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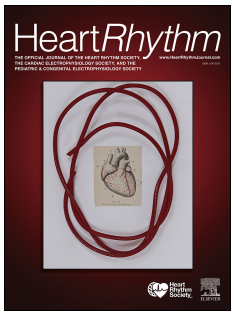

Ablation of cavo-tricuspid isthmus dependent atrial flutter using a focal monopolar pulsed-field ablation catheter: Feasibility, periprocedural coronary spasms and conduction disorders.

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CTI ABLATION

N=109
2 centers

PULSED-FIELD Ablation
(PFA, n=82)
CardioFocus generator
Biphasic monopolar PFA 22 / 25 A

FOCAL ABLATION CATHETER
SmartTouch / TactiCath

+ NAVIGATION SYSTEM
Carto / EnsiteX

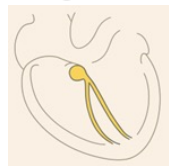
RADIOFREQUENCY
(RFA, n=27)
35W / 40s

CTI-dependent atrial flutter ± AF ablation

FEASIBILITY

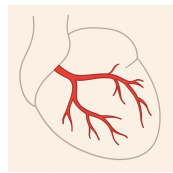
	PFA	RFA
Duration, *min*	7	17
Ablation time, *s*	110	649
Applications, *n*	11	17
1st pass block, *n (%)*	76 (93)	15 (55)
Bidirectional block, *n*	82	27

SAFETY
With focal PFA / absent with RFA



CONDUCTION DISORDERS

- **Transient AVB** during procedure (2%)
- **PR prolongation** after procedure and persistent at 3 months (4/17)



CLINICAL VASOSPASM

- **ST elevation** : 5%
- Despite prior NO administration
- Treated with titrated IV NO
- No coronary event at 3 months

Distance to the His (EAM) NOT predictive

Distance to the RCA (CT) NOT predictive

Ablation of cavo-tricuspid isthmus dependent atrial flutter using a focal monopolar pulsed-field ablation catheter: Feasibility, periprocedural coronary spasms and conduction disorders.

Short/running title: Treatment of CTI-dependent atrial flutter by focal monopolar PFA.

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Abstract

Background: Pulsed-field ablation (PFA) for the treatment of cavo-tricuspid isthmus (CTI) dependent atrial flutter (AFL) has been associated with coronary spasms (CS) and AV conduction disorders (CD).

Objectives: To evaluate the feasibility of CTI ablation using a monopolar focal PFA (F-PFA) catheter and to assess the risk of CS and CD during and after the procedure.

Methods: We prospectively enrolled patients with AFL treated by a F-PFA system (CardioFocus) or focal radiofrequency ablation (RFA) through contact-force sensing catheters integrated in electroanatomical mapping systems. Intravenous nitroglycerine was administered prior to F-PFA. Feasibility and safety (focus on CS or CD) were assessed. In a subgroup of patients, the course of the right coronary artery (RCA) and the His position were determined.

Results: In total, 82 patients underwent CTI-ablation by F-PFA (18% female, 66±8 years, CHA2DS2VA 1.6±1.3) and 27 patients underwent CTI-ablation by RFA (23% female, 63±9 years, CHA2DS2VA 2±1.3). For F-PFA, the proportion of first pass block was higher (93% vs 55%) and procedure times were shorter (7 [5,11] min vs 17 [15,19] min) than for RFA. In the F-PFA group, four patients (5%) presented transient ST elevation and 2 patients (2%) showed a transient complete AV block during ablation. There was a small, but significant prolongation in PQ interval after CTI ablation in the F-PFA group.

Conclusion: CTI ablation using F-PFA is feasible, but operators should be aware of rare but critical CD and CS during the procedure, even when preventive measures such as nitroglycerine administration are employed.

Abbreviations

AVB = AV block

CTI = Cavo-tricuspid isthmus

PFA = Focal Pulsed-field ablation

RCA = Right coronary artery

RFA = Radiofrequency ablation

Keywords:

Catheter ablation, atrial flutter, pulsed-field ablation, coronary spasm, AV conduction

Introduction

In patients with ECG-documented typical atrial flutter, linear point-by-point catheter ablation of the cavo-tricuspid isthmus (CTI) is the preferred treatment strategy over pharmacological treatment.[1] Additionally, CTI ablation is also recommended and commonly performed in patients undergoing atrial fibrillation (AF) ablation in case of prior history or intraprocedural induction of CTI-dependent flutter.[1,2] Until now, radiofrequency ablation (RFA) is the most commonly used energy source for CTI ablation, offering a safe and effective approach.[3] However, RFA for CTI ablation relies on thermal energy, which may pose a risk of collateral damage to adjacent structures (gastroparesis, damage of the right coronary artery) and of tamponades due to steam pops. Additionally, CTI ablation by RFA can require prolonged applications to achieve durable lesion formation.

In contrast, pulsed-field ablation (PFA) has been introduced as a novel close to non-thermal ablation technology consisting of a high voltage train with very short pulses, which results in tissue-specific damage in the heart by cardiomyocyte selective electroporation without thermal damage of surrounding organs.[4] While PFA has demonstrated well-established success and safety profiles for AF ablation, its application in CTI ablation for typical atrial flutter is still emerging.[5-11] Available data comes from smaller subgroups of patients undergoing CTI ablations as concomitant procedures to AF ablation using mainly bipolar PFA through a pentaspline catheter.[7,8,9,10] Coronary spasms and AV conduction disturbances have been described as possible periprocedural complications in these observational studies. This has led to routine prophylactic use of intravenous nitroglycerine to prevent the occurrence of coronary spasm and reinforced the importance of maintaining a safe distance from coronary arteries during ablation.[12-14] Despite relatively wide clinical uptake, data on CTI ablation using monopolar focal PFA systems with contact force-sensing, solid-tip catheters are sparse.[9,10]

The purpose of this study was to describe the procedural success and safety of using a monopolar biphasic focal PFA system with a commercial, contact force-sensing, solid-tip ablation catheter for CTI ablation as a stand-alone procedure or concomitant procedure in patients undergoing AF ablation. Additionally, we compared vasospastic effects and longitudinal changes in the ECG after CTI ablation

using focal PFA to using focal RFA. In a subset of patients, we characterized the spatial relationship of the CTI ablation line to the AV conduction system and the course of the right coronary artery (RCA).

Method

Study design and population

This international and multicenter (two academic hospitals: Maastricht University Medical Center, Maastricht, The Netherlands, and Gentofte Hospital, University of Copenhagen, Denmark) study included consecutive patients who underwent CTI ablation by focal biphasic monopolar PFA using the CENTAURI PFA system (CardioFocus, Inc, Marlborough, MA, US) between January 2023 and March 2024. The groups were named Gentofte PFA cohort and Maastricht PFA cohort according to the center of origin. A matched cohort using RFA ablation for CTI (Maastricht RFA cohort) was then selected for comparison. The decision of CTI ablation was based on ECG-documentation of CTI-dependent atrial flutter.

The study is part of the prospective ISOLATION (ClinicalTrials.gov identifier: NCT04342312) study and was approved by the local ethical review board (NL:70787.068.19/METC:19-052).[15] All participants provided written informed consent. The research reported in this paper adhered to the Helsinki Declaration as revised in 2013.

Preprocedural workup

Prior to the procedure, all patients underwent trans-thoracic echocardiography (with assessment of left ventricular ejection fraction, right and left atrial volumes), and ECG review (to document CTI-dependent or atypical atrial flutter and quantify conduction properties (PR time, QRS width and presence/absence of specific conduction disturbance pattern (left/right bundle branch block, fascicular block, atrioventricular block)). A PFA subgroup in the Maastricht cohort underwent preprocedural cardiac computed tomography (CT) angiogram (to determine CTI anatomy and evaluate the course of the right coronary artery in relation to the targeted ablation zone and to exclude left atrial appendage thrombus). Patients were admitted on the day of ablation and the procedure was carried out without interruption of anticoagulation.

CTI ablation procedure

The procedures were performed under general anesthesia or sedation in case of CTI ablation as a concomitant ablation in addition to AF ablation procedures or local anesthesia in case of isolated CTI ablation. After femoral access, a decapolar catheter was placed in the coronary sinus (Webster CS catheter, Biosense Webster, Inc, Diamond Bar, CA, United States). In the case of CTI ablation as a concomitant ablation in addition to AF ablation procedures, AF ablation was performed according to the institutional clinical workflow.[9]

For CTI ablation, the ablation catheter (ThermoCool SmartTouch Catheter, Biosense Webster, Inc /Tacticath Catheter, Abbott, Inc) was retracted in the right atrium and in the coronary sinus to perform respiration gating and define the septal portion of the right atrium. The region with a His bundle signal was mapped, marked and electroanatomical mapping of the CTI region was performed (CARTO 3 System Version 7, Biosense Webster, Inc, NavX System, Abbott, Inc), using the ablation catheter. The target for ablation was the mid-CTI, which was also confirmed by fluoroscopy with a left anterior oblique (LAO) view at 45°, with the ablation catheter pointing at 6-7 o'clock. The annular (distal) part of the CTI was defined as the presence of both atrial and ventricular signals on the distal electrode of the ablation catheter, where pacing was not associated with ventricular capture and without catheter-induced ventricular premature beats. The caval (proximal) extremity of the CTI was defined as the disappearance of signals on a distal electrode of the ablation catheter, where pacing was not associated with atrial capture.

For focal PFA, the CENTAURI PFA generator (CardioFocus, Inc) was connected through a dedicated connector box to the electro-anatomical mapping system and the open irrigated contact force-sensing ablation catheter. The energy delivery setup was point-by-point focal biphasic monopolar and R-asynchronized pulsed field energy. The ablation catheter's irrigation rate was set to 4 mL/min continuously. The force applied was targeted between 10 and 25 g. Manual application-tags of 6 mm diameter were placed with 20–30% overlap. Ablation was performed using focal PFA with a current of 22 A (7 pulse trains) for the annular part and 25 A (10 pulse trains) for the caval part of the CTI or using 25 A (10 pulse trains) only (at the discretion of operator). Nitroglycerine was administered intravenously

before starting PFA, using 100-400 micrograms of short-acting trinitrate according to the center. No additional bolus or nitroglycerine was administrated, except in case of coronary spasm.

For RFA, the open irrigated contact force-sensing ablation catheter was connected to a standard RFA generator. The ablation catheter's irrigation rate was set to 2 mL/min continuously and to 17 mL/min during ablation. The power used was 35W and a contact force between 10 and 30 was targeted. The application was Ablation Index-guided with a minimum target of 500 and an ablation time of minimum 40s.

A successful procedure was defined as the occurrence of bidirectional block across the ablation lines, defined by double potentials of ≥ 100ms along the ablation line during CS pacing and a differential pacing protocol.

Evaluation of Coronary spasm: A 12 lead ECG was continuously monitored in all patients during the procedure. In case of any repolarization abnormalities (ST-segment elevation or depression, T wave inversion), additional doses of IV nitroglycerine were titrated up to disappearance of repolarization abnormalities. In case of persistent repolarization abnormalities, despite additional i.v. nitroglycerine or in case of hemodynamic instability, a coronary angiogram was performed.

Conduction disturbances: Conduction disturbance was defined as a prolongation of the PR of ≥ 20ms, a widening of ≥ 20ms of the QRS, the appearance of AV block (new onset PR > 200ms, and/or second or third-grade AVB), or appearance of specific intraventricular conduction disturbance pattern (right or left bundle branch block, left posterior or left anterior fascicular block). Conduction properties were evaluated in the Maastricht PFA and RFA cohorts both the beginning and at the end of the procedure, and 3 months after the procedure. Patients with anti-arrhythmic drug modification and/or with significant heart rate variation (≥20 bpm) were excluded from analysis.

All electro-anatomical maps were reviewed after the procedure to assess procedural timings, number of ablation points, and length of ablation lines. In the Maastricht PFA cohort, the shortest distance of the CTI ablation line to the His bundle was measured, and the pre-procedural CT angiograms were used to evaluate the distance between the RCA and the endocardium at the target region for ablation. The

measurements were performed on 0.6mm slice imaging and included 2 measurements (one standard vertical, the second using the shortest distance between the RCA and the endocardium in the section plane).

Post-ablation and in-hospital management

After the procedure, a systematic trans-thoracic echocardiography was performed to rule out pericardial effusion. A figure-of-8 stitch and 4-hour compressive bandage was placed at the site of femoral puncture to avoid bleeding. Patients were then transferred to the dedicated cardiology ward. Patients were discharged the same day or the next day after evaluation of the punction site, and an ECG before discharge.

Statistics

Quantitative data have been analyzed using univariate one-way analyses of variance. For non-normally distributed variables, Mann-Whitney test has been used. For qualitative measures, chi-square tests have been applied, except when numbers were lower than 5: in these situations, Fisher exact tests have been used. All these analyses have been performed using SAS 9.4. To correct for potential confounders, multivariate analyses have been performed using linear and generalized linear models with the lm and glm procedures of R (version 4.4.1), respectively. Models have been built using a stepwise approach, obtained with the stepAIC procedure of the MASS module.

Result

Patient characteristics

The patient inclusion is shown in **Supplemental Figure S1**. The characteristics of the population are presented in **Table 1**. The population included 82 consecutive patients in the full PFA cohort (65 in the Gentofte cohort and 17 in the Maastricht cohort) and 27 consecutive patients in the RFA cohort.

For the full PFA cohort, mean age was 66±9 years, with a majority of male patients (82%). The mean CHADS-VA was 1.6±1.3 and there was a majority of obese patients (mean BMI 27±5kg/m² and 54% of patients with a BMI > 25kg/m²). The mean left ventricular ejection fraction (LVEF) was 52±10% with 24% of patients presenting a reduced LVEF < 50%. The mean time since the first diagnosis of atrial flutter was 24 [6,94] months.

For the RFA cohort, the mean age was 63±9 years, with a majority of male patients (74%). The mean CHADS-VA was 2±1.3 and there was a majority of obese patients (mean BMI 28±4kg/m² and 74% of patients with a BMI > 25kg/m²). The mean left ventricular ejection fraction (LVEF) was 51±11%, with 37% of patients presenting a reduced LVEF < 50%.

There were no statistical differences between the full PFA and RFA groups, except for BMI which was higher (1 point) in the RFA group (p=0.017) and LVEF < 50% which was more frequent in the RFA group.

Procedural data

Procedural data are presented in **Table 2**. Most procedures were performed under general anesthesia (85% in the RFA and 87% in the PFA cohort), followed by deep sedation (11 and 13% for RFA and PFA respectively). One procedure was performed under local anesthesia in the matched RFA group (CTI alone). A minority of procedures were stand-alone CTI ablation procedures (18% and 4% in the PFA and RFA cohorts respectively).

In the full PFA cohort, the median time for CTI ablation was 7 [5,11] minutes, with an ablation time of 110 [80,130] seconds, which was shorter than in the matched RFA cohort (time for CTI ablation (17 [14,19] min ($p<0.0001$)) and ablation time (649 [568,705] s ($p<0.0001$)). While the median CTI ablation line length was similar in both cohorts (29 [24,34] mm for the full PFA cohort and 31 [27,33] mm for the RFA cohort ($p=0.639$)), the median number of ablation points was significantly higher in the RFA cohort (17 [12,20] points versus 11 [9,14] points in the full PFA cohort ($p<0.0001$)), as was the number of ablation points/cm (4 in the full PFA cohort vs 5.5 in the RFA group ($p<0.0001$)). Bidirectional block was achieved in all patients in both groups (100%) but with a higher rate of first pass block in the full PFA cohort (93% vs. 55%, $p<0.0001$). No reconnection was observed within 15 minutes waiting time.

Safety

In the full PFA cohort, neither serious groin site complications nor pericardial tamponade occurred. The prevalence of coronary spasm and conduction disturbances and relevant clinical and procedural details are presented in **Tables 3 - 5**.

Coronary spasms: Despite prophylactic administration of nitroglycerine intravenously before ablation, four patients (5%) presented ST elevation during CTI ablation (**Table 3**). None of the four patients had a medical history of coronary artery disease. All ST elevations were transient and effectively treated with titrated intravenous injection of nitroglycerine (maximum of 450µg). Post-procedural echocardiography showed no new kinetic disorders nor new impairment of systolic function. No coronary event occurred at 3 months follow-up. No persistent repolarization abnormalities were identified at 3 months follow-up.

Conduction disorders: In the full PFA cohort, two patients (2%) presented transient complete AV block during ablation (**Table 4**). ECG-based conduction properties were studied longitudinally in the RFA cohort (n=27 patients) and in the Maastricht PFA cohort (n=17 patients). In the Maastricht PFA cohort, four patients (24%) experienced a PR prolongation of more than 20 ms directly after the procedure, which was sustained up to 3 months after ablation (**Table 4**). The remaining 13 patients did not experience PR prolongation, neither in the immediate aftermath nor during the 3 months following the

initial procedure. The sustained PR prolongation occurred irrespective of complete AV block during the procedure. Detailed procedural characteristics of patients presenting conduction disorders are presented in **Table 5**. Of note, in the RFA group, no PR prolongation or AV block was observed. No patient developed ventricular conduction disorders.

Spatial relationship between CTI line and the RCA and His area

In the Maastricht PFA cohort, the spatial relationship of the CTI ablation line to the RCA and the His area was assessed (**Figure 1&2**). Pre-procedural cardiac CT was analyzed in 17 PFA patients. The vertical and closest distance between right coronary artery and CTI were 4.1 [3.2,4.6] mm and 2.8 [1.8,3.8] mm respectively. In electroanatomic mapping of the Maastricht PFA cohort, the median distance between the ablation line and the His bundle was 37 [35,42] mm. The distance between the ablation line and the His bundle for the patient suffering transient AV block (AVB) in the Maastricht PFA cohort was 31 mm and these distances for the patients presenting with PR prolongation were 35, 36, 41 and 52mm, which was not discriminant to predict the occurrence of these complications during the pre-ablation phase. The second patient suffering transient complete AVB was part of the Gentofte PFA cohort where the distance between the ablation line and the His bundle was not evaluated.

Discussion

In this consecutive series of CTI ablation as a stand-alone procedure or in combination with AF ablation, bidirectional conduction block was achieved in all patients with a higher rate of first-pass CTI conduction block in the monopolar PFA cohort as compared with the RFA cohort, using the same focal ablation catheters for both technologies. Nonetheless, operators must remain vigilant for rare but critical complications like peri-procedural transient complete AV block, persistent PR prolongation, and transient coronary spasm, even when preventive measures such as nitroglycerine administration are employed.

- Risk of coronary spasm

The CTI is located in close proximity to the RCA. Reddy et al. and Malyshev et al.[12,13] performed systematic coronary angiography during CTI ablation using bipolar PFA revealing that a RCA spasm was present in all cases of CTI ablation, which was the basis for the advice of using prophylactic administration of i.v. nitroglycerin. In our study where monopolar focal PFA was used with prophylactic i.v. nitroglycerine, clinical coronary spasm was observed in 4 cases (5%) presenting as transient ST-segment elevation in the inferior ECG leads. This prevalence of coronary spasms despite prophylactic nitroglycerin application may be higher compared to what has been previously reported for bipolar PFA systems, which could be linked to the monopolar focal PFA delivery in our patient cohort, which may be associated with a larger and deeper PFA fields. These episodes resolved with titrated administration of nitroglycerin (total maximum of 1000µg), without requiring coronary angiography. Previous studies in pigs estimated the safe distance of epicardial bipolar[16] and monopolar[17] PFA applications through a linear catheter close to the coronary arteries at >6.5 mm. In the current study, we used pre-operative cardiac CT to evaluate the course of the RCA in relation to the targeted CTI line. Despite a distance from the CTI line to the RCA below the threshold of 6.5 mm, clinical coronary spasm was not observed in the majority of the patients in our series. This could be due to the prophylactic i.v. nitroglycerine administration or due to the observation that ST elevation is not very sensitive to detect vasospasm, which might have resulted in an underestimation of peri-procedural coronary spasms. It could also

suggest that a part of the focal PFA energy is diminished, likely by the multiple tissue layers below the CTI, which may reduce the spasmic impact on the RCA.

Post-operative echocardiography showed no new kinetic disorders nor new impairment of systolic function or ECG changes. Based on this series, the occurrence of clinically relevant coronary spasm appears to be a complication limited to the procedural period: all patients were treated conservatively using titrated administration of nitroglycerin, no patient required coronary angiography. No repolarization abnormality persisted after the procedure and no acute coronary syndrome was identified during the routine clinical 3 months follow-up period. Preclinical models identified chronic neointimal hyperplasia, tunica media fibrosis and mild coronary artery narrowing as potential long-term complications. Conversely, a recent animal study revealed that these remodeling effects were present both with PFA (mono-/bi-polar) and RFA, and that this effect was independent of spastic phenomena during ablation[18]. Further preclinical studies and clinical studies with longer follow-up are warranted.

- Risk of conduction disorders

Our series revealed the occurrence of two transient complete AV blocks during the ablation procedure. The occurrence of conduction disorders during CTI ablation is very rare, but has been described previously, both for RFA[19] and PFA[20]. Although the exact mechanism of transient conduction disturbances is unclear, there are three hypotheses currently: the first is direct damage to the conduction tissue, particularly in the case of septal ablation. In our series, the His area was mapped prior to any ablation, and its position and that of the coronary sinus ostium were used in the electro-anatomical mapping system to define the septal portion of the atrium. The distance between the closest ablation point to the His bundle was 31 mm, making a direct effect unlikely. In fact, a series of AVNRT ablations has shown that PFA deliveries up to 2mm from the His was not associated with intraprocedural conduction disturbances[21,22]. The second hypothesis is that the parasympathetic ganglia, abundant in this region, might be affected, which could explain the transient nature of the conduction disorders identified in this series[23,24]. The third and maybe most plausible hypothesis is the occurrence of transient coronary spasm of the RCA. Furthermore, a more selective spastic effect of the small AV node artery is also possible.

As a novel finding, we document a more than 20 ms prolongation of the PQ time in some patients after CTI ablation using focal monopolar PFA, which is not transient but sustains at least for 3 months. This prolongation in PQ time occurred irrespective of complete AV blocks during the procedure. Importantly, similar sustained prolongation in PQ intervals was not observed after CTI ablation using RFA. The long-term evolution of these conduction disorders beyond the follow up of 3 months remains unclear and will warrant further evaluation.

- Implications for clinical practice

The herein described complications during CTI ablation procedures using focal monopolar PFA may have implications for the clinical ablation workflow. From a biophysical perspective, keeping a sufficient distance to the His area and limiting the PFA delivery close to the RCA should be able to reduce the risk of AV conduction impairment and coronary spasm. An adapted clinical pathway (**Figure 3**) starting the ablation line more lateral may help to keep a sufficient distance from the septum and the His region. As it is impossible not to cross the RCA during a CTI ablation, starting the ablation line with a lower PFA current of 22 A (7 pulse trains) for the first annular third of the line and continuing the ablation line with a higher PFA current of 25 A (10 pulse trains) for the remaining caval part of the CTI line can help to limit PFA delivery on the RCA. Coronary spasms and conduction disturbances are difficult to anticipate and operators must be aware of their possible occurrence as they need to be managed actively.

Limitations

A routine coronary angiogram to assess for coronary spasm was not performed. Therefore, the true prevalence of peri-procedural coronary spasms might have been underestimated, as ST elevation is not very sensitive and severe vasospasm is not always associated with ST elevation. Additionally, the follow up was limited to 3 months to look for coronary event and long term consequences following periprocedural coronary spasms remain unclear. Just one focal catheter with a specific monopolar PFA waveform was tested in this study. Whether the findings can be generalized to other PFA systems such as the bipolar pentaspline catheter or a lattice tip catheter is unclear.

Conclusion

CTI ablation using focal monopolar PFA is associated with a high rate of first-pass CTI conduction block in patients with typical atrial flutter as stand-alone procedure and in combination with AF ablation. However, despite preventive nitroglycerine administration, periprocedural conduction disorders and coronary spasms are rare but possible complications of which the operator must be aware. These findings highlight the need for greater understanding of the effect of focal monopolar PFA on coronary arteries as well as studying the progressive coronary damage and conduction disturbances.

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TABLES

Table 1: Patients characteristics. P value 1 compares the full PFA cohort (N=82) with the RFA cohort. P value 2 compares PFA subgroup (N=17) with the RFA cohort (multivariate comparison).

Patient characteristics	**PFA** **N=82**	**PFA subgroup** **N=17**	**RFA** **N=27**	**P value 1**	**P value 2**
Age, years	66±8	66±7	63±9	0.096	0.125
Female sex (%)	18	23	26	0.561	0.858
CHADS-VA	1.6±1.3	1.9±1.6	2±1.3	0.205	0.411
BMI, kg/m² **BMI > 25, n (%)**	27±5 45 (54)	27±3 13 (76)	28±4 20 (74)	0.017 0.117	0.191 0.858
Echocardiography data					
LVEF, % **LVEF < 50%, n (%)**	52±10 20 (24)	55±7 2 (12)	51±11 10 (37)	0.681 0.370	0.095 <0.001
LAVI, ml/m²	41±22	44±18	40±25	0.685	0.732

PFA=pulsed field ablation, RFA=radiofrequency ablation, BMI=body mass index, LVEF=left ventricular ejection fraction, LAVI=left atrial volume indexed

Table 2: Procedural data and feasibility data of CTI-ablation using PFA or RFA (multivariate comparison).

Procedure data	**PFA (N=82)**	**RFA (N=27)**	**P value**
General information			
Anesthesia			0.33
General, n (%)	71 (87)	23 (85)	
Deep sedation	11 (13)	3 (11)	
Local anesthesia	0 (0)	1 (4)	
Navigation system			0.003
Carto	80 (98)	21 (78)	
EnsiteX	2 (2)	6 (22)	
Ablation set			
CTI alone, n (%)	15 (18)	1 (4)	0.113
CTI+, n (%)	67 (82)	26 (96)	0.113
PVI, n (%)	62 (76)	22 (81)	
Other, n (%)	12 (15)	11 (41)	
CTI ablation			
Duration, min	7 [5,11]	17 [14,19]	<0.0001
Ablation time, sec	110 [80,130]	649 [568,705]	<0.0001
Distance to the His, mm	37 [35,42]	ND	
Line length, mm	29 [24,34]	31 [27,33]	0.7873
Ablation points, n	11 [9,14]	17 [12,20]	<0.0001
Ablation points/cm	4 [3.2,4.5]	5.5 [4.3,6.6]	<0.0001
First pass block, n (%)	76 (93)	15 (55)	<0.0001
Bidirectional block, n (%)	82 (100)	27 (100)	1

PFA=pulsed field ablation, RFA=radiofrequency ablation, CTI=cavotricuspid isthmus, PVI=pulmonary vein isolation.

Table 3: Detailed procedural characteristics of patients presenting coronary spasm.

	# 1	**# 2**	**# 3**	**# 4**
ST elevation	Yes (inferior)	Yes (inferior)	Yes (inferior)	Yes (inferior)
Duration	5 min	2 min	5 min	15 min
Nitroglycerine				
Prophylactic	150 µg	400 µg	200 µg	400 µg
Additional	450 µg	200 µg	200 µg	1000 µg
Previous CAD	No	No	No	No
Switch to RFA	Yes	No	No	Yes

CAD=coronary artery disease, RFA=radiofrequency ablation

Table 4: Conduction disturbances during the procedure and at 3 months follow up in patients undergoing CTI-ablation using pulsed field ablation (PFA) or radiofrequency ablation (RFA) (multivariate comparison).

Conduction disorders	**PFA**	**RFA**	**P value**
Total AVB	N=82	N=27	
Per-procedure, n (%)	2 (2)	0 (0)	0.843
Post-procedure, n (%)	0 (0)	0 (0)	1
PR prolongation	*N=17*	*N=27*	
Post-procedure, n (%)	4 (24)	0 (0)	0.018
3 months, n (%)	4 (24)	0 (0)	0.018
QRS widening	*N=17*	*N=27*	
Post-procedure, n (%)	0 (0)	0 (0)	1
3 months, n (%)	0 (0)	0 (0)	1

PFA=pulsed field ablation, RFA=radiofrequency ablation, AVB=atrioventricular block

Table 5: Detailed procedural characteristics of patients presenting conduction disorders.

	# 1	**# 2**	**# 3**	**# 4**	**# 5**	**# 6**
Complete AVB	Yes	Yes	No	No	No	No
PR prolongation	No	No	Yes	Yes	Yes	Yes
Block duration	<1min*	2 beats	>3months	>3months	>3months	>3months
HV - pre - post	na	50 ms 50 ms	na	na	na	na
Escape rhythm	No	No	na	na	na	na
Switch to RFA	No	Yes	No	No	No	No
Nitroglycerine prophylactic	200µg	100µg	150µg	150µg	150µg	150µg
Details	1st ablation: PVI / PWI / CTI	1st ablation: PVI / CTI	1st ablation: PVI / PWI / CTI	4th ablation: PWI / MAL / CTI	1st ablation: PVI / PWI / CTI	3rd ablation: PVI / CTI

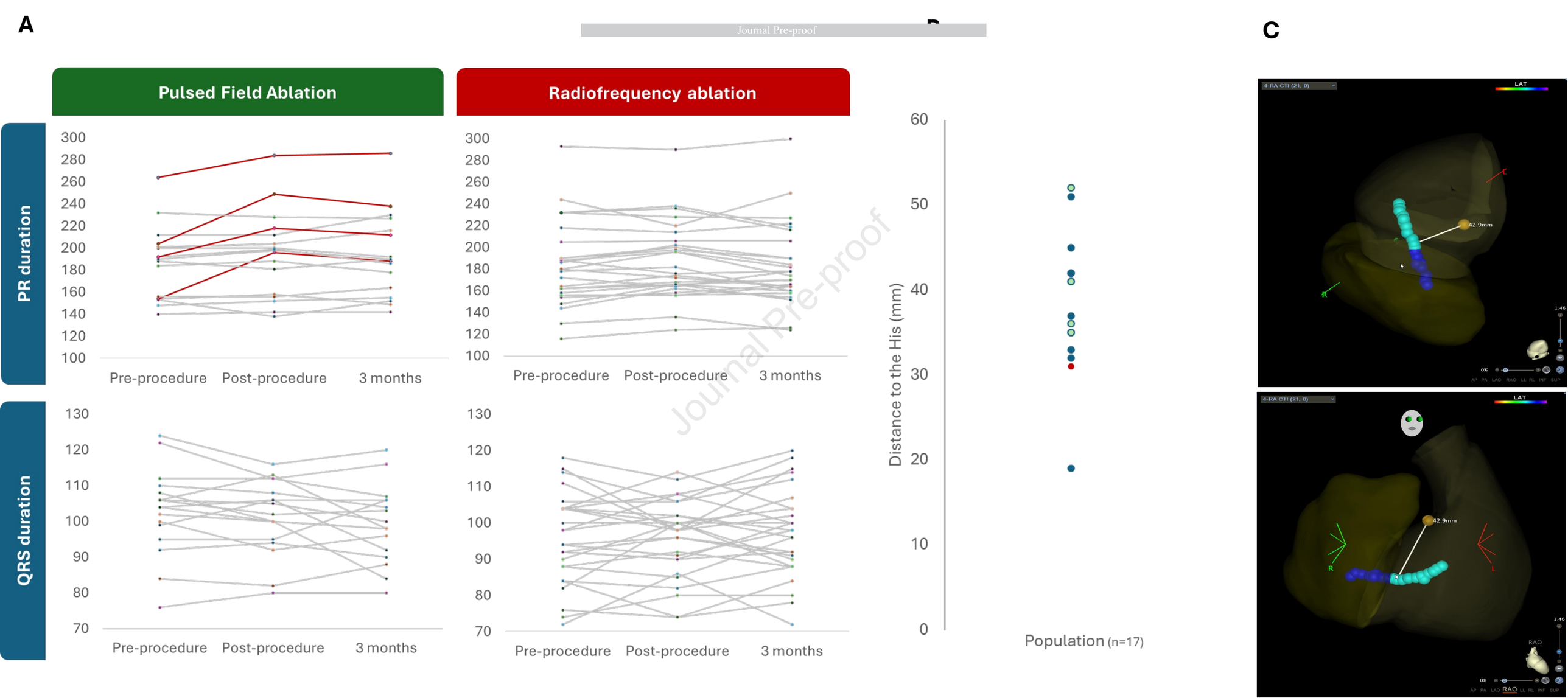
*AVB=AV block, CTI=cavo-tricuspid isthmus, MAL=mitral anterior line, PVI=pulmonary vein isolation, PWI=posterior wall isolation, RFA=radiofrequency ablation. *RV pacing was performed for rhythm and hemodynamic stabilization.*

FIGURES

Figure 1. A) PQ and QRS duration before, immediately after and at 3 months after the ablation procedure in the RFA group and the PFA subgroup. In the absence of significant modification comparing to the initial situation, the line is grey. In case of significant modification, the line is red. Four patients presented significant PR prolongation in the PFA sub-group. **B)** Distance of the CTI line to the His region in the PFA sub-group. The red point is a patient with transient total AV block during procedure, the green points are 4 patients presenting PR prolongation and the blue points are patients without conduction disturbances. **C)** Representative CT anatomy merged with the ablation tags and the Bundle of His location derived from the electroanatomical map to determine the distance between the CTI line and HIS region (upper: left anterior oblique from below. Below: right anterior oblique).

Figure 2. **A**) Representative coronary anatomy derived from CT angiogram merged with the ablation tags and derived from the electroanatomical map to determine the distance between the ablation line and the right coronary artery (A: from left anterior oblique. B: from right anterior oblique). **B**) Distance of the CTI line to the RCA in the PFA sub-group. The red point is a patient with transient coronary spasm during the ablation procedure. RCA=right coronary artery, X=distance between ablation line and right coronary artery.

Figure 3. A segmented pre-procedural CT angiogram aligned with the CTI ablation line derived from the procedural electroanatomical map. Note the relatively lateral position of the CTI ablation line with lower 22A PFA delivery in the antral part of the CTI up to the RCA and then higher 25A PFA delivery in the caval part of the CTI. The goal is to reduce PFA delivery close to the RCA and His area.



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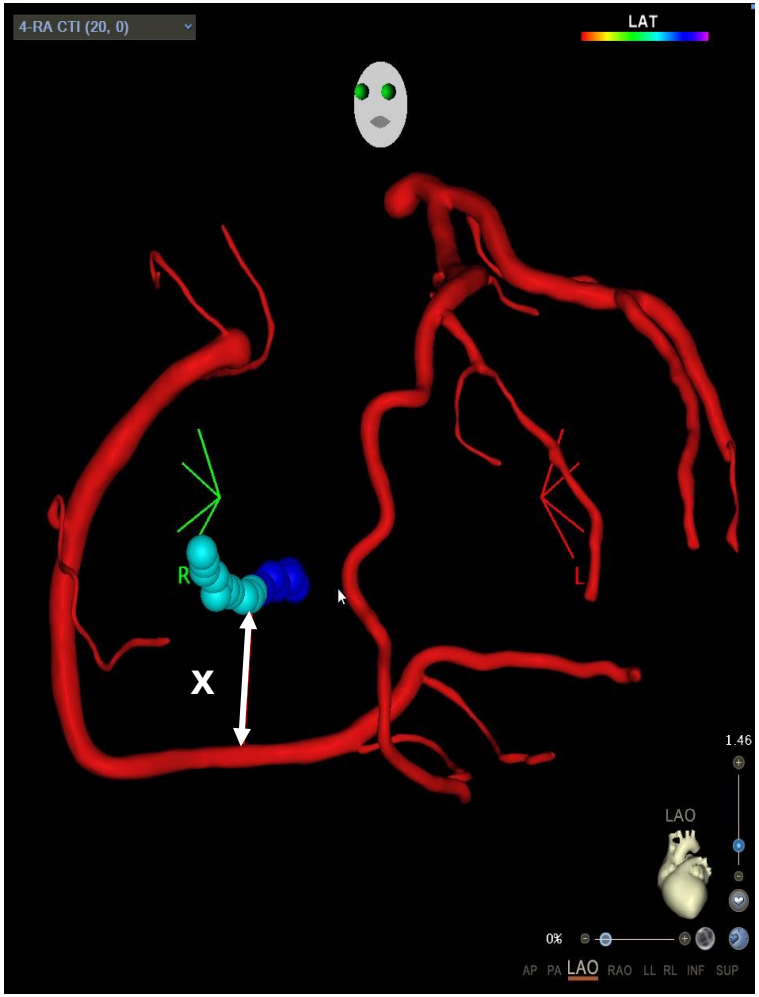

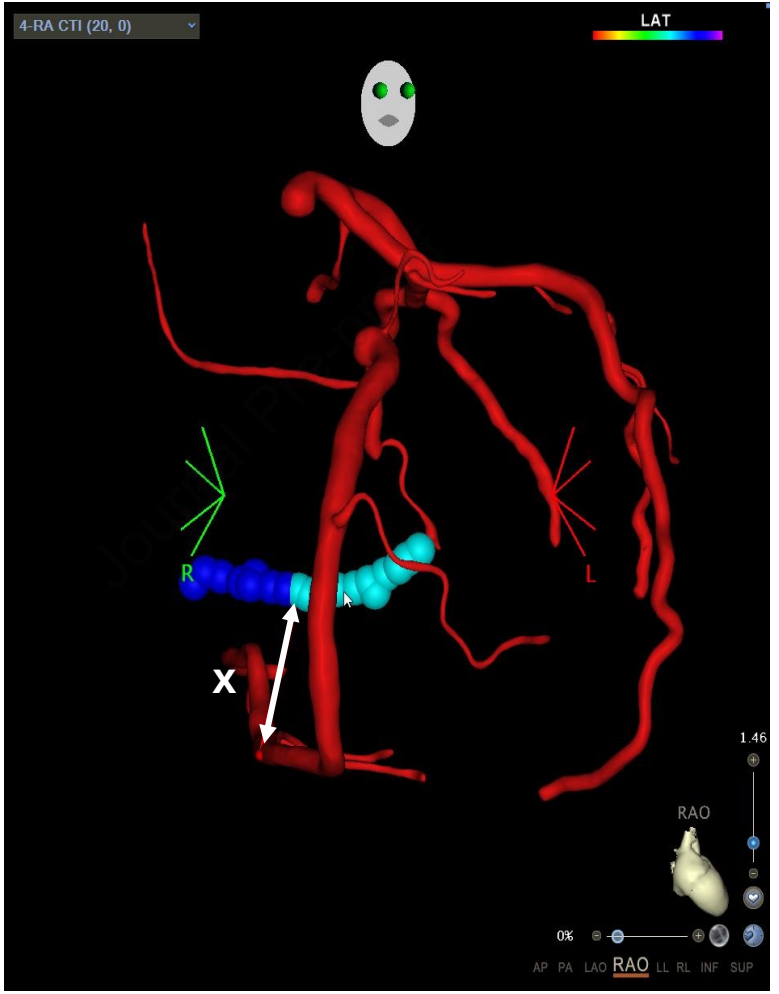

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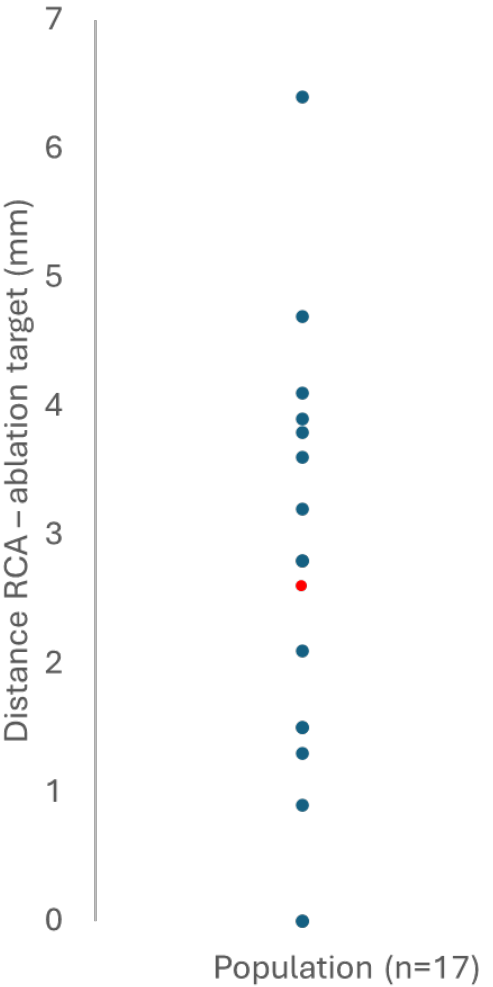

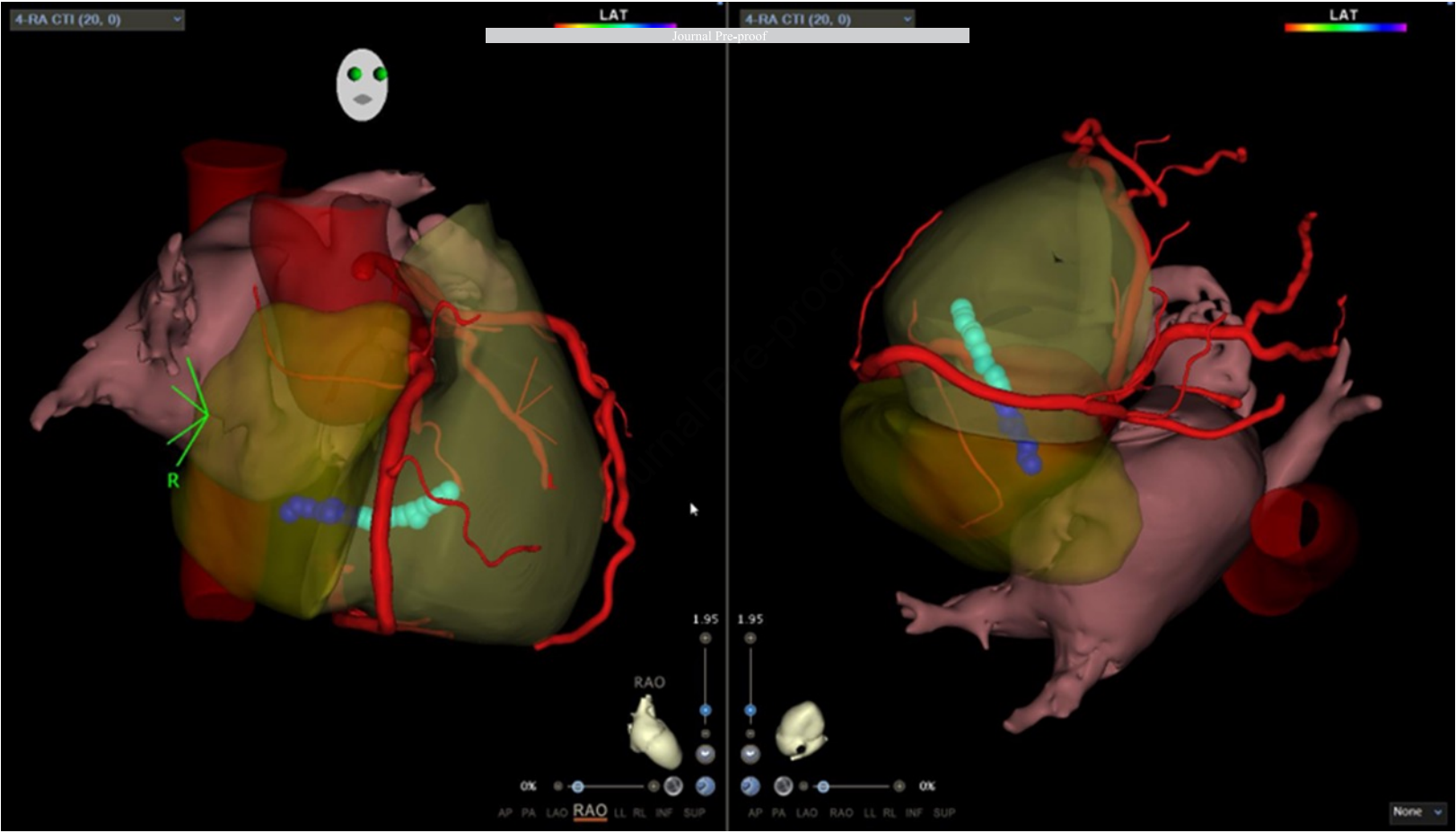

Supplemental Material

Figure S1 Distribution of analysis performed in the different subgroups.