA patients (N=111)	p value
Fluoroscopy time (s)	17.0 (13.5-28.5)	2.0 (1.0-4.0)	3.0 (1.0-12.0)	**<0.001**
Fluoroscopy dose (mGy)	1.3 (0.7-1.5)	0.1 (0.05-0.2)	0.2 (0.05-0.6)	**<0.001**
Dose Area Product (Gy*cm2)	0.35 (0.17-0.45)	0.02 (0.01-0.06)	0.04 (0.01-0.14)	**<0.001**
Effective dose (mSv*100)	7.0 (3.3-9.0)	0.4 (0.2-1.2)	0.8 (0.2-2.9)	**<0.001**

Results are reported as n (%) for categorical variables and median (interquartile range) or mean±standard deviation for continuous variables.
FAM = Fast Anatomical Mapping; PVs = Pulmonary Veins; ZFA = Zero Fluoroscopy Approach.

Table 4. Predictors of ZFA failure at univariate and multivariate logistic regression analysis.

	Univariate analysis		Multivariate analysis	
	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value
Age (years)	0.71 (0.23-1.95)	0.53		
Male	0.62 (0.26-1.45)	0.27		
BMI >35 kg/m²	5.52 (1.10-41.07)	0.05	6.10 (1.15-46.49)	**0.04**
Hypertension	1.05 (0.42-2.51)	0.92		
Dyslipidemia	2.74 (0.93-8.01)	0.06	2.12 (0.56-8.06)	0.26
Smoke History	2.22 (0.52-9.00)	0.26		
Type 2 diabetes	4.94 (1.13-25.4)	0.04	2.88 (0.54-16.68)	0.21
CAD History	4.18 (0.66-32.99)	0.13		
Previous AF ablation	1.77 (0.66-4.58)	0.24		
LVEF (%)	1.35 (0.18-7.41)	0.74		
LA diameter (mm)	0.71 (0.29-1.65)	0.43		
Paroxysmal AF	0.72 (0.26-1.84)	0.51		

AF = Atrial Fibrillation; BMI = Body Mass Index; CAD = Coronary Artery Disease; LA = Left Atrium; LVEF = Left Ventricle Ejection Fraction; PVs = Pulmonary Veins; ZFA = Zero Fluoroscopy Approach

SUPPLEMENTAL FIGURE AND TABLE LEGEND

Supplemental Figure 1. **Procedural time, Transseptal time, and Fluoroscopy time comparisons between ZFA group and HCs within subgroups of the study cohort.**

Supplemental Figure 2. Fluoroscopy time in the total series of ZFA procedures.

Supplemental Figure 3. **Representation of the trend of the monthly mean and median procedural time during the study period.**

Supplemental Table 1. Protocol for personalized ablation parameters adapted to left atrial wall thickness and for high frequency low-tidal volume ventilation.

Supplemental Table 2. Patients' Baseline Characteristics before Propensity Score-Matching.

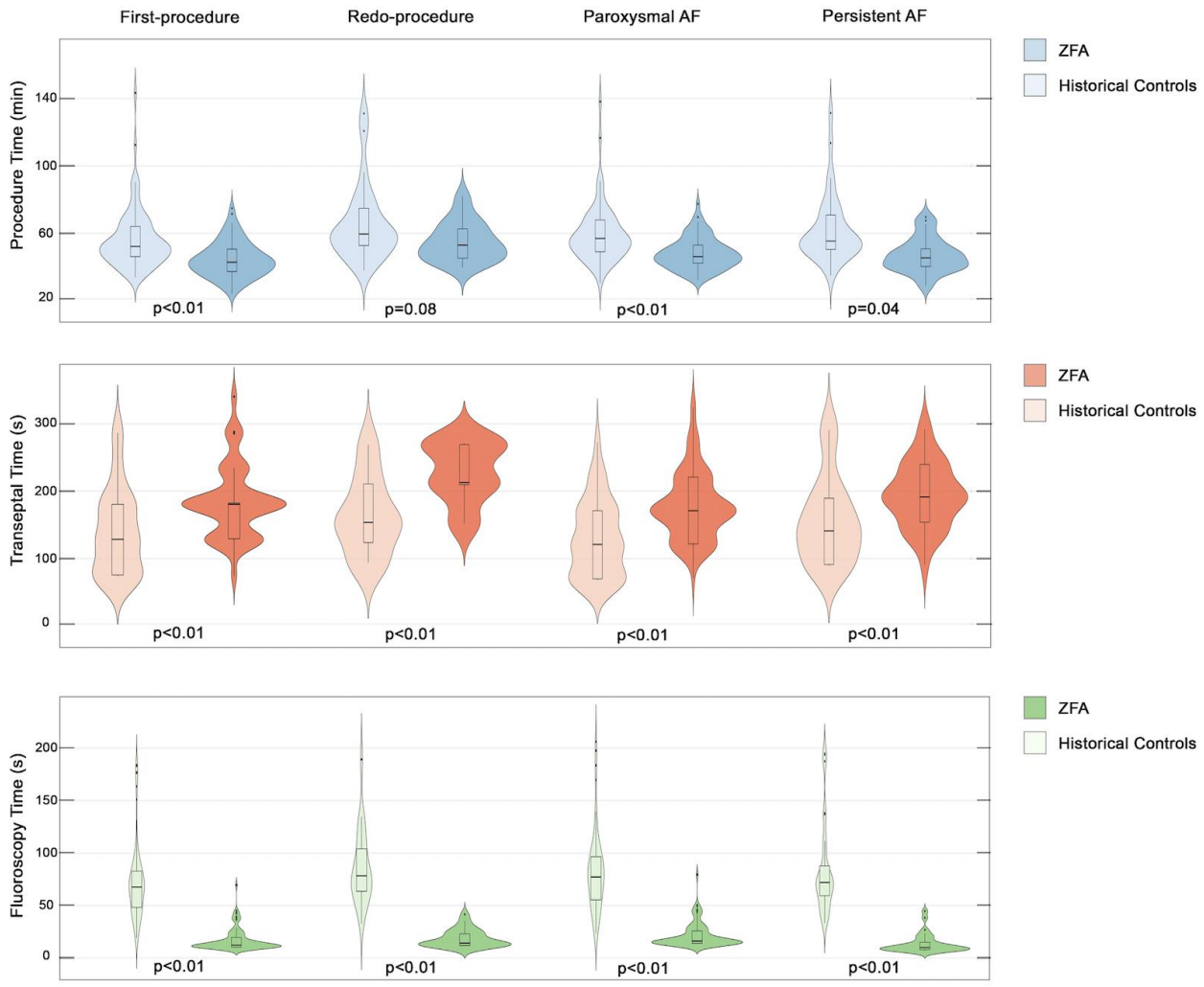
Supplemental Table 3. Subgroup analysis of peri-procedural and ionizing radiation data.

Supplemental Video 1. TEE-guidance of pull-back maneuver.

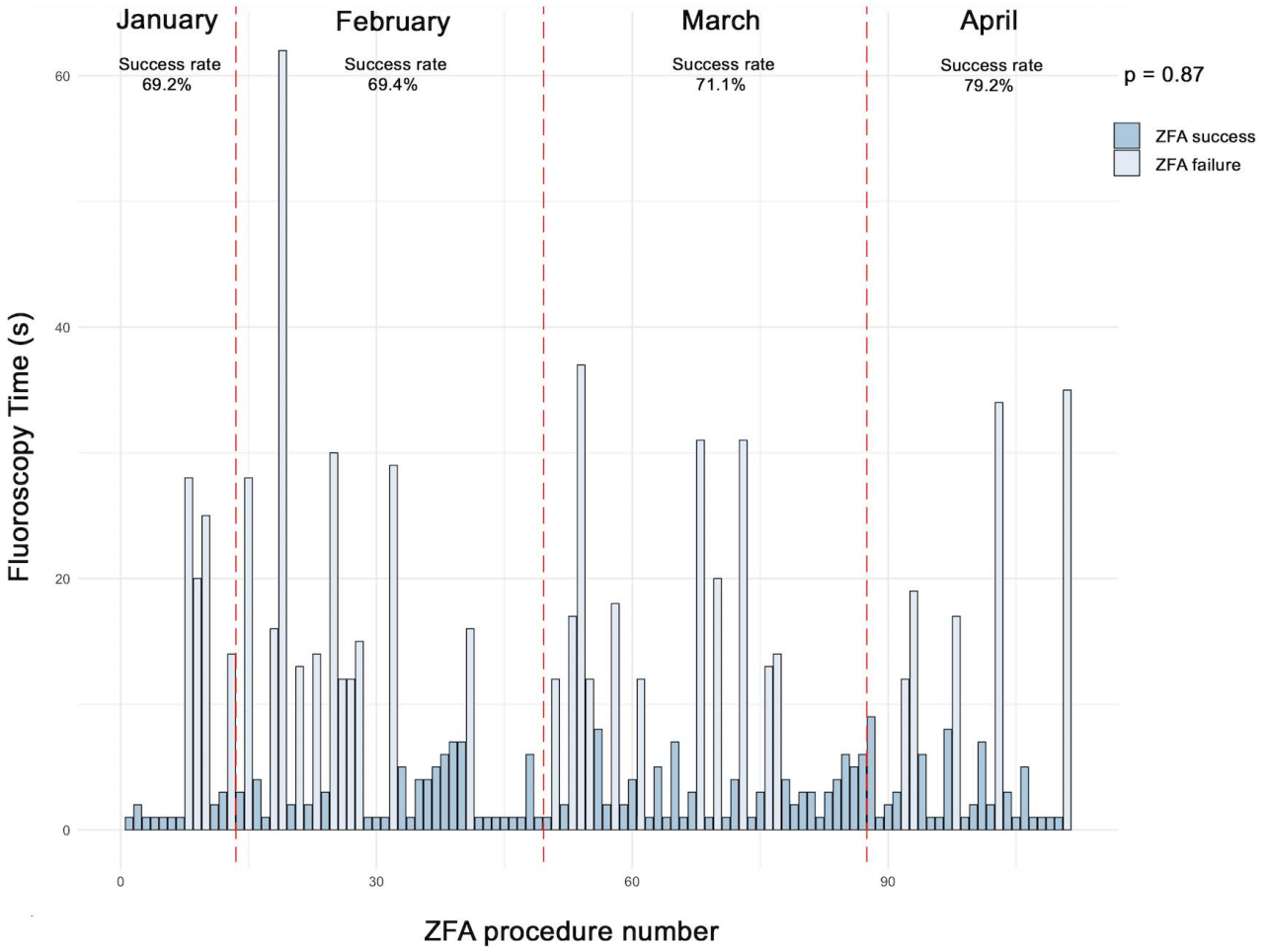
Supplemental Video 2. TEE- guidance of ablation catheter insertion in left atrium through the sheath.

Supplemental Video 3. Image integration of the 3D FAM and the preprocedural MDCT-derived maps with LAWT information using CartoMerge software.

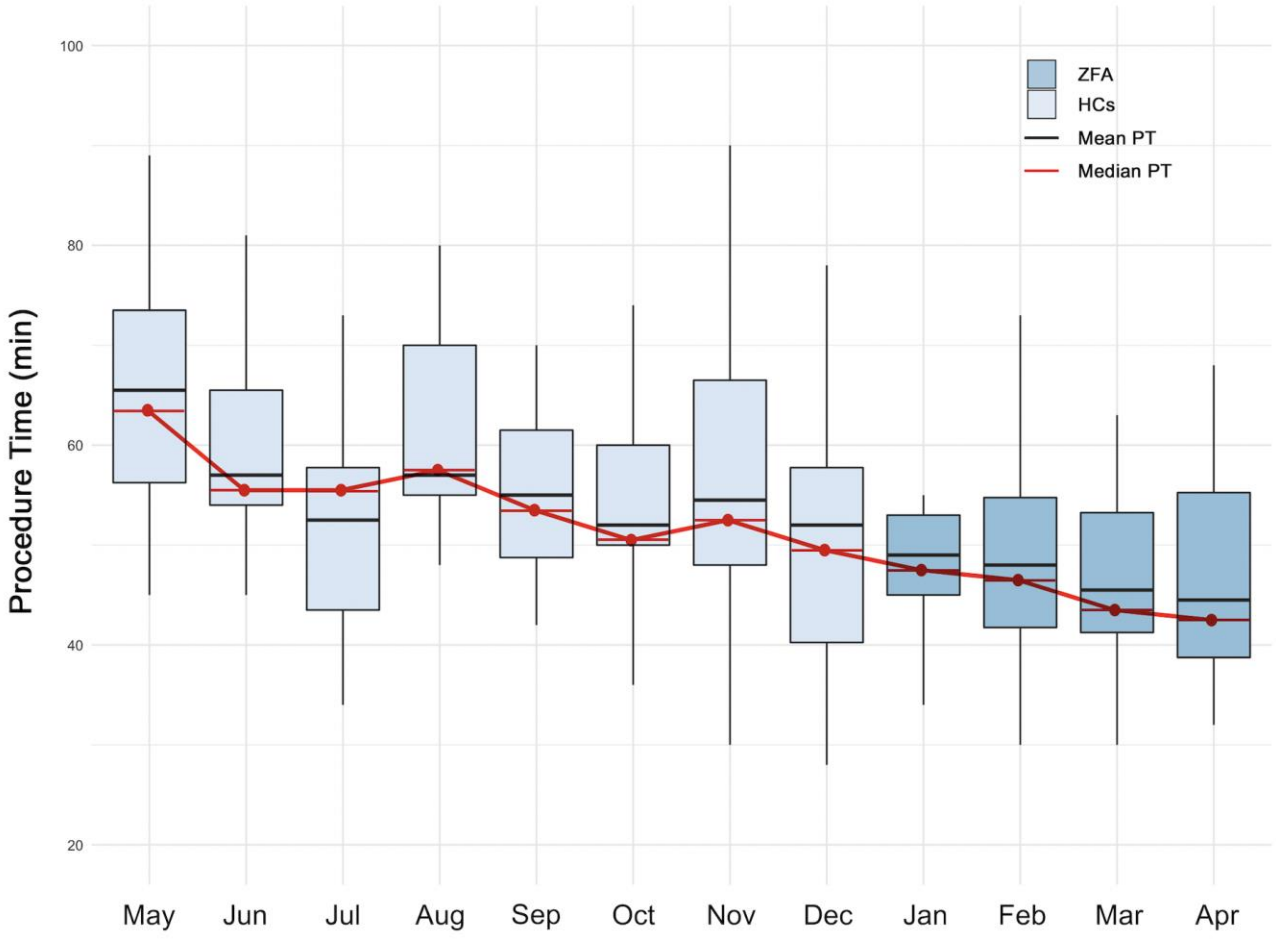
Supplemental Figure 1. Procedural time, Transeptal time, and Fluoroscopy time comparisons between ZFA group and HCs within subgroups of the study cohort. ZFA: Zero-Fluoroscopy Approach.



Supplemental Figure 2. Fluoroscopy time in the total series of ZFA procedures. ZFA: Zero Fluoroscopy Approach.



Supplemental Figure 3. Representation of the trend of the monthly mean and median procedural time during the study period. PT: Procedural Time; ZFA: Zero-Fluoroscopy Approach.



Supplemental Table 1. Protocol for ablation parameters adapted to left atrial wall thickness and for high frequency low-tidal volume ventilation.

Supplemental Table 1a. Protocol for ablation parameters adapted to left atrial wall thickness.

LAWT	Color code	Ablation Index		Ablation Time (seconds)		RF Energy (Watts)	
		Anterior	Posterior	Anterior	Posterior	Anterior	Posterior
< 1mm	Red	300	300	12	12	40	35
1-2 mm	Yellow	350	350	18	18	40	35
2-3 mm	Green	400	400	18	24	50	35
3-4 mm	Blue	450	450	24	30	50	35
> 4 mm	Purple	500	500	30	36	50	35

Supplemental Table 1b. Protocol for standard high frequency low-tidal volume ventilation.

FiO2 (%)	60%
Ventilation Rate (breath/min)	45-50
Inspiration / Expiration ratio	1 - 2
Tidal Volume (ml/kg)	3.5 - 4

FiO2: Fraction of inspired oxygen; LAWT: Left Atrial Wall Thickness, RF: Radiofrequency.

Supplemental Table 2. Patients' Baseline Characteristics before Propensity Score-Matching.

	Historical controls (N=216)	ZFA group (N=111)	Total patients (N=327)	p value
Age (years)	63.0 (54.2 - 70.8)	62.0 (56.0 - 71.0)	63.0 (55.0 - 71.0)	0.97
Male	137 (63.4)	70 (63.1)	207 (63.3)	0.99
Height (cm)	170.0 (163.2 - 178.0)	172.0 (163.0 - 177.0)	170.0 (163.0 - 178.0)	0.92
Weight (kg)	80.0 (69.5 - 89.0)	76.0 (70.0 - 86.2)	78.0 (70.0 - 88.5)	0.22
BMI (kg/m^2)	26.5 (24.2 - 30.1)	25.9 (24.2 - 29.1)	26.3 (24.2 - 29.8)	0.27
Hypertension	94 (43.5)	35 (31.5)	129 (39.4)	**0.04**
Dyslipidemia	38 (17.6)	17 (15.3)	55 (16.8)	0.64
Smoke History	8 (3.7)	9 (8.1)	17 (5.2)	0.11
Type 2 diabetes	16 (7.4)	8 (7.2)	24 (7.3)	0.99
CAD History	13 (6.0)	5 (4.5)	18 (5.5)	0.80
Previous AF ablation	47 (21.8)	24 (21.6)	71 (21.7)	0.99
LVEF (%)	58.0 (56.0 - 62.0)	58.0 (57.0 - 61.0)	58.0 (56.0 - 62.0)	0.12
LA diameter (mm)	40.0 (35.0, 45.0)	39.0 (34.0, 43.0)	40.0 (35.0 - 44.0)	0.26
Paroxysmal AF	138 (63.9)	81 (73.0)	219 (67.0)	0.11
CHA_2DS_2-VASc score	1.7 ± 1.5	1.8 ± 1.6	1.7 ± 1.5	0.91
HAS-BLED score	0.8 ± 1.0	0.8 ± 1.0	0.8 ± 1.0	0.86
Four Independent Ostia	165 (76.4)	79 (71.2)	244 (74.6)	0.35
Common left ostium	44 (20.4)	31 (27.9)	75 (22.9)	0.13
Common right ostium	7 (3.2)	1 (0.9)	8 (2.4)	0.27

Results are reported as n (%) for categorical variables and median (interquartile range) or mean ± standard deviation for continuous variables.
AF = Atrial Fibrillation; BMI = Body Mass Index; CAD = Coronary Artery Disease; LA = Left Atrium; LVEF = Left Ventricle Ejection Fraction; PVs = Pulmonary Veins; ZFA = Zero Fluoroscopy Approach

Supplemental Table 3. Subgroup analysis of peri-procedural data and ionizing radiation data.

Supplemental Table 3a. Peri-procedural data and ionizing radiation data in first-ablation procedures subgroup.

	Historical controls (N=87)	ZFA group (N=87)	First-ablation procedures (N=174)	p value
Ventilation rate (breaths/min)	47.0 (46.0 - 52.0)	47.0 (45.0 - 52.0)	47.0 (46.0 - 52.0)	0.18
Tidal volume (ml)	252.0 (251.0 - 282.8)	253.0 (251.0 - 266.5)	252.0 (251.0 - 281.0)	0.67
Procedural time (min)	55.5 (50.0 - 66.2)	47.0 (42.0 - 54.0)	51.0 (45.0 - 58.5)	**<0.01**
Transeptal time (s)	123.0 (63.0 - 182.0)	182.0 (124.0 - 184.0)	181.0 (122.0 - 184.0)	**<0.01**
EAM and merge time (min)	12.0 (11.0 - 15.0)	12.0 (11.0 - 13.0)	12.0 (11.0 - 14.0)	0.20
RF time (min)	14.9 (13.6 - 16.8)	14.1 (12.3 - 16.6)	14.7 (12.9 - 16.7)	0.07
Total Visitags	59.0 (52.5 - 67.0)	54.0 (50.0 - 66.0)	57.0 (50.0 - 66.0)	0.15
Complete PVs isolation	87 (100.0)	87 (100.0)	174 (100.0)	0.99
First pass isolation	68 (78.2)	66 (75.9)	134 (77.0)	0.86
Acute procedural complication	2 (2.3)	1 (1.1)	3 (1.7)	0.99
Fluoroscopy time (s)	60.0 (40.0 - 77.5)	3.0 (1.0 - 10.5)	26.0 (3.0 - 60.0)	**<0.01**
Fluoroscopy Dose (mGy)	5.2 (3.5 - 7.1)	0.2 (0.04 - 0.5)	1.5 (0.2 - 5.8)	**<0.01**
Dose Area Product (Gy*cm2)	1.2 (0.8 - 1.6)	0.04 (0.01 - 0.1)	0.4 (0.04 - 1.3)	**<0.01**
Effective dose (mSv*100)	23.8 (15.6 - 31.6)	0.8 (0.2 - 2.8)	8.2 (0.8 - 25.1)	**<0.01**

Supplemental Table 3b. Peri-procedural data and ionizing radiation data in redo-ablation procedures subgroup.

	Historical controls (N=24)	ZFA group (N=24)	Redo procedures (N=48)	p value
Ventilation rate (breaths/min)	47.5 (45.2 - 52.0)	47.0 (46.0 - 49.5)	47.0 (46.0 - 52.0)	0.86
Tidal volume (ml)	253.0 (251.0 - 302.2)	253.5 (251.0 - 254.0)	253.0 (251.0 - 275.0)	0.95
Procedural time (min)	51.0 (43.8 - 67.2)	44.0 (35.8 - 54.2)	48.0 (37.8 - 56.0)	0.08
Transeptal time (s)	123.0 (106.5 - 182.0)	184.0 (181.0 - 242.2)	182.0 (122.8 - 241.0)	**<0.01**
EAM and merge time (min)	12.0 (10.8 - 14.0)	12.0 (12.0 - 14.0)	12.0 (11.0 - 14.0)	0.54
RF time (min)	5.9 (3.7 -7.3)	7.2 (5.1 - 8.9)	5.9 (4.3 - 8.3)	0.24
Total Visitags	19.0 (12.0 - 30.0)	26.5 (19.5 - 33.2)	21.5 (14.2 - 30.8)	0.27
Complete PVs isolation	24 (100.0)	24 (100.0)	48 (100.0)	0.99
Acute procedural complication	0 (0.0)	0 (0.0)	0 (0.0)	0.99
Fluoroscopy time (s)	69.5 (53.8 - 104.0)	3.5 (1.0 - 12.2)	28.0 (3.8 - 69.2)	**<0.01**
Fluoroscopy Dose (mGy)	7.5 (5.6 - 12.4)	0.2 (0.03 - 0.7)	2.1 (0.2 - 7.5)	**<0.01**
Dose Area Product (Gy*cm2)	1.8 (1.3 - 3.6)	0.1 (0.01 - 0.2)	0.7 (0.1 - 1.8)	**<0.01**
Effective dose (mSv*100)	36.6 (26.9 - 71.9)	1.0 (0.2 - 4.4)	13.5 (1.1 - 36.5)	**<0.01**

Supplemental Table 3c. Peri-procedural data and ionizing radiation data in paroxysmal AF patients subgroup.

	Historical controls (N=75)	ZFA group (N=81)	Paroxysmal AF patients (N=156)	p value
First ablation procedure	60 (80.0)	64 (79.0)	124 (79.5)	0.99
Redo procedure	15 (20.0)	17 (21.0)	32 (20.5)	0.99
Ventilation rate (breaths/min)	48.0 (46.0 - 52.0)	48.0 (46.0 - 52.0)	48.0 (46.0 - 52.0)	0.65
Tidal volume (ml)	252.5 (251.0 - 283.0)	253.0 (251.0 - 274.0)	253.0 (251.0 - 282.0)	0.94
Procedural time (min)	55.0 (47.0 - 66.2)	44.0 (40.0 - 51.0)	49.0 (42.0 - 58.0)	**<0.01**
Transeptal time (s)	123.0 (63.0 - 182.0)	182.0 (124.0 - 241.0)	181.0 (122.0 - 184.0)	**<0.01**
EAM and merge time (min)	12.0 (11.0 - 15.0)	12.0 (11.0 - 14.0)	12.0 (11.0 - 14.0)	0.41
RF time (min)	13.9 (11.7 - 16.4)	12.8 (10.6 - 14.8)	13.3 (11.0 - 15.8)	0.06
Total Visitags	56.0 (44.0 - 62.0)	52.0 (46.5 - 60.5)	54.0 (45.0 - 62.0)	0.78
Complete PVs isolation	75 (100.0)	81 (100.0)	156 (100.0)	0.99
Acute procedural complication	2 (2.7)	0 (0.0)	2 (1.3)	0.23
Fluoroscopy time (s)	60.5 (39.8 - 79.2)	3.0 (1.0 - 12.0)	22.0 (3.0 - 60.0)	**<0.01**
Fluoroscopy Dose (mGy)	5.8 (3.4 - 7.1)	0.1 (0.03 - 0.5)	1.4 (0.1 - 5.8)	**<0.01**
Dose Area Product (Gy*cm2)	1.2 (0.7 - 1.6)	0.03 (0.01 - 0.2)	0.4 (0.02 - 1.2)	**<0.01**
Effective dose (mSv*100)	24.5 (14.9 - 32.4)	0.6 (0.2 - 3.2)	7.6 (0.4 - 24.0)	**<0.01**

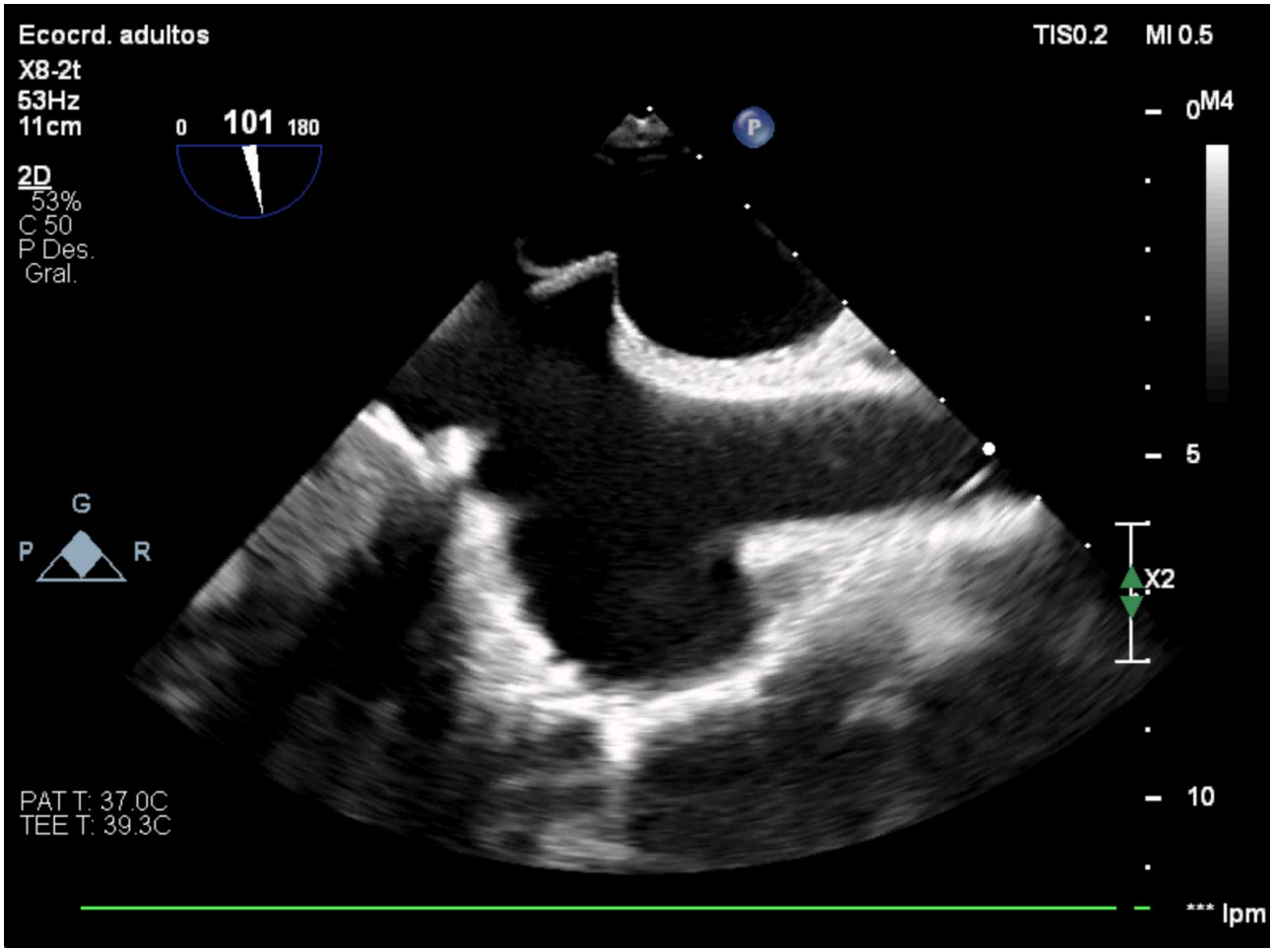
Supplemental Table 3d. Peri-procedural data and ionizing radiation data in persistent AF group.

	Historical controls (N=36)	ZFA group (N=30)	Persistent AF patients (N=66)	p value
First ablation procedure	27 (75.0)	23 (76.7)	50 (75.8)	0.99
Redo procedure	9 (25.0)	7 (23.3)	16 (24.2)	0.99
Ventilation rate (breaths/min)	47.0 (46.0 - 52.0)	45.0 (44.0 - 47.0)	46.5 (44.0 - 50.0)	0.08
Tidal volume (ml)	252.0 (251.0 - 293.5)	252.0 (251.0 - 254.0)	252.0 (251.0 - 260.0)	0.56
Procedural time (min)	54.5 (49.8 - 69.2)	50.5 (47.0 - 57.0)	54.0 (48.0 - 61.8)	**0.04**
Transeptal time (s)	123.0 (63.0 - 182.2)	183.0 (138.2 - 241.0)	181.0 (122.0 - 184.0)	**<0.01**
EAM and merge time (min)	12.0 (11.0 - 14.0)	12.0 (11.0 - 13.0)	12.0 (11.0 - 14.0)	0.65
RF time (min)	15.1 (12.7 - 16.2)	15.2 (12.8 - 17.4)	15.1 (12.7 - 16.8)	0.50
Total Visitags	59.0 (49.5 - 64.0)	57.0 (52.2 - 69.5)	58.0 (51.0 - 67.0)	0.35
Complete PVs isolation	36 (100.0)	30 (100.0)	66 (100.0)	0.99
Acute procedural complication	0 (0.0)	1 (3.3)	1 (1.5)	0.46
Fluoroscopy time (s)	65.0 (51.8 - 100.2)	4.0 (2.0 - 8.8)	36.0 (5.0 - 65.8)	**<0.01**
Fluoroscopy Dose (mGy)	6.3 (4.1 - 20.1)	0.2 (0.1 - 0.8)	3.3 (0.3 - 7.9)	**<0.01**

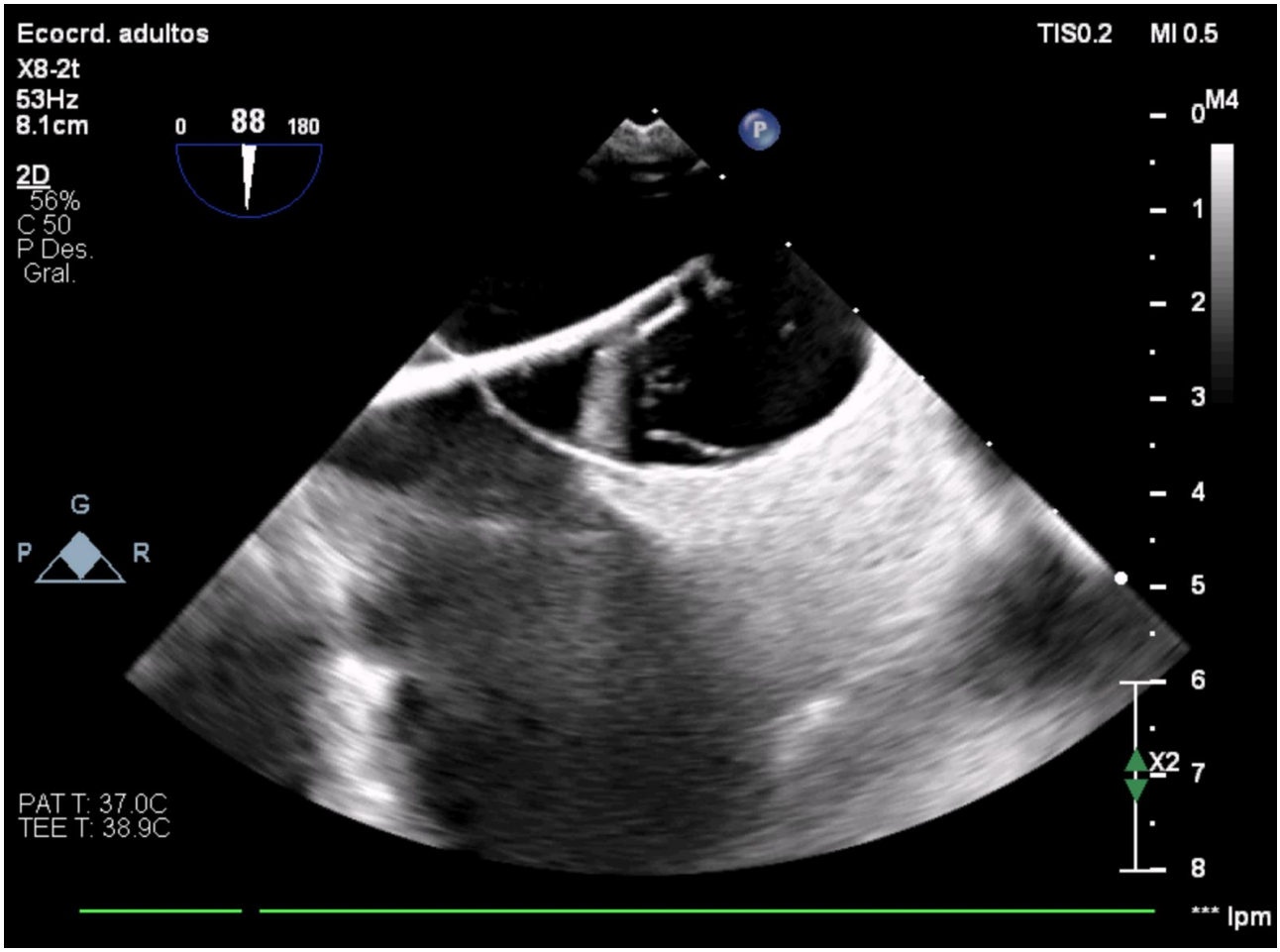
Dose Area Product (Gy*cm2)	1.5 (0.8 - 4.7)	0.06 (0.02 - 0.1)	0.7 (0.1 - 1.8)	**<0.01**
Effective dose (mSv*100)	29.6 (16.6 - 93.1)	1.2 (0.5 - 2.6)	14.9 (1.2 - 36.4)	**<0.01**

Results are reported as n (%) for categorical variables and median (interquartile range) or mean ± standard deviation for continuous variables.
FAM = Fast Anatomical Mapping; RF = Radiofrequency ; PVs = Pulmonary Veins; ZFA = Zero Fluoroscopy Approach.

Supplemental Video 1. TEE- guidance of ablation catheter insertion in left atrium through the sheath.



Supplemental Video 2. TEE-guidance of pull-back maneuver.



Supplemental Video 3. Image integration of the 3D FAM and the preprocedural MDCT-derived maps with LAWT information using CartoMerge software.

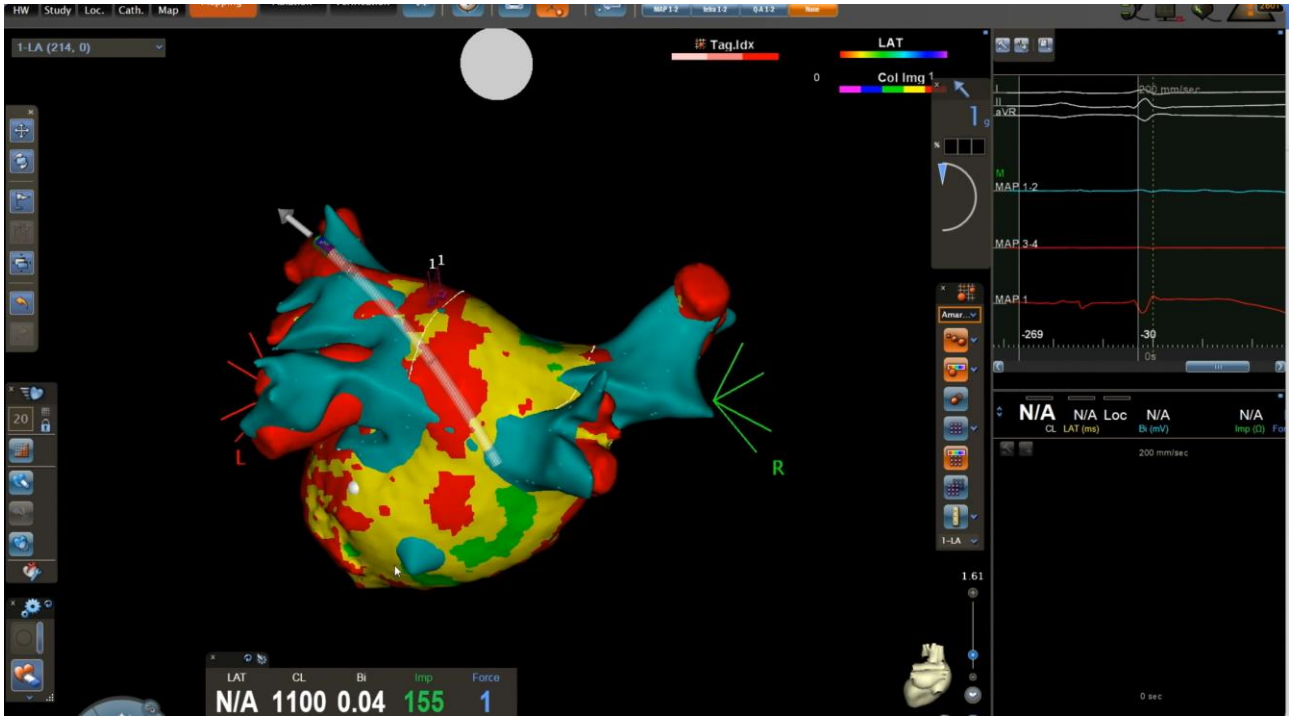


Figure 1

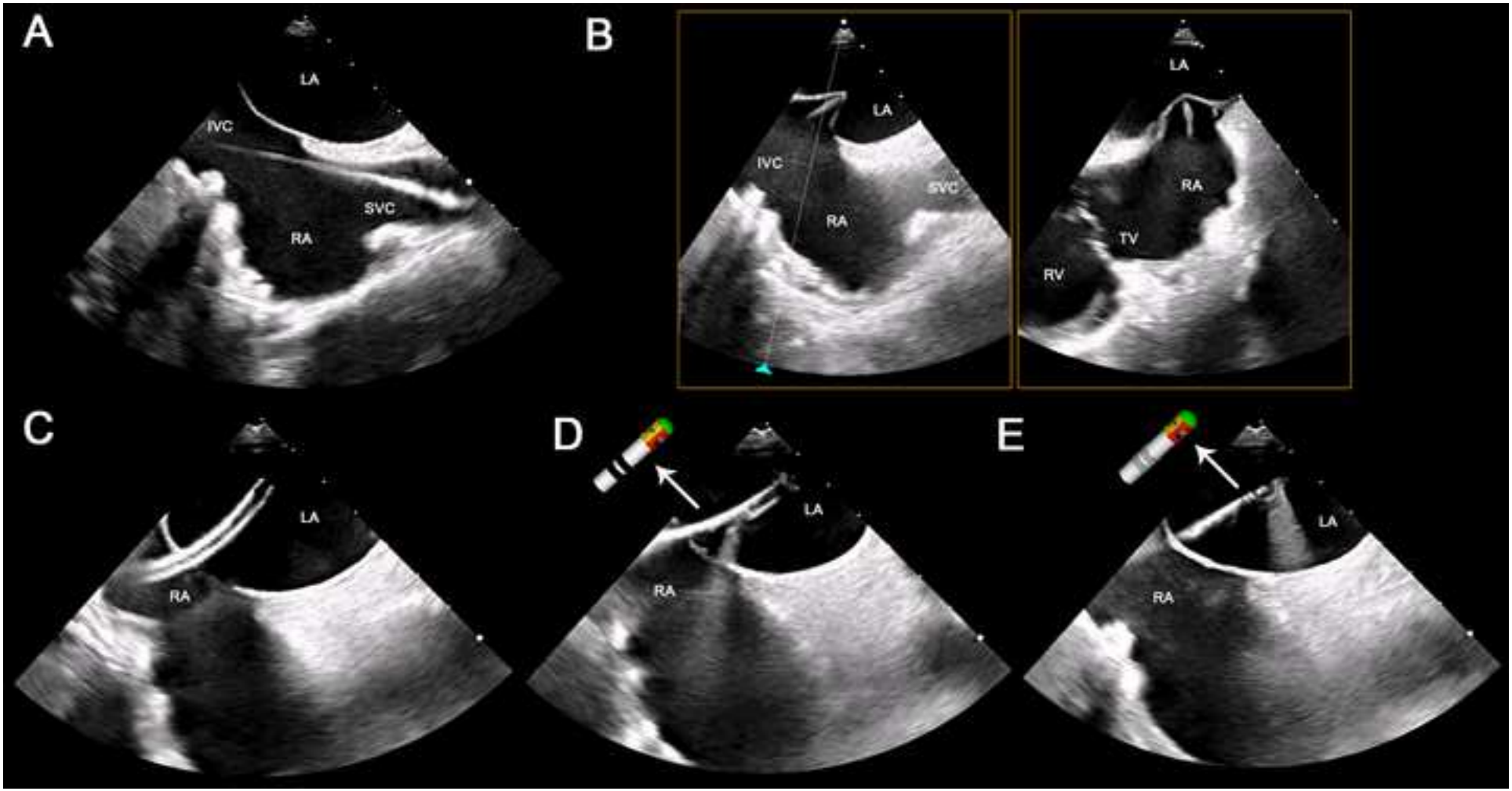


Figure 2

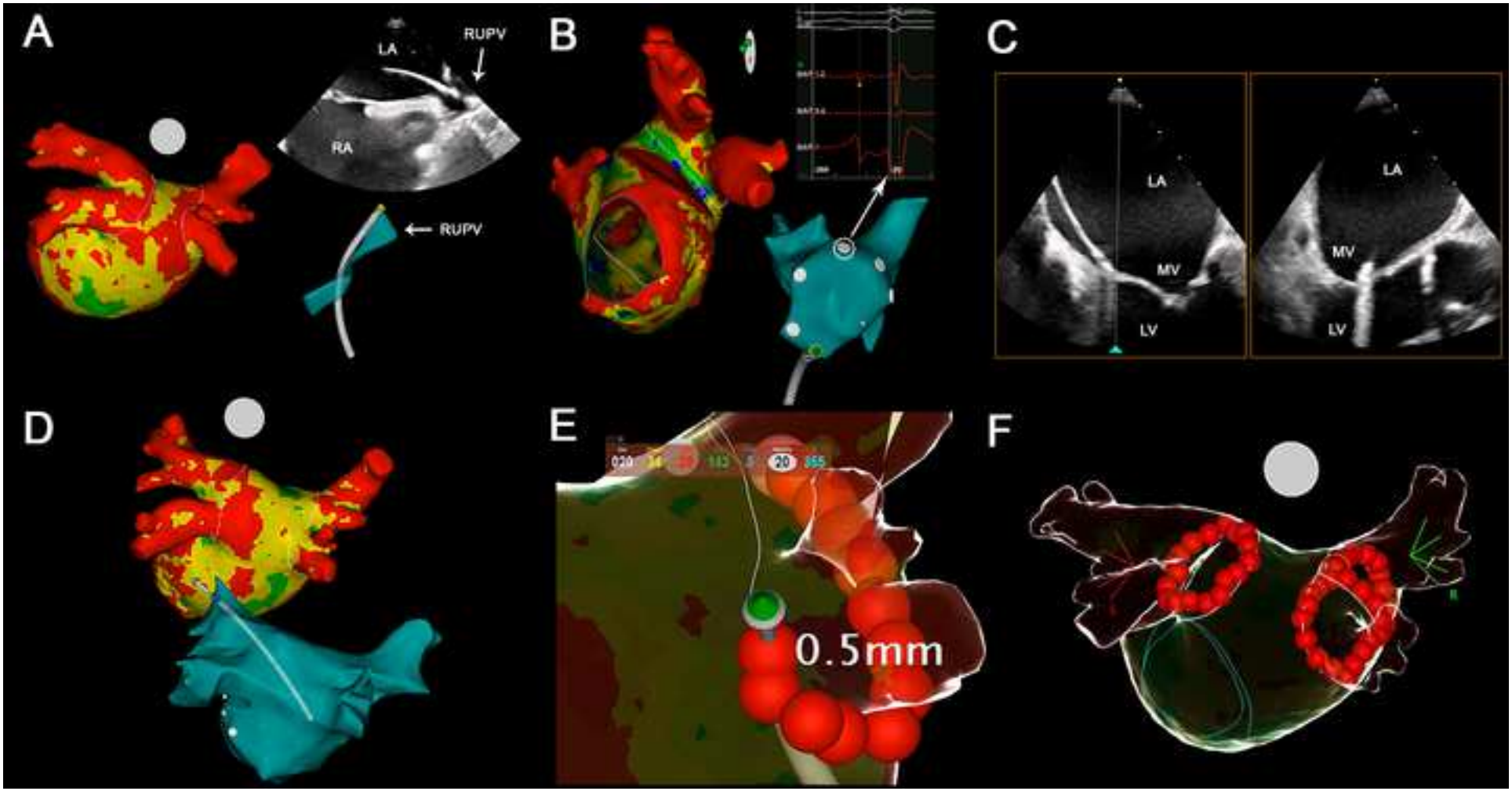


Figure 3

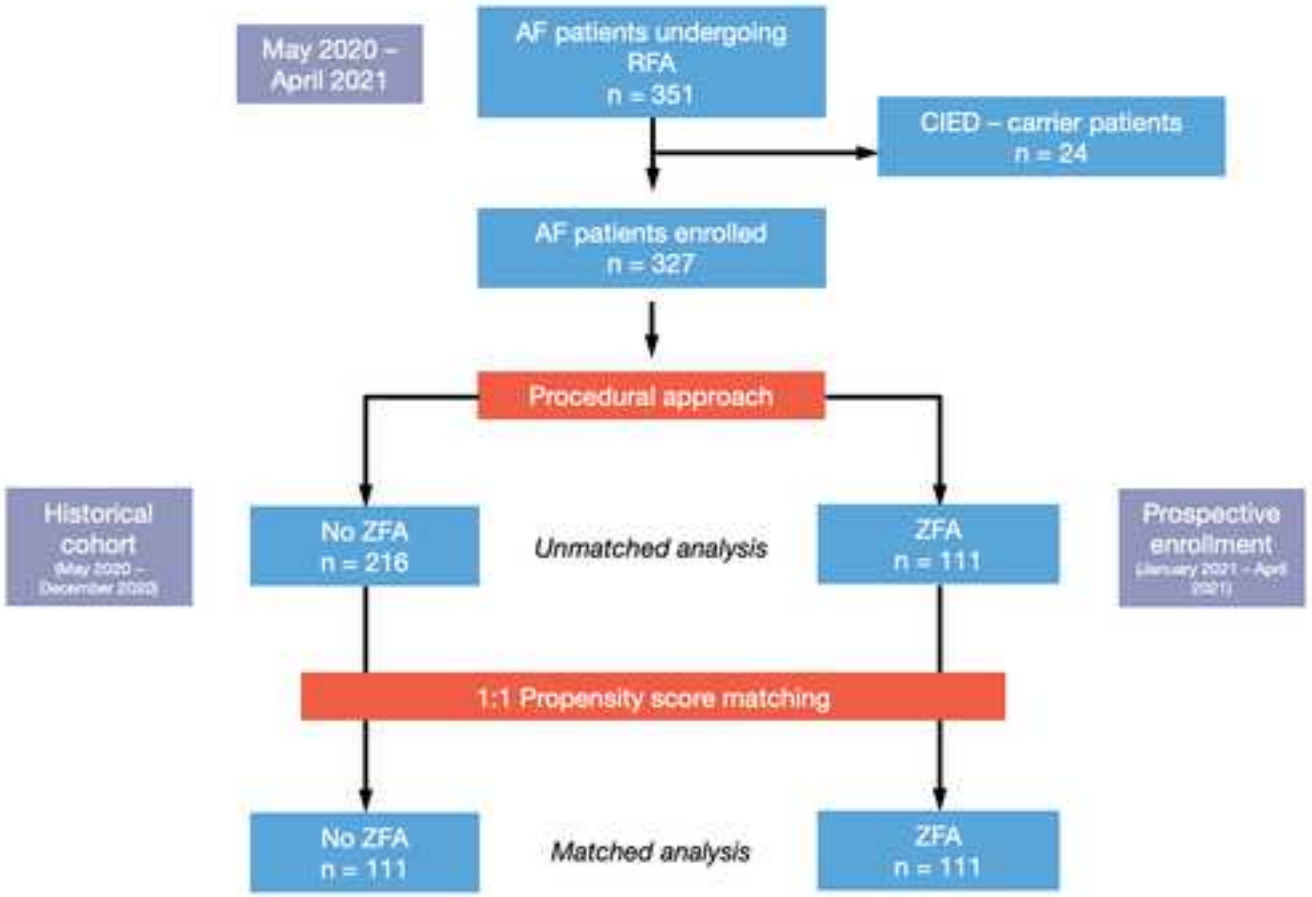
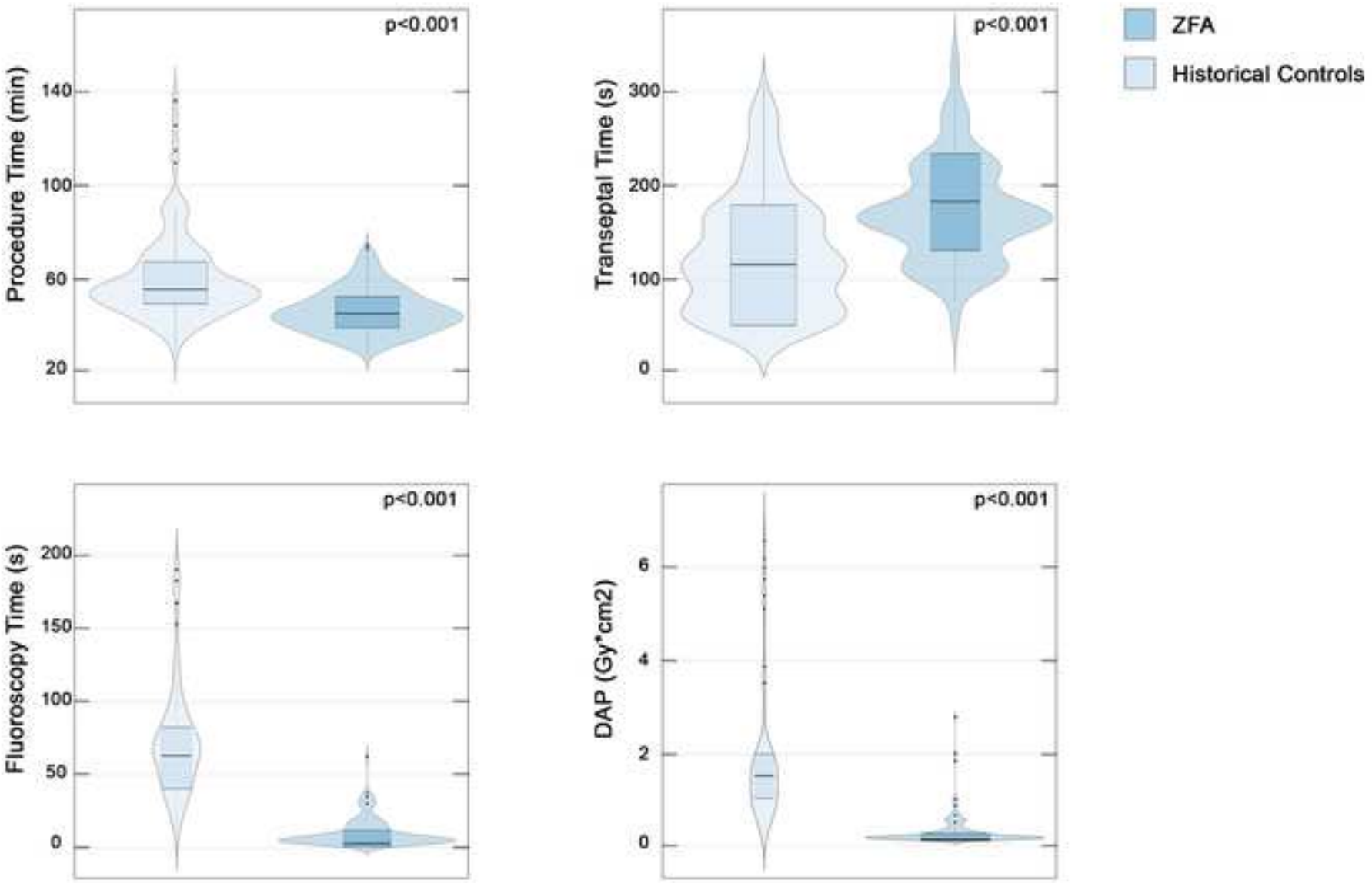


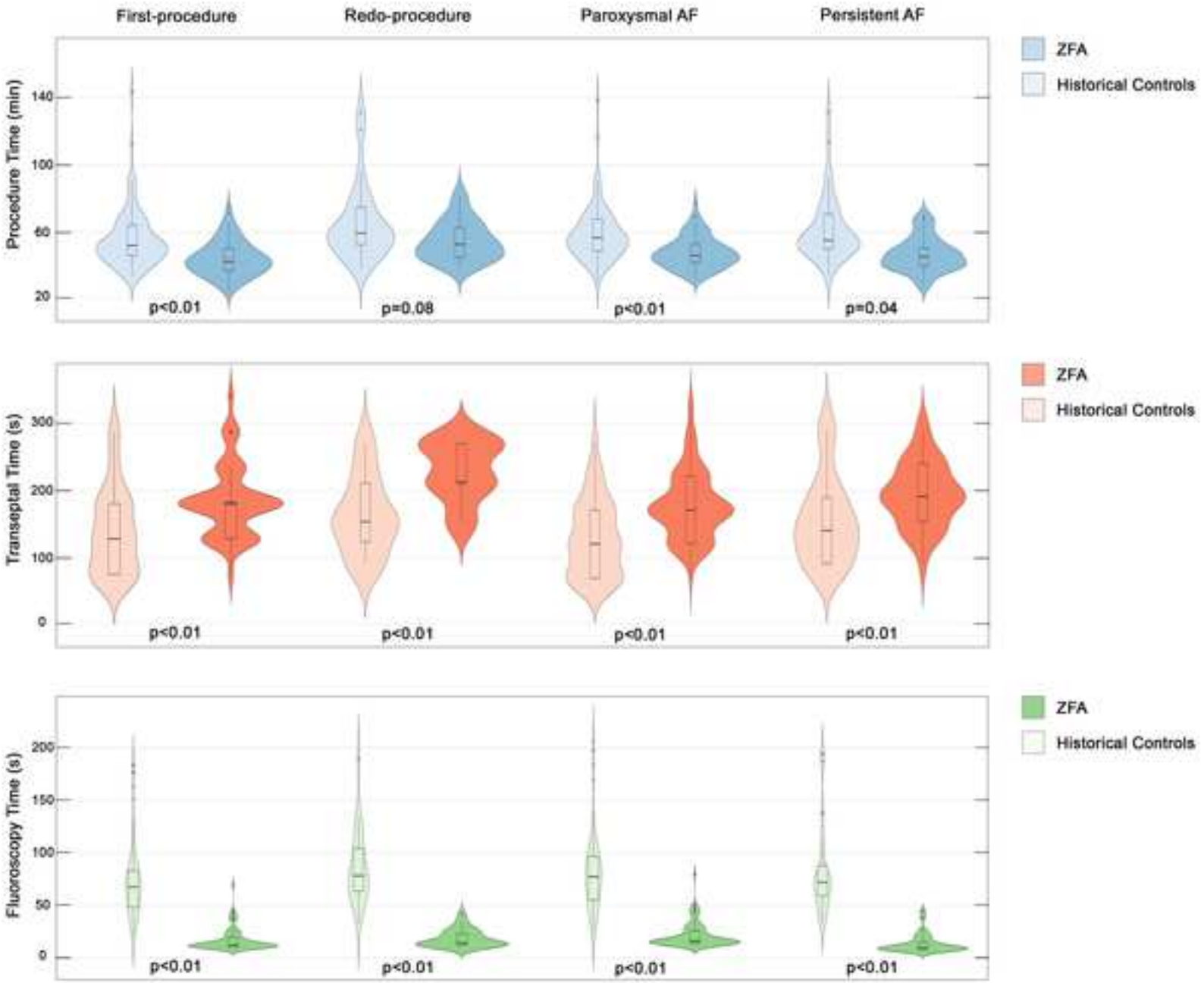
Figure 4

Click here to access/download;Figure;Figure 4 v4.tif



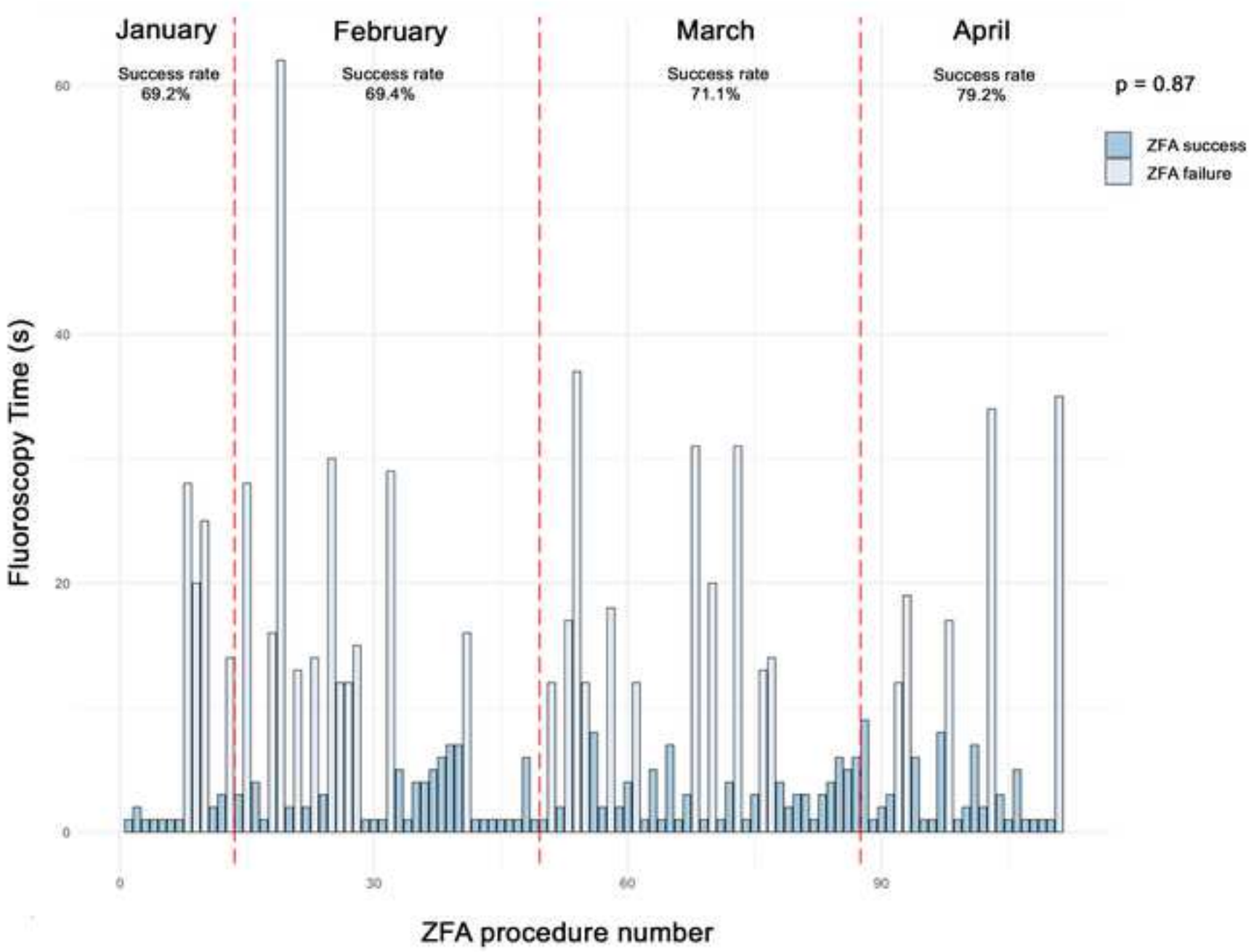
Supplemental Figure 1

Click here to access/download;Figure;Supplemental Figure 1.tif



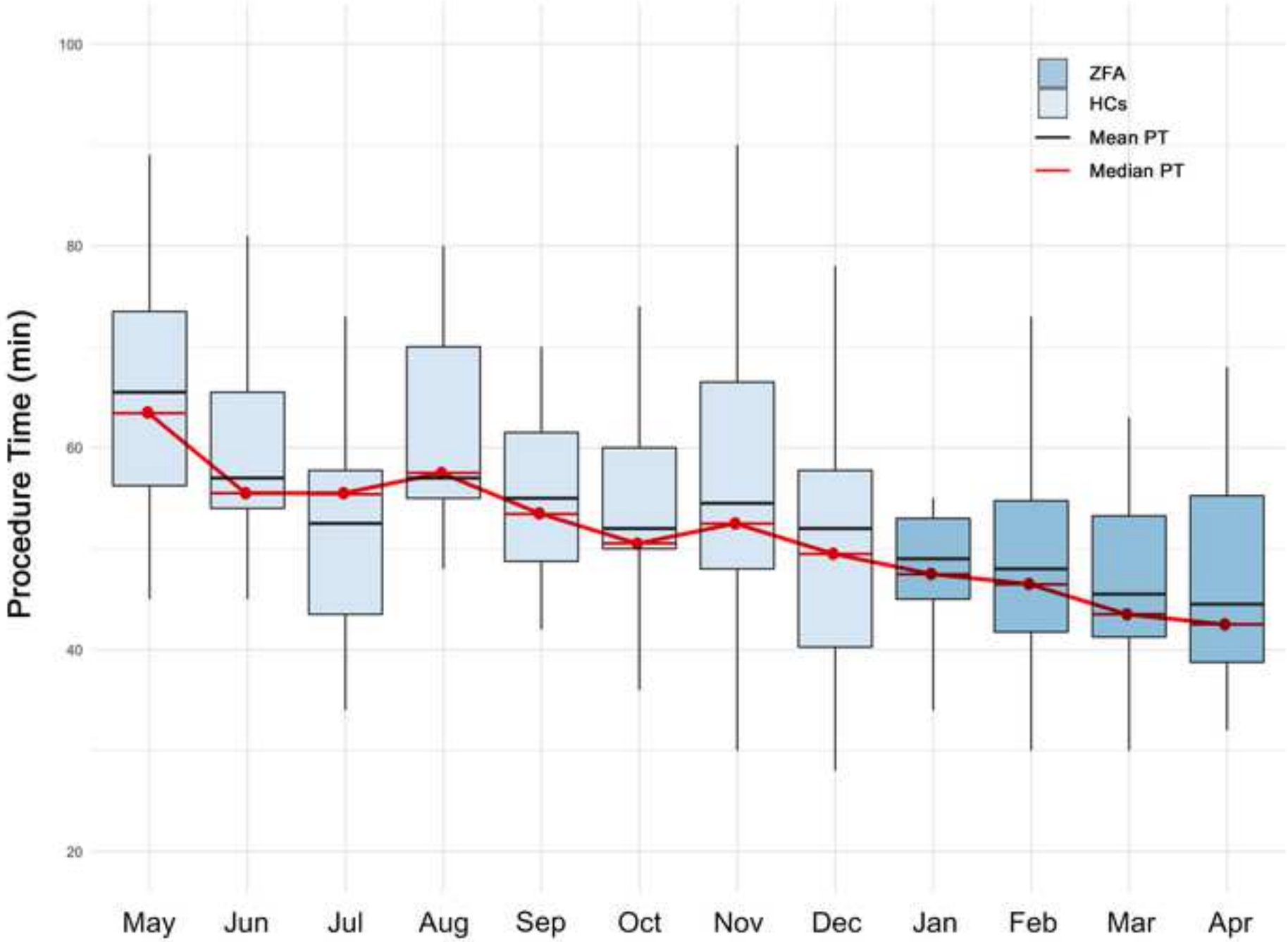
Supplemental Figure 2

Click here to access/download;Figure;Supplemental Figure 2 v2.tif



Supplemental Figure 3

Click here to access/download;Figure;Supplemental Figure 3.tif



Supplemental Video 1

Click here to access/download

Video Clip (50 MB max.)

Supplemental Video 1.mp4

Supplemental Video 2

Click here to access/download

Video Clip (50 MB max.)

Supplemental Video 2.mp4

Supplemental Video 3

Click here to access/download

Video Clip (50 MB max.)

Supplemental Video 3 v2.mp4