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Review Article

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Intra-arrest transesophageal echocardiography during cardiopulmonary resuscitation

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Determining the cause of cardiac arrest (CA) and the heart status during CA is crucial for its treatment. Transesophageal echocardiography (TEE) is an imaging method that facilitates close observation of the heart without interfering with cardiopulmonary resuscitation (CPR). Intra-arrest TEE is a point-of-care ultrasound technique that is used during CPR. Intra-arrest TEE is performed to diagnose the cause of CA, determine the presence of cardiac contraction, evaluate the quality of CPR, assist with catheter insertion, and explore the mechanism of blood flow during CPR. The common causes of CA diagnosed using intra-arrest TEE include cardiac tamponade, aortic dissection, pulmonary embolism, and intracardiac thrombus, which can be observed on a few simple image planes at the mid-esophageal and upper esophageal positions. To operate an intra-arrest TEE program, it is necessary to secure a physician who is capable of performing TEE, provide appropriate training, establish implementation protocols, and prepare a plan in collaboration with the CPR team.

Keywords Transesophageal echocardiography; Heart arrest; Cardiopulmonary resuscitation

Capsule Summary

What is already known

The use of point-of-care ultrasound during cardiopulmonary resuscitation (CPR) has been suggested.

What is new in the current study

Intra-arrest transesophageal echocardiography can be used as a point-of-care ultrasound method to diagnose the cause of cardiac arrest, determine the presence of cardiac contractions, evaluate the quality of CPR, assist with catheter insertion, and explore the mechanism of blood flow during CPR.

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INTRODUCTION

Transesophageal echocardiography (TEE) is a diagnostic tool that can obtain images of the heart from its nearest location. It provides numerous types of echocardiographic information, including two-dimensional or three-dimensional images, M-mode, color flow imaging, Doppler studies, and related calculations, such as transthoracic echocardiography (TTE). Compared with TTE, TEE provides excellent echocardiographic windows to the heart regardless of the patient's body type. Despite its advantages, TEE has rarely been used in patients with cardiovascular emergencies in the emergency department (ED) when it was initially introduced into clinical practice. TEE in the ED has been used in urgent situations such as cardiac arrest (CA). Recent cardiopulmonary resuscitation (CPR) guidelines recommend or suggest the use of point-of-care ultrasound as a method to determine the reversible cause of CA during CPR, thus encouraging the use of echocardiography during the performance of advanced life support.[1,2]

TTE is an easy and simple method for point-of-care ultrasound during resuscitation. However, it is not suitable for close inspection of the heart while chest compressions are being performed. By employing TEE, rescuers can continuously observe the heart without interfering with CPR because the probe is located in the esophagus. Owing to the increasing use of TEE during resuscitation (intra-arrest TEE), the American College of Emergency Physicians and the American Society of Echocardiography have jointly published guidelines for point-of-care applications in CA resuscitation.[3] Since the publication of these guidelines, considerable experience has been accumulated with TEE during CPR. Korea, one of the first countries to use TEE in the ED, began employing TEE accordingly in 1992.[4] Recently, almost all EDs in Korea have been equipped with echocardiography machines; the remaining EDs are being prepared to support it. However, considering limitations in professional human resources and procedural time, it is unreasonable to conduct a comprehensive TEE study in the ED. By contrast, intra-arrest TEE as a point-of-care ultrasound is feasible in the ED and can be helpful in resuscitating patients who experienced CA. This review is intended to provide an overview of the practical use of intra-arrest TEE in emergency medicine.

INDICATIONS AND PREVIOUS EXPERIENCES

Intra-arrest TEE is performed to explore the mechanism of blood flow during CPR, diagnose the possible cause of CA, monitor the presence of cardiac contraction, assess the effectiveness of chest compression, guide catheter cannulation, and evaluate the complications of CPR. Table 1 summarizes the indications and objectives of intra-arrest TEE and the echocardiographic findings of intra-arrest TEE in the literature.[5-47]

PREPARATION FOR INTRA-ARREST TEE

Multiple factors should be considered when implementing intra-arrest TEE in the ED. These include the cost of the equipment; equipment maintenance, including probe disinfection; the input of additional personnel and technical training; evaluation of the operation quality; and collaboration with experts from other clinical fields, including cardiology.[48] For intra-arrest TEE, the TEE probe and related software must be purchased together with the echocardiography machine. The most appropriate area to place the echocardiography machine is a room in the resuscitation area. Drugs and devices for intensive monitoring and advanced life support, including airway support, defibrillation, and emergency medications, should be available at all times during TEE. According to Spaulding's classification for disinfection and sterilization of patient care items and equipment, the TEE probe is classified as a semi-critical instrument with an endoscope. Cleaning and disinfection after every use are required according to these guidelines.[49,50]

TEE should be performed by physicians who have (1) knowledge of cardiovascular anatomy and physiology, (2) knowledge of echocardiographic imaging, (3) proficiency and experience in performing TTE and TEE procedures, (4) knowledge required for interpretation of TEE results, and (5) knowledge of the management of TEE equipment and related instruments.[51] Considering these requirements, the guidelines recommend supervised performance and interpretation of at least 50 to 100 TEE procedures prior to the independent undertaking of TEE.[52-54] The American College of Emergency Physicians recommends a minimum of 10 proctored TEE examinations on live patients and simulation models with TEE-specific continuing medical education for the use of TEE in the ED for ultrasound-guided resuscitation during or after CA.[55] Therefore, emergency physicians performing TEE in the ED should have the qualifications for performing echocardiography, skills for TEE procedures, and competent TEE experience. Echocardiography is an operator-dependent procedure; therefore, the operator should conduct the procedure only after becoming certain that he or she can perform TEE on his or her own with consideration of the patient's safety. Lack of substantial training may result in misdiagnosis or misinterpretation of echocardiographic findings, possibly causing catastrophic outcomes.

INTRA-ARREST TEE PROCEDURE

A physician who is capable of performing TEE and is not part of

Table 1. Indications and findings of intra-arrest TEE in the literature

Study	Study type	No. of patients[a)]	Indication/objective[b)]	Main echocardiographic finding
Higano et al.[5] (1990)	Case report	2	Exploratory	Compression of RV and LV and closure of MV during compression
Kuhn et al.[6] (1991)	Case report	1	Exploratory	Opening of AV during thoracic compression with simultaneous closure of mitral and tricuspid valves
Porter et al.[7] (1992)	Prospective observational	17	Exploratory	Closure of MV during downstroke of chest compression and absence of correlation between MV flow and LV fractional shortening
Redberg et al.[8] (1993)	Prospective observational	20	Exploratory	MV opening during cardiac release, reduction of ventricular cavity size with compression, and atrioventricular regurgitation supporting the cardiac pump theory
Tucker et al.[9] (1993)	Prospective observational	5	Exploratory	Improved transmitral flow, end-decompression LV volume, and stroke volume with ACD CPR
Barton et al.[10] (1994)	Case report	1	Diagnostic	Massive pulmonary embolism as a cause of PEA
Ma et al.[11] (1994)	Case report	1	Complications	AV disruption complicating CPR
Pell et al.[12] (1994)	Prospective observational	18	Exploratory	Compression of all four cardiac chambers resulting in forward flow in pulmonary and systemic circulations, retrograde pulmonary vein flow, and incomplete MV closure
				Antegrade pulmonary vein flow and LV filling observed during relaxation phase
Pell et al.[13] (1994)	Prospective observational	7	Exploratory	Improved right heart compression, antegrade blood flow patterns, and LV filling during ACD CPR
Ma et al.[14] (1995)	Prospective observational	17	Exploratory	Presence of opened MV with forward mitral flow and backward pulmonary venous flow during chest compression, suggesting "LA pump"
Gilon et al.[15] (1996)	Case report	1	Exploratory	RV compression and tricuspid valve closure
Huemer et al.[16] (1996)	Case report	1	Exploratory	Closure of MV, opening of AV, and reduction of LV cross-sectional area during downstroke of chest compression
Van der Wouw et al.[17] (1997)	Prospective observational	48	Diagnostic	Cardiac tamponade (n = 6), myocardial infarction (n = 21), pulmonary embolism (n = 6), ruptured aorta (n = 1), aortic dissection (n = 4), papillary muscle rupture (n = 1), other diagnosis (n = 2), and absence of structural cardiac abnormalities (n = 7)
Hwang et al.[18] (1998)	Prospective observational	52	Diagnostic	Pericardial effusion (n = 10), aortic dissection (n = 5), occlusion of the mitral orifice by thrombus (n = 2), main pulmonary artery thrombus (n = 2), thrombotic occlusion of the prosthetic valve (n = 1), hypertrophic cardiomyopathy (n = 1), and aortic stenosis (n = 1)
Tsai et al.[19] (1999)	Case report	1	Diagnostic	Total tricuspid valve obstruction and massive pulmonary embolism
Comess et al.[20] (2000)	Prospective observational	36	Diagnostic	Pulmonary emboli in 9 of 25 patients (36%) with pulseless electrical activity as initial event
Hwang et al.[21] (2001)	Prospective observational	14	Exploratory	Deformation of the aorta at maximal compression site and increase in cross-sectional area of proximal aorta
Liu et al.[22] (2002)	Prospective observational	6	Exploratory	Closure of mitral and tricuspid valves with simultaneous opening of AV during chest compression
Memtsoudis et al.[23] (2006)	Retrospective observational	22	Exploratory	Thromboembolic events (n = 9), acute myocardial ischemia (n = 6), hypovolemia (n = 2), and pericardial tamponade (n = 2)
Lin et al.[24] (2006)	Prospective observational	10	Diagnostic	Myocardial infarction (n = 5), pulmonary embolism (n = 2), and severe hypovolemia and ventricular arrhythmia without specific pathology (n = 2)
Blaivas[25] (2008)	Case report	6	Diagnostic/monitoring	Identification of VF in patients with asystole on ECG
Kim et al.[26] (2008)	Prospective observational	10	Exploratory	Retrograde flow to LA and forward blood flow to aorta on LV contrast echocardiography during compression phase
Hwang et al.[27] (2009)	Prospective observational	34	Exploratory	Significant narrowing of LV outflow tract or aorta during compression phase
Weidman et al.[28] (2014)	Case report	1	Exploratory	Formation of multiple thrombi in heart and descending thoracic aorta during CA
Fair et al.[29] (2016)	Prospective observational	10	Guiding catheter cannulation	ECMO guidewire placement and cannula positioning
Liu et al.[30] (2016)	Prospective observational	20	Exploratory	Cardiac effect at beginning of CA, faded with time, making the thoracic pump dominant mechanism during prolonged CPR
Arntfield et al.[31] (2016)	Retrospective observational	23	Diagnostic/feasibility of TEE by emergency physicians	High degree of feasibility and clinical utility of ED-based TEE

(*Continued on the next page*)

Table 1. (Continued)

Study	Study type	No. of patients[a)]	Indication/objective[b)]	Main echocardiographic finding
Catena et al.[32] (2019)	Retrospective observational	19	Outcome prediction	LV outflow tract opening associated with successful CPR
Fair et al.[33] (2019)	Prospective interventional	25	Efficacy of TEE on pulse check time	Shorter pulse check times with TEE compared with TTE
Kim et al.[34] (2019)	Retrospective observational	20	Exploratory	Measurement of compression depth at RV free wall and calculation of compression velocity
Lee et al.[35] (2019)	Case report	1	Complications	Acute aortic dissection complicating CPR
Teran et al.[36] (2019)	Prospective observational	21	Diagnostic/CPR quality	Identification of pseudo-PEA and fine VF, determination of reversible pathology, and optimization of CPR quality
Giorgetti et al.[37] (2019)	Case report	1	Guiding catheterization	Monitoring of mechanical chest compression performance and guiding cannulation for ECPR
Long et al.[38] (2020)	Case report	1	Monitoring cardiac status	Monitoring of CA due to anaphylaxis
Merlin et al.[39] (2020)	Case report	1	Trial of out-of-hospital TEE	Report of initial case of out-of-hospital TEE
Jung et al.[40] (2020)	Retrospective observational	158	Diagnostic/prediction of outcome	Total of 40 patients (25.3%, TEE positive group) with specific TEE findings, including possible causes of CA (n = 31, 19.6%) and sequelae of CA (n = 9, 5.7%)
				Positive TEE findings were associated with poor resuscitation outcomes
Kim et al.[41] (2020)	Case report	1	Diagnostic	Paradoxical embolism of right heart thrombi visualized on TEE during CPR
Orihashi[42] (2020)	Case report	4	Guiding catheterization	Monitoring chest compressions, guiding catheter insertion, and assisting pericardiocentesis
Rublee et al.[43] (2020)	Case report	1	Diagnostic	Cardiac tamponade and type A aortic dissection
Kim et al.[44] (2021)	Retrospective observational	45	Diagnostic	Diagnosing aortic dissection as cause of CA
Poppe et al.[45] (2021)	Case report	1	Diagnostic	Massive intracardiac thrombus and subsequent thrombolysis
Horowitz et al.[46] (2021)	Case report	1	Diagnostic	Clot in transit in RA and thrombolysis
Jung et al.[47] (2022)	Retrospective observational	97	Evaluation of intracardiac shunt	Assessment for presence of right-to-left shunt during CPR

TEE, transesophageal echocardiography; RV, right ventricle; LV, left ventricle; MV, mitral valve; AV, aortic valve; ACD, active compression decompression; CPR, cardiopulmonary resuscitation; PEA, pulseless electrical activities; LA, left atrium; VF, ventricular fibrillation; ECG, electrocardiogram; CA, cardiac arrest; ECMO, extracorporeal membrane oxygenation; ED, emergency department; TTE, transthoracic echocardiography; ECPR, extracorporeal cardiopulmonary resuscitation; RA, right atrium.
[a)]Number of patients only includes those who underwent TEE during CA. [b)]Exploratory, determination of mechanism of blood flow during cardiopulmonary resuscitation; Diagnostic, diagnosis of cause of CA.

the CPR team is required for the intra-arrest TEE procedure. Intra-arrest TEE is usually initiated after endotracheal intubation is complete. The patient in CA is not able to swallow the TEE probe; therefore, the operator must push the TEE probe into the esophagus. Before insertion of the TEE probe into the esophagus, the operator initially checks whether the probe is located behind the endotracheal tube and then bends the probe tip (anteflexion position) and pushes it into the back of the pharynx. When the TEE probe reaches the pharynx, it is inserted into the esophagus by straightening (unlocked position) and pushing the tip of the probe. If resistance is sensed while inserting the probe, the probe tip is not inserted into the esophagus. Insertion with excessive force may cause damage to the hypopharynx or upper esophagus.[56,57] Care should be taken not to dislodge the endotracheal tube during TEE.

IMAGING PROTOCOL AND VIEWS FOR INTRA-ARREST TEE

The protocol for intra-arrest TEE includes a quick scan to assess the possible cause of CA and the presence of cardiac contraction, assessment of CPR quality, monitoring of resuscitation measures, and guidance of catheter cannulation. To perform an initial scan immediately after probe insertion, the mid-esophageal (ME) four-chamber view, ME long-axis (ME LAX) view, ME ascending aorta short-axis (SAX) view, ME ascending aorta LAX view, descending aorta SAX view, and upper esophageal aortic arch LAX view are obtained in order (Fig. 1).[40] Transgastric views during chest compressions are not recommend because the forceful anterograde or retrograde flexion position for the transgastric views may cause injury to the esophagus or stomach.[58,59] After quick observation of the heart and great vessels, a TEE probe with a four-chamber view is placed at the ME level to monitor for cardiac movement

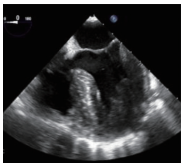
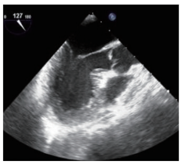
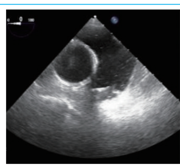
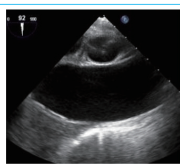
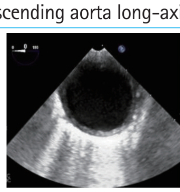
Two-dimensional imaging plane	Acquisition position (transducer angle)	Structures imaged	Cause of cardiac arrest to be observed
 ME four-chamber view	30–35 cm from incisor (approximately 0°–10°)	RA, RV, LA, LV, MV, AV, TV	Cardiac tamponade, clots in transit, thrombi in LA or LV, papillary muscle rupture, and septal rupture Presence of cardiac contraction
 ME long-axis view	30–35 cm from incisor (approximately 120°–140°)	LA, LV, LVOT, MV, AV, aortic root, and RVOT	Cardiac tamponade, aortic dissection, thrombi in LA or LV, papillary muscle rupture, and septal rupture Presence of cardiac contraction
 ME ascending aorta short-axis view	30–35 cm from incisor (approximately 0°–30°)	Ascending aorta, main and bifurcation of pulmonary artery, and SVC	Aortic dissection and pulmonary embolism
 ME ascending aorta long-axis view	30–35 cm from incisor (approximately 90°–110°)	Ascending aorta and right pulmonary artery	Aortic dissection and pulmonary embolism
 Descending aorta short-axis view	25 cm or deeper from incisor (approximately 0°–10°)	Descending aorta, left thorax	Aortic dissection Left pleural effusion
 Upper esophageal aortic arch long-axis view	25–30 cm from incisor (approximately 0°–10°)	Aortic arch Innominate vein	Aortic dissection, aneurysm, and atheromatous ulcer

Fig. 1. Suggested intra-arrest transesophageal echocardiography imaging planes and the corresponding structures or pathologies imaged. ME, mid-esophageal; RA, right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle; MV, mitral valve; AV, aortic valve; TV, tricuspid valve; LVOT, left ventricular outflow tract; RVOT, right ventricular outflow tract; SVC, superior vena cava.

and assist resuscitation measures. When catheterization is required for resuscitative measures, such as employing a central venous catheter, extracorporeal membrane oxygenation, or resuscitative endovascular balloon occlusion of the aorta (REBOA), ME bicaval view and the descending aorta SAX and LAX view are optimal for visualizing the vena cava or aorta. After the return of spontaneous circulation, a comprehensive examination of cardiac function, morphology, and regional-wall motion is needed.

FINDINGS OF INTRA-ARREST TEE

The diagnostic sensitivity, specificity, and positive predictive value of TEE for the cause of CA were reported to be 93%, 50%, and 87%, respectively.[17] One-fourth of the patients who underwent intra-arrest TEE showed specific evidence associated with CA. Such evidence is associated with poor resuscitation outcome.[40] The common causes of CA confirmed by TEE are cardiac tamponade, aortic dissection, pulmonary embolism, and intracardiac thrombi. Cardiac tamponade is easily diagnosed and appears as a large amount of pericardial effusion with the collapse of the right ventricle (RV) in ME views (Fig. 2). A large pericardial effusion and/or left pleural effusion may be a sign of aortic rupture (Fig. 3). Aortic dissection can be diagnosed by the presence of an intimal flap in the ascending aorta, aortic arch, and descending aorta views (Fig. 4). High suspicion or diagnosis of pulmonary embolism is possible when thrombi are observed in the right atrium, RV, or pulmonary artery (Figs. 5, 6). Intracardiac or disseminated thrombi, observed as echogenic densities in the left-side cardiac chambers and/or the aorta without right heart thrombus, is a sequela of CA (Fig. 7). During a quick scan of the possible causes of CA, cardiac contraction and movement during chest compressions can be observed. Fibrillary or mechanical contractions of the ventricle can be observed during ventricular fibrillation or pulseless electrical activity (Supplemental Video 1). Catheterizations for in-

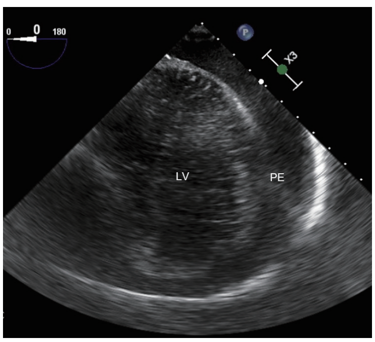


Fig. 2. Cardiac tamponade. The mid-esophageal view shows a large amount of pericardial effusion (PE) surrounding the left ventricle (LV).

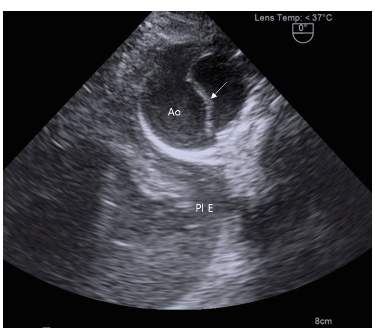


Fig. 3. Ruptured aortic dissection. A dissecting flap (arrow) and left pleural effusion (Pl E) are noted on the descending aorta (AO) short-axis view.

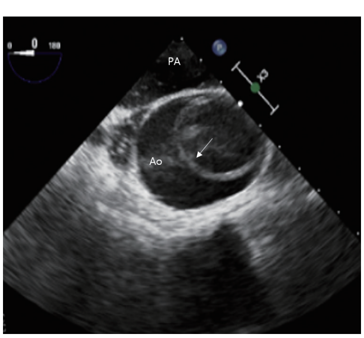


Fig. 4. Aortic dissection. The mid-esophageal ascending aorta short-axis view shows a dissecting flap (arrow) in the ascending aorta (Ao). PA, pulmonary artery.

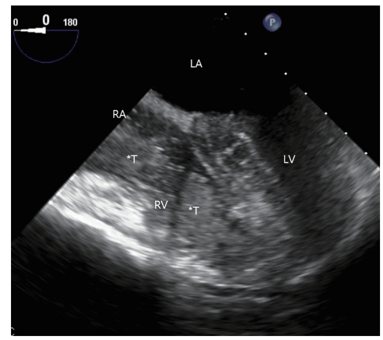


Fig. 5. Thrombi (T*) in the right-sided chambers. Echogenic densities occupying the right atrium (RA) and the right ventricle (RV) on the mid-esophageal four-chamber view suggest pulmonary embolism as a possible cause of cardiac arrest. LA, left atrium; LV, left ventricle.

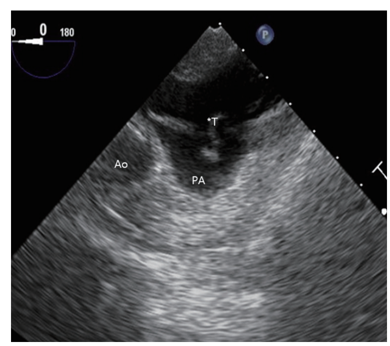


Fig. 6. Thrombi (T*) in the pulmonary artery (PA). The mid-esophageal view for the PA shows echogenic densities in the main and right PA. Ao, ascending aorta.

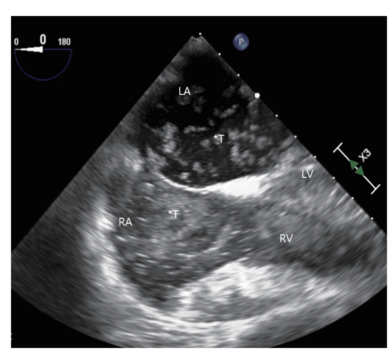


Fig. 7. Intracardiac thrombi (T*). Echogenic densities with variable sizes are noted in all cardiac chambers suggesting sequelae of prolonged cardiac arrest. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

terventional measures, such as REBOA or extracorporeal CPR, can be assisted by intra-arrest TEE.[29,60] Cardiac movement, including compression of the cardiac chambers and valvular motion, can be continuously monitored during TEE.[7,8,14,21] Kinetic analysis of chest compressions can be performed by measuring the excursions of the free wall of the RV.[34] An intracardiac shunt or paradoxical embolism can be detected during intra-arrest TEE.[41,47]

SAFETY OF INTRA-ARREST TEE

TEE is relatively safe. The overall complication rate of diagnostic and intraoperative TEE ranges from 0.18% to 2.8%, and the mortality rate is less than 0.01% to 0.02%.[61-63] However, no study has reported the safety of intra-arrest TEE. From our experience (unpublished data), intra-arrest TEE was successfully performed with no complications in 179 of 183 patients (97.8%) who experienced out-of-hospital CA. Failure of TEE probe insertion into the esophagus occurred in three patients (1.6%), while vallecular injury was confirmed in one patient (0.5%) after intra-arrest TEE. The electrical safety of using TEE during transthoracic defibrillation remains controversial.[64] Operator injury or equipment failure was not reported during transthoracic defibrillation. No study has reported the harmful effects of transthoracic defibrillation on operators or patients when a TEE probe is inserted. However, the effect of defibrillation on TEE machines has not yet been evaluated.

CONCLUSION

TEE is now widely practiced not only by cardiologists, but also by doctors who manage patients with cardiovascular disorders, including emergency physicians, intensivists, and anesthesiologists. Excellent imaging windows, easy accessibility, and high portability have enabled TEE to be a point-of-care imaging modality during CA in the ED. Intra-arrest TEE facilitates the diagnosis of the CA cause, enables the evaluation of cardiac contractions and CPR quality, and aids in catheter insertion for therapeutic procedures. Trained experts, protocols, coordination, and equipment maintenance are essential for the successful application of an intra-arrest TEE program in the ED. Future research should evaluate the effect of intra-arrest TEE on resuscitation outcomes in patients with CA.

SUPPLEMENTARY MATERIAL

Supplementary Video 1. Illustrative case of ventricular fibrillation observed on intra-arrest transesophageal echocardiography. The mid-esophageal four-chamber view shows fine fibrillary contraction of the left ventricle and mitral valve movement.
Supplementary material is available at https://doi.org/10.15441/ceem.22.399.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

Conceptualization: SOH; Data curation: WJJ; Investigation: KCC; Methodology: SOH; Resources: WJJ; Supervision: SOH; Visualization: YIR; Writing–original draft: SOH; Writing–review & editing: all authors.
All authors read and approved the final manuscript.

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