Assessing the perforation site of cardiac tamponade during radiofrequency catheter ablation using gas analysis of pericardial effusion

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BACKGROUND The incidence of pericardial effusion (PE) during radiofrequency catheter ablation (CA) for atrial fibrillation is approximately 1%. PE is a major complication during CA, but there has been limited literature about the perforation site responsible.

OBJECTIVE This study aimed to retrospectively investigate the characteristics of the procedure and the patients in whom PE developed during CA.

METHODS Of 1363 consecutive patients who underwent catheter ablation from January 2015 to June 2019 in Kyorin University Hospital, we reviewed patients who developed PE during CA.

RESULTS PE during CA occurred in 18 (1.32%) patients (median age, 71 [interquartile range (IQR) 65–77] years, 7 women). The median body mass index was 24 (IQR 20–27). Target arrhythmias for CA of patients with PE include atrial fibrillation (AF) (n = 13, 72%), premature ventricular contraction (n = 2, 11%), ventricular tachycardia (n = 1, 6%), atrial flutter (n = 1, 6%), and orthodromic reciprocating tachycardia (n = 1, 6%). Seventeen patients required pericardiocentesis, resulting in 300 (IQR 192.5–475) mL of drainage. Two patients required emergency surgical repair, and 1 died from aortic dissection. Based on the gas analysis, the drained blood was of venous origin in 47% of the total events and 54% of AF ablation.

CONCLUSION PE caused by a diagnostic catheter in the right heart is not uncommon, even in AF ablation.

KEYWORDS Atrial fibrillation; Catheter ablation; Gas analysis; Pericardial effusion; Pericardiocentesis

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Introduction

Pericardial effusion (PE) due to cardiac perforation is a known major complication of radiofrequency (RF) catheter ablation (CA). The reported incidence of PE during CA was 0.5%–4.0% for atrial fibrillation (AF)[1,2] and 2% for ventricular tachycardia (VT).[3,4] It can be caused by mechanical trauma during catheter manipulation, inadvertent injury during transseptal puncture, or steam pop during CA. The majority of PE cases are usually controlled by pericardiocentesis, but some require emergency surgical repair and blood transfusion. Only a limited number of studies identified the perforation site either by emergency surgery or by coronary angiography.[5–7] There is a paucity of data on the perforation site in patients who developed PE during CA. In a report by Bunch and colleagues,[7] 2 of 15 patients who required open surgery had a perforation site at the left atrial dome, but the perforation site was not evaluated in the remaining patients. We sought to investigate the characteristics of procedures and patients with PE and retrospectively identify the possible perforation site using gas analysis of PE.

Methods

Study population

The clinical description of this research was approved by the Institutional Review Board of Kyorin University Hospital. Written informed consent was obtained from each patient. We reviewed 1363 consecutive patients who underwent CA from January 2015 to June 2019 in our hospital. Of these patients, 18 patients who developed PE were retrospectively analyzed.

Set-up and workflow

All procedures were performed under mild-to-moderate conscious sedation using dexmedetomidine, fentanyl, and thiopental. All patients had continuous arterial blood pressure monitored with an arterial line and received oxygen (5 L/min) either with a face mask or noninvasive positive-pressure ventilation in case of sleep apnea syndrome. Our usual

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KEY FINDINGS

- Gas analysis of the pericardial effusion during catheter ablation, including atrial fibrillation ablation, revealed that almost half of the blood was of venous origin.
- In half of the cases, pericardial effusion detection was not timed with catheter manipulation; 11% was after cardioversion, 11% during programmed stimulation, and 28% during hemostasis at the procedure's end.
- Care should be taken in the catheters' position during cardioversion, mapping, or manipulation as a left heart ablation may cause perforation in the right heart.

practice has been to skip anticoagulation on the morning of CA, except for patients on warfarin or patients on direct oral anticoagulant with a history of stroke or low left atrial appendage blood flow velocity. Unfractionated heparin was administered during the left heart CA to maintain the activated clotting time (ACT) of ≥300 seconds. Diagnostic catheters were introduced via femoral and internal jugular veins and positioned at the coronary sinus (CS), tricuspid annulus, His recording site, and right ventricle (RV) apex according to the physician's decision. A 3-dimensional electroanatomic mapping system was created using CARTO (Biosense Webster, Diamond Bar, CA), Ensite (Abbott Laboratories, Chicago, IL), or Rhythmia (Boston Scientific, Cambridge, MA), except in patients who were ablated using the cryoballoon system. As per our safety protocol, we used intracardiac echocardiography (ICE) just for the transseptal puncture and usually remove it prior to the insertion of the ablation catheter to minimize venous access.

Management of PE

Patients were monitored with continuous arterial pressure monitoring. Our usual practice is to check the heart border motion in left anterior oblique (LAO) view if the blood pressure declines. If reduced cardiac motion was recognized, transthoracic echocardiography or ICE was used to check the PE. If cardiac tamponade was identified, pericardiocentesis via the subxiphoid and drainage were performed with volume expansion and administration of norepinephrine. If unfractionated heparin was used during the procedure, protamine was administered intravenously to reverse anticoagulation. If the bleeding was not controlled, blood transfusion and emergency surgical repair were performed. Continuation of the procedure was decided by the physician according to the patient's condition.

Gas analysis of PE and blood

We evaluated whether there was a difference of more than 36.9 mm Hg in pO_2 between PE and peripheral venous blood gas, which was sampled at the same time of PE drainage,[8] except in the case where PE could be clearly assessed as of venous origin from the pO_2 value. If peripheral venous blood gas was not collected at the time, we set pO_2 > 55 mm Hg and $sO_2 > 84\%$ as the cut-off for arterial origin.

Statistical analysis

For descriptive statistics, numbers were stated as the exact number or percentage. Continuous variables were reported as median and first and third interquartile range (IQR).

Results

Of 1363 patients who underwent CA, 18 (1.32%) patients developed PE during the procedures, and PE was seen in 1.30% of atrial tachycardia / AF ablation, 1.75% of atrial flutter ablation, 2.13% of atrioventricular reentrant tachycardia ablation, and 1.83% of VT / premature ventricular contraction (PVC) ablation. Of the patients who underwent atrial tachycardia / AF ablation, 91.5% were taking direct oral anticoagulants. Characteristics of the 18 patients with PE are shown in Table 1. All events were detected in the catheter laboratory and no subsequent or chronic PE was observed. The median age was 71 years (IQR 65–77), and 7 (39%) were women. The median body mass index was 24 (IQR 20–27), and 2 patients had sleep apnea syndrome. Sixteen (89%) patients were on anticoagulants and 1 (6%) patient was taking antiplatelets. Target arrhythmias for CA of patients with PE were AF in 13 (72%), PVC in 2 (11%), VT associated with nonischemic cardiomyopathy in 1 (6%), atrial flutter in 1 (6%), and orthodromic reciprocation tachycardia in 1 (6%) (Figure 1). One patient treated with a cryoballoon catheter developed PE. Characteristics of the procedures and outcomes are shown in Table 2. Diagnostic catheters were positioned at the His recording area in 1 case, at His-RV in 14, at CS in 17 cases, and at Halo in 1 patient. Multipolar mapping catheter was used in 17 (94%) procedures. For the ablation catheter, 10 (56%) with contact force and 8 (44%) without contact force were used. The median of the last ACT prior to the cardiac tamponade was 271 (IQR 245–296) seconds. Seventeen (94%) patients required pericardiocentesis, resulting in 300 (IQR 192.5–475) mL of drainage. Two (11%) patients required emergency surgical repairs, and 1 (6%) patient died from tamponade caused by the incidental aortic dissection despite attempts at emergency surgical repair. Reasons for PE identification were declined blood pressure in 15 (83%) and reduced cardiac motion in the LAO view in 3 (17%).

Timing of the PE detection

Figure 2 summarizes the timing of PE detection. PE was recognized during mapping in 2 (11%), during CA in 4 (22%), after cardioversion in 2 (11%), during induction by burst pacing and program stimulation in 2 (11%), post CA mapping in 3 (17%), and at the time of sheath extraction post procedure in 5 (28%) patients. Of these patients, 3 (patients 1, 2, and 8) had ICE catheter placement during the

Table 1 Characteristics of patients with pericardial effusion

Pt	Age (years)	Sex	BMI	Dx	Heart disease	LVEF (%)	Anti coagulants		Antiplatelets	Deep sedation	SAS	Comorbidity	BNP (pg/mL)	Risk score*
							DOAC	WF						
1	65	M	27.3	AF		62	+	-	-	+	+	HTN, DM	75.5	2
2	70	F	19.3	AF		61	+	-	-	-	-	-	30.7	2
3	64	F	17.5	AF		62	-	+	-	-	-	-	1086	3
4	68	F	27.5	AF		58	+	-	-	-	-	HTN	22.9	2
5	72	M	26.3	AF		65	+	-	-	-	-	HTN	30.3	1
6	79	M	23.5	AF		54	+	-	-	-	-	HTN	71.1	1
7	81	F	25.3	AF		58	+	-	-	+	-	HTN	47.1	3
8	73	F	21.3	AF		63	+	-	-	+	-	HTN	228	3
9	78	F	22.6	AF		63	+	-	-	-	-	HTN	43.1	2
10	72	M	25.2	VT	NICM	57	-	+	-	-	-	-	444	1
11	55	M	17.8	PVC	Post PVI	54	-	-	-	-	-	-	15.8	0
12	76	M	19.9	AF		60	+	-	-	-	-	HTN	339	1
13	78	F	30.3	AF		62	+	-	-	-	-	HTN	17.2	2
14	69	M	24.9	PVC		48	+	-	-	-	-	-	62.5	1
15	69	M	20.4	AFL	OMI	66	+	-	+	-	-	HTN, DM	5.1	0
16	60	M	23.3	ORT		61	-	-	-	-	-	-	40	0
17	71	M	29.7	AF		71	+	-	-	-	+	-	25.1	1
18	61	M	24.2	AF		60	+	-	-	+	-	HTN	83.7	2

AF = atrial fibrillation; AFL = atrial flutter; BMI = body mass index; BNP = brain natriuretic peptide; DM = diabetes mellitus; DOAC = direct oral anticoagulant; Dx = diagnosis; HTN = hypertension; Hx = history; LVEF = left ventricular ejection fraction; NICM = nonischemic cardiomyopathy; OMI = old myocardial infarction; ORT = orthodromic reciprocating tachycardia; Pt = patient; PVC = premature ventricular contraction; PVI = pulmonary vein isolation; SAS = sleep apnea syndrome; VT = ventricular tachycardia; WF =warfarin.

*Risk scores include deep sedation, reduced left ventricular function, warfarin, atrial fibrillation, and female sex.

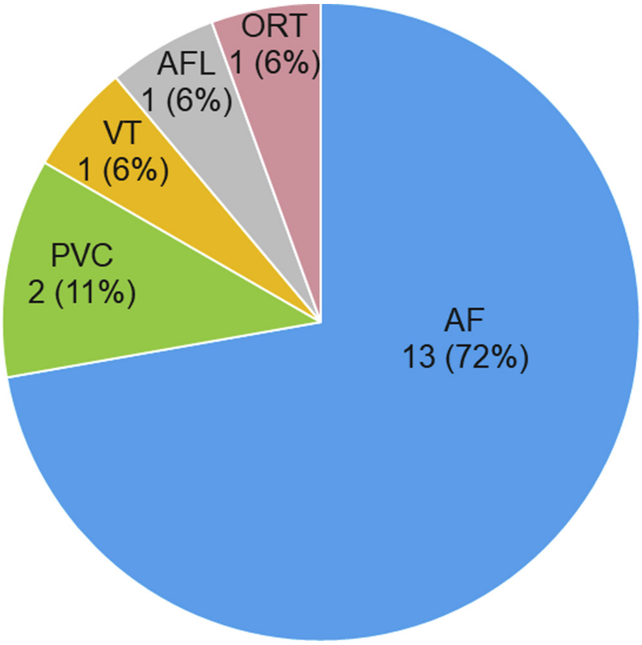

Figure 1 Target arrhythmias for catheter ablation of patients with pericardial effusion. Ventricular tachycardia was associated with nonischemic cardiomyopathy. AF = atrial fibrillation; AFL = atrial flutter; ORT = orthodromic reciprocating tachycardia; PVC = premature ventricular contraction; VT = ventricular tachycardia.

ablation, and PE was detected by ICE. One patient had more obvious PE with transthoracic echo than with ICE. Of 17 patients who had pericardiocentesis, 47% were of venous origin (Supplemental Table). In patients with CA for AF, 54% were of venous origin (Figure 3). Of the 15 patients who underwent AF ablation, 3 had cavotricuspid isthmus (CTI) ablation and/or superior vena cava (SVC) isolation (patients 6, 7, and 18). One patient developed PE during pulmonary vein isolation (patient 18), but pericardiocentesis stabilized the patient's condition; therefore, CTI ablation was completed. In 2 patients, following CTI and SVC ablation, cardioversion was performed. After the cardioversion, they became hypotensive, and PE was detected. We compared the time from echo detection of the PE to pericardiocentesis. The interval was similar (median, 7.5 minutes in venous origin [IQR 5.25–22] vs 6 minutes in arterial origin [IQR 2–13.5], $P = .40$).

Procedure outcome

Five patients with PE resulted in failure as ablation outcome. One patient died from aortic dissection during the procedure despite emergency open heart surgery. Another patient with VT associated with nonischemic cardiomyopathy underwent CA of VT in the left ventricular endocardium after blood pressure was controlled by pericardiocentesis; however, inducibility of VT remained. In 2 patients with AF, PE was recognized after left pulmonary vein isolation, and further ablation was deferred to prevent recurrent hemorrhage with continuous anticoagulation. Of 3 AF patients, 2 underwent a second session later, which was successful.

Discussion

This study showed 2 important clinical findings: (1) gas analysis of PE during CA revealed that almost half of the drained blood was of venous origin even in AF ablation, and (2) in half of the cases, PE detection was not timed with catheter manipulation: 11% was after cardioversion, 11% was during the program stimulation for induction, and 28% was identified at the procedure end during hemostasis.

One study compared the blood gas analysis between the central vein and the PE upon pericardiocentesis.[9] Gas analysis of PE, some of which were subacute in nature, such as following open heart surgery, showed higher pCO_2, similar hematocrit, and lower pO_2 than the venous blood. In our series, PE was acute in nature, but pO_2 higher than the venous blood supports the arterial origin of the hemorrhage. The visualized site of perforation correlated with the gas analysis of PE in 2 patients, which might support that gas analysis helps in identifying the perforation site. Despite the usual assumption of the dominant perforation site being the left atrium for AF ablation, our study showed that over half of the cases were in the right heart, suggesting that the diagnostic catheters in the right atrium or ventricle might be responsible for the perforation. The timing of PE identification can be done anytime during the procedure, and not predominantly during RF delivery, which also supports diagnostic catheter involvement. As regards AF patients who underwent not only pulmonary vein isolation but CTI ablation and/or SVC isolation, the perforation by ablation catheter during CTI and/or SVC RF application cannot be denied. However, 5 of 12 patients who had not undergone CTI ablation and/or SVC isolation showed venous-origin blood gas, so it may be important to pay attention to catheters other than the one being manipulated. It is difficult to identify the perforation site in 1 place, except for patients with surgical repairs, because all patients who showed venous blood gas of PE used multiple diagnostic catheters for the right heart in this study. To avoid cardiac perforation, we should minimize the use of catheters as far as possible. Our usual protocol for AF ablation included adenosine triphosphate bolus to check for the dormant conduction of the pulmonary vein. Therefore, we usually use the RV catheter. We can consider the use of the RV catheter if the ventricle cannot be captured by the CS catheter. Deep sedation, reduced left ventricular function, warfarin, AF, and female sex have been reported as risk factors for PE.[2,10] Of these 5 risks, they distributed from 0 to 3 points in this study. Another paper reported that no significant factors are associated with the occurrence of tamponade, including age, body mass index, sex, AF type, left atrial dimension, use of an RF needle, operators, peak ACT, and direct oral anticoagulant use except for the use of a cryoballoon.[11] If cardiac perforation occurs, early detection of PE can prevent life-threatening cardiac tamponade. Continuous blood pressure monitoring and periodic check of cardiac motion in LAO view are useful. Given the advances in 3-dimensional electroanatomic mapping

Table 2 Procedural characteristics

Pt	Diagnostic catheter				Multipolar mapping catheter	ABL Catheter	Heparin	ACT (s) peak/last	Reasons of PE identification	Pericardio centesis	Drained blood (mL)	Gas analysis of PE	Surgery	ABL outcome	Outcome
	His	RV	CS	Halo											
1	-	+	+	-	+	CF+	+	260/N.A.	Declined BP	+	800	Artery	-	Failure	Survived
2	-	+	+	-	+	CF+	+	333/333	LAO motion	+	190	Vein	-	Success	Survived
3	-	+	+	-	+	CF-	+	303/N.A.	Declined BP	+	200	Vein	-	Success	Survived
4	-	+	+	-	+	CF-	+	291/291	Declined BP	+	125	Vein	-	Success	Survived
5	-	+	+	-	+	CF-	+	254/244	Declined BP	+	131	Vein	-	Success	Survived
6	-	+	+	-	+	CF-	+	306/294	Declined BP	+	650	Vein	-	Success	Survived
7	-	+	+	-	+	CF+	+	279/N.A.	Declined BP	+	100	Vein	-	Success	Survived
8	-	+	+	-	+	CF+	+	263/224	Declined BP	+	400	Artery	-	Failure	Survived
9	-	+	+	-	+	Balloon	+	304/252	Declined BP	+	250	Artery	-	Success	Survived
10	-	+	+	-	+	CF-	+	287/287	Declined BP	+	500	Artery	-	Failure	Survived
11	-	-	+	-	+	CF-	-	Not tested	Declined BP	-	-	-	-	Success	Survived
12	-	+	+	-	+	CF+	+	313/298	LAO motion	+	400	Vein	-	Success	Survived
13	-	+	+	-	+	CF+	+	347/N.A.	Declined BP	+	300	Artery	-	Failure	Dead
14	-	-	+	-	+	CF+	+	311/271	Declined BP	+	N.A.	Artery	+	Failure	Survived
15	-	+	-	+	+	CF-	+	339/230	Declined BP	+	1000	Vein	+	Success	Survived
16	+	+	+	-	-	CF+	+	249/249	Declined BP	+	300	Artery	-	Success	Survived
17	-	-	+	-	+	CF+	+	330/330	LAO motion	+	300	Artery	-	Success	Survived
18	-	-	+	-	+	CF+	+	315/246	Declined BP	+	300	Artery	-	Success	Survived

ABL = ablation; ACT = activated clotting time; BP = blood pressure; CF = contact force; CS = coronary sinus; LAO = left anterior oblique; N.A. = not available; PE = pericardial effusion; Pt = patient; RV = right ventricle.

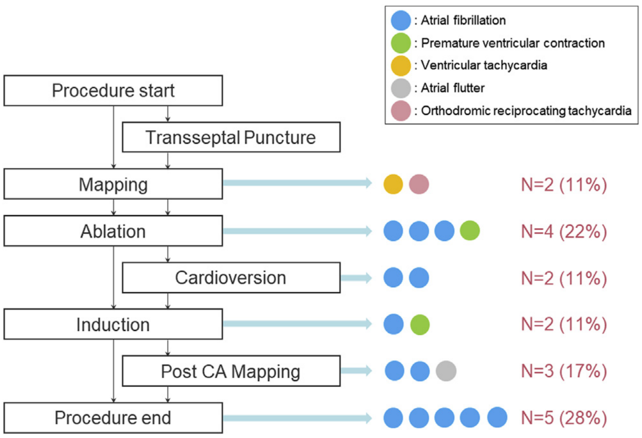

Figure 2 Timing of pericardial effusion detection. The timing of the pericardial effusion detection is depicted with tags. Blue tag represents atrial fibrillation, green tag represents premature ventricular contraction, yellow tag represents ventricular tachycardia, gray tag represents atrial flutter, and pink tag represents orthodromic reciprocating tachycardia. CA = catheter ablation.

system and the ALARA ("as low as reasonably achievable") principle, fluoroscopy use is minimized, and PE is more likely detected by blood pressure decline rather than decreased cardiac motion. In addition, ICE is useful for early detection of PE.

In this study, 1 patient died from massive PE caused by the aortic dissection. He underwent CA of the PVC, and mapping was performed retrogradely in the left ventricle and the aortic cusp. Following the successful RF ablation, reduced cardiac motion in LAO view was noticed and echocardiography showed massive PE. Immediate pericardiocentesis was unable to control the bleeding, and emergency open heart surgery was performed. However, the patient died. Autopsy showed aortic dissection from the ascending aorta to the bifurcation of the common iliac artery with severe atherosclerosis at the arch. The dissection could have been spontaneous or caused by mechanical stress. Despite detailed analysis of the autopsy, the cause remained unclear.

Study limitations

If arterial and venous blood are mixed through the transseptal route, it may not be accurate to identify the perforation site using only gas analysis data. However, this phenomenon is unlikely without frequent sheath or catheter removal from the left atrium. The pO_2 value in inferior pulmonary veins has been reported lower than superior pulmonary veins, and it is possible that the pO_2 value might be lower if the perforation occurs close to the ostium of inferior pulmonary veins.[12] Second, it is unclear whether normal blood gas analysis can be applied to the accumulated PE. The reliability of the gas analysis of PE is not definite, as there were only 2 cases with visually confirmed site of perforation. Third, based on the small number of patients with PE, it is difficult to extract real trends of perforation site during various ablations.

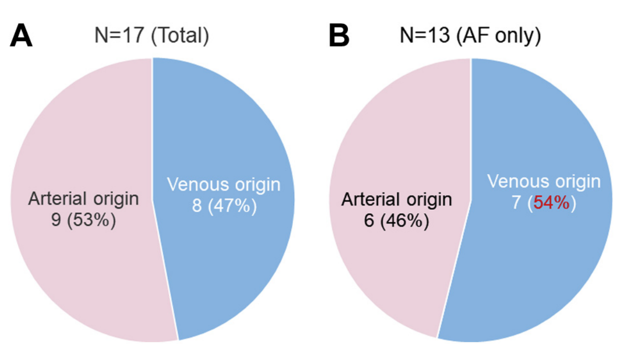

Figure 3 Gas analysis of pericardial effusion. **A:** Percentage of gas analysis of the pericardial effusion of all patients with pericardiocentesis. **B:** Percentage of gas analysis of the pericardial effusion in atrial fibrillation (AF).

Clinical implication

Care should be paid to the catheter position during cardioversion, mapping, or manipulation, since even the left heart ablation might cause perforation from the right heart.

Conclusion

PE caused by a diagnostic catheter seems to be common, even in AF ablation.

Acknowledgments

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Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hroo.2020.06.005.

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