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Evaluation of out-of-hospital cardiac arrest using transesophageal echocardiography in the emergency department

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Abstract

Background: Transesophageal echocardiography (TEE) has been proposed as a modality to assess patients in the setting of cardiac arrest, both during resuscitation care and following return of spontaneous circulation (ROSC). In this study we aimed to assess the feasibility and clinical impact of TEE during the emergency department (ED) evaluation during out-of-hospital cardiac arrest (OHCA).

Materials and methods: We conducted a prospective observational study consisting of a convenience sample of adult patients presenting to the ED of an urban university medical center with non-traumatic OHCA. TEE was performed by emergency physicians following intubation. Images and clinical data were analyzed. TEE was used intra-arrest in order to assist in diagnosis, assess cardiac activity and determine CPR quality by assessing area of maximal compression (AMC), using a 4 view protocol.

Results: A total of 33 OHCA patients were enrolled over a one-year period, 21 patients (64%) presented with ongoing CPR and 12 (36%) presented with ROSC. The 4-view protocol was completed in 100% of the cases, with an average time from ED arrival to TEE of 12 min (min 3 max 30 SD 8.16). Fine ventricular fibrillation (VF) was recognized in 4 (12%) cases thought to be in asystole, leading to defibrillation, and 2 cases of pseudo-PEA were identified. Right ventricular (RV) dilation, was seen in 12 (57%) intraarrest cases. Intra-cardiac thrombus was found in one case, leading to thrombolysis. The AMC was identified over the aortic root or LVOT in 53% of cases. TEE was found to have diagnostic, therapeutic or prognostic clinical impact in 32 of the 33 cases (97%).

Conclusions: TEE is feasible and clinically impactful during OHCA management. Resuscitative TEE may allow for characterization of cardiac activity, including identification of pseudo-PEA and fine VF, determination of reversible pathology, and optimization of CPR quality.

Keywords: Cardiac arrest, Resuscitation, Transesophageal echocardiography, Ultrasound, Point-of-care ultrasound

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Introduction

Transthoracic echocardiography (TTE) has been proposed as a tool with the potential to improve outcomes in cardiac arrest. The 2015 ILCOR resuscitation guidelines recommend that cardiac ultrasound evaluation may be used during resuscitation care to identify reversible causes of cardiac arrest, provided it does not interfere with standard cardiac arrest treatments.[1,2] However, an important limitation to the practice of TTE during cardiac arrest resuscitation is the technical difficulty in obtaining adequate cardiac windows during the seconds available during CPR pauses for rhythm checks. Other common impediments to cardiac assessment by TTE during arrest include external and patient-related factors such as defibrillator pads, automated compression devices, obesity, lung disease and gastric insufflation, represent. Transesophageal echocardiography (TEE) overcomes many of these limitations, offering diagnostic information without physically interfering with ongoing resuscitation tasks, and providing higher quality cardiac images. The use of TEE in cardiac arrest, undifferentiated shock and hemodynamic decompensation has been proposed in emergency department,[3,4] intensive care[5,6] and surgical environments.[7,8].

In addition to providing similar or superior diagnostic information (e.g. characterization of cardiac activity, identification of RV dysfunction, pericardial tamponade, intravascular volume status, etc.), TEE offers other potential advantages over TTE. These include the possibility of minimizing chest compression interruptions, real-time feedback on the effectiveness of cardiac compressions, identification of fine ventricular fibrillation (VF) or pseudo-PEA, changes in CPR physiology and procedural guidance in establishing extracorporeal life support (ECLS).

The purpose of this study was to describe the feasibility and clinical findings following the implementation of resuscitative TEE during the evaluation of patients presenting with out-of-hospital cardiac arrest (OHCA) in a tertiary care medical center in the United States.

Methods

Study overview and patient population

We conducted a prospective observational study involving a convenience sample of adult patients presenting to the ED with non-traumatic OHCA with either pulseless electrical activity (PEA) or asystole as the initial rhythm, as well as OHCA patients who achieved return of spontaneous circulation (ROSC) during prehospital care, between September 2017 and September 2018 at the Hospital of the University of Pennsylvania (Philadelphia, USA). Study subjects were patients in whom TEE was performed during resuscitation or as part of immediate post-ROSC evaluation upon arrival to the ED. Patients were excluded if they were under 18 years old, pregnant, found to be DNR upon arrival to ED or had any evidence of trauma. The study was approved by the University of Pennsylvania Institutional Review Board.

TEE protocol

An OHCA protocol with inclusion of TEE was established in August 2017. This protocol included the use of TEE during active resuscitation, the placement of femoral arterial and venous central catheters, monitoring of continuous waveform capnography (ETCO2), use of a mechanical compression device (mCPR) (LUCAS2® Physio-Control™ Inc. Redmond WA, USA), and initiation of ECLS, when indicated. TEE using a multiplane 2D probe (Mindray Medical International™ Shenzhen, China) was performed by emergency physicians (EPs). The ED staff receiving all EMS notifications were instructed to call the study lead investigator and study coordinator for all OHCA cases throughout the study period. This call would activate the research team, and if available, a physician would come in to perform TEE and enroll eligible patients.

As an observational, pragmatic protocol, treating physicians leading the resuscitation proceeded with standard resuscitation care. The EP performing the TEE examination reports findings in real time to the leader of the resuscitation team. Per the protocol, a TEE probe is inserted after airway control with endotracheal intubation. Four primary views are sought: midesophageal 4 chamber (ME4C), midesophageal long axis (MELAX), transgastric short axis (TGSAX) and midesophageal bicaval (ME Bicaval). The core views of this protocol and main applications in cardiac arrest are depicted in Fig. 1. Additional views were obtained depending on specific diagnostic needs (e.g. evaluation of the thoracic aorta if suspecting aortic dissection or during cannulation for ECMO).

For purposes of description and analysis we considered intraarrest and post arrest as two subgroups of OHCA patients. Although these two groups were analyzed separately, it is probable that the beneficial role of TEE in the evaluation of cardiac arrest continues beyond the intraarrest period for those with ROSC. Thus, in all patients whose TEE was initiated intraarrest, it was continued during the post resuscitation phase for further diagnostic assessment and monitoring (e.g. identification of reversible causes, guidance of vasopressor therapy and fluid administration, and prompt identification of re-arrest).

In cases where TEE was performed intraarrest, an immediate assessment was made of the area of maximal compression (AMC), defined as the area within the heart that receives the greatest compression during CPR. This assessment was made using the MELAX view, because it is the only view within this protocol that demonstrates the structures of interest for the determination of AMC (the LV, LVOT and aortic root) in a single imaging plane. As noted, the EP performing the TEE reported the location of AMC along with diagnostic information, such as type of cardiac activity and presence of reversible pathology to the resuscitation team leader. The team could choose to reposition the AMC or otherwise modify resuscitation care based on TEE findings at their discretion, but there was no intervention specified as part of this study.

TEE competency and training

All physicians performing TEEs in this study completed a minimum standardized training consisting of 8-hours of didactics, along with hands-on training including high-fidelity simulation (HeartWorks® TEE, Medaphor™, Alpharetta GA, USA), and proctored examinations in the operating theaters and ED. Prior studies have demonstrated that this curriculum is sufficient to train EPs facile in TTE in the motor and cognitive skills needed to perform resuscitative TEE.[4] As part of the credentialing requirement of our resuscitative TEE program, all providers performing TEE complete a minimum of 10 proctored examinations, using a high-fidelity simulator and live cases in the

TEE view	Cardiac Structures	Utility in Cardiac Arrest
ME4C*	All cardiac chambers Pericardium LV / RV walls Mitral and Tricuspid Valves	Evaluation for tamponade Assessment of cardiac activity Identification of intra-cardiac thrombus Assessment of LV / RV size and function Detection of fine VF
MELAX**	LV, LA and RV chambers LV Outflow Tract Aortic root Mitral and Aortic Valves	Determination of area of maximal compression (AMC) during CPR
TGSAX***	All LV Walls and Septum	Assessment of cardiac activity LV / RV size and function
ME Bicaval	IVC, RA and SVC	Procedural guidance (ECMO) Volume responsiveness in post arrest

*ME4C: Mid-esophageal 4 chamber view
**MELAX: Mid-esophageal long axis view
***TGSAX: Trans-gastric short axis view at level of papillary muscles

Fig. 1 – Resuscitative TEE views and applications in cardiac arrest.
*ME4C: mid-esophageal 4 chamber view.
**MELAX: mid-esophageal long axis view.
***TGSAX: trans-gastric short axis view at level of papillary muscles.

operating theater. At the time of initiation of the study, three of the providers performing TEE had performed between 10–20 examinations, two had performed between 20–30 examinations, and two had performed over 30 examinations.

Data collection

All significant TEE findings were recorded as still images and digital video clips of up to 12 s. Images and clinical data, including code timeline sheet, were collected prospectively and analyzed for this study. Cardiac arrest variables were extracted from the electronic medical records by two study investigators following standard Utstein convention (FT, CC) using a clinical research database instrument (RedCap, Vanderbilt University, Nashville, TN). Data from cardiac monitors (Intellivue, Philips Medical, Andover, MA) including minute-to-minute ETCO2 and invasive blood pressure were extracted electronically and entered manually into our dataset. All TEE video clips and images along with procedure notes were reviewed by study investigators (FT, CC). Demographic and cardiac arrest data were collected and entered by the study investigators in a standardized data collection form. EMS incident report forms were collected if available, and Utstein style dates and time points from the EMS incident reports were extracted. Descriptive statistical analysis was performed using statistical software (Stata® 14.0, Statacorp™, College Station, TX).

Data analysis

We employed descriptive statistics to analyze demographics and baseline characteristics of study subjects, clinical findings and outcomes. We calculated the time to TEE by subtracting the time of ED arrival from time of first recorded TEE image. We conducted exploratory analysis for correlation between several patient characteristics (e.g. age, gender, comorbidities, etc.) and time dependent variables. We performed regression analysis to assess for correlation between multiple patient characteristics, reported comorbidities, and time-dependent variables and the location of AMC. Similar analysis was performed exploring for potential predictors of RV dilation intra-arrest, as well as differences in patient outcomes.

Results

Feasibility and safety of resuscitative TEE protocol

A total of 33 OHCA events were enrolled between September 2017 and September 2018. Patient characteristics are summarized in Table 1. There were a total of 114 OHCA cases during the study period, from which 72 would have met inclusion criteria. Patients that were eligible but were not enrolled, either presented when a provider able to perform TEE was not available or because the research team was not notified of an incoming arrest patient.

The TEE probe was successfully inserted during cardiac arrest following endotracheal intubation and all 4 specified TEE windows of the resuscitative protocol were successfully obtained in 100% of cases. The mean time from patient arrival to ED to first recorded TEE image in those who arrived in cardiac arrest was 12 min (min 3 max 30 SD 8.16).

Clinical cohort and TEE findings

From the total number enrolled, twenty-one patients (64%) presented to the ED with ongoing CPR and 12 (36%) presented with ROSC, or had ROSC achieved within the first five minutes of ED arrival. In this cohort 7 patients had PEA (21%), 6 (18%) had asystole, 2 (6%) had non-pulseless ventricular arrhythmias and 16 (48%) had perfusing rhythms at arrival (ROSC). Two of the patients who arrived with perfusing rhythms rearrested soon after arrival and received intra-arrest TEE.

In 2 of 7 (28%) cases presenting to the ED with initial rhythm of PEA, patients were found on TEE evaluation to have pseudo-PEA, defined as organized cardiac mechanical activity visualized on TEE with organized electrical activity observed on the monitor. Fine VF was visualized in TEE in 3 of the cases with suspected asystole. One

patient who had achieved ROSC rearrested, and TEE identified fine VF, which was not identifiable on the cardiac monitor. The identification of fine VF led to defibrillation in all these patients. A summary of TEE findings is provided in Table 2.

Right ventricular (RV) dilation was seen in the first TEE image in 13 patients (39%), but only 2 were suspected by the resuscitation team to have pulmonary embolism (PE) as the likely underlying etiology of arrest. We found no statistically significant association between witnessed arrest or bystander CPR and presence of intraarrest RV dilation. A perfusing presenting rhythm (ROSC), was found to be a negative predictor of intra-arrest RV dilation with $OD = 0.7$ ($p < 0.05$ 95% CI 0.006–0.82).

In one case TEE identified an intra-cardiac mass thought to be a thrombus, and led to administration of thrombolytic therapy. We had no cases of aortic dissection or hypovolemia as intraarrest findings on TEE.

Assessment of the AMC was performed in 17 of the intraarrest cases. We were able to perform AMC assessment only in 17 out of the 21 intraarrest cases because in 4 cases the patients had ROSC before this assessment was made. Of these, 8 (47%]) were found to have AMC appropriately located over the left ventricle (LV), and 9 (53%) over the left ventricular outflow tract (LVOT) or the aortic root. In all cases where AMC was not optimally located over the LV, repositioning of hands or the mechanical CPR device resulted in optimal ventricular compression with appropriate functioning of the mitral and aortic valves visualized in real time by TEE. Insufficient pre-and post AMC repositioning data precludes statistical analysis of the effect of change of position on hemodynamic parameters (ETCO2, SBP and DBP). However, in several cases the resuscitation team observed an improvement of these parameters following the optimization of compression site. In one case where AMC was repositioned under TEE guidance, the patient exhibited CPR-dependent consciousness which prompted the decision to initiate ECLS. In 3 other cases, ROSC was achieved within 2 min following change in AMC. We found no statistically significant correlation between the presence of AMC over LV or LVOT/Aortic root and age, gender, history of heart failure (HF), hypertension (HTN), chronic kidney disease (CKD), Coronary artery disease (CAD), diabetes

Table 2 – Clinical findings in resuscitative TEE during evaluation of OHCA patients.

	Intra-arrest TEE [N = 21]	Post-arrest TEE [N = 12]	All OHCA TEE [N = 33]
Change in Management — n [%]	20 [95.2]	12 [100]	32 [97]
Likely Etiology Established — n [%]	7 [33.3]	4 [33.3]	11[33]
AMC[a] over LV — n [%]	8 [47]	–	8 [47]
AMC over LVOT[b]/Ao Root — n [%]	9 [52.9]	–	9 [53]
AMC changed — n [%]	9 [52.9]	–	9 [53]
RV Dilation — n [%]	12 [57.1]	1 [8.3]	13 [39]
LV Dysfunction — n [%]	21 [100]	7 [58.3]	28 [85]
Intracardiac Thrombosis — n [%]	1 [4.7]	0 [0]	1 [3]
Hypovolemia — n [%]	0 [0]	2 [16.67]	2 [6]
Aortic Dissection — n [%]	0 [0]	0 [0]	0 [0]
Fine Ventricular Fibrillation — n [%]	3 [14.2]	1 [8.3]	4 [12]
Obstructive Shock — n [%]	3 [14.2]	0 [0]	3 [9]

[a] AMC: Area of maximal compression.
[b] LVOT: Left ventricular outflow tract.

Table 1 – Demographics, outcomes and resuscitation characteristics.

	Intra-arrest TEE [N = 21]	Post-arrest TEE [N = 12]
Age Mean year [Min–Max]	65 [29–96]	53 [37–81]
Male Sex — No [%]	13 [62]	6 [50]
Outcomes		
- ROSC — n [%]	16 [76]	N/A
- Survived ED — n [%]	7 [33]	11 [92]
- Survived Hospital Discharge — n [%]	1 [5]	3 [25]
Bystander CPR — n [%]	14 [67]	N/A
Witnessed Cardiac Arrest — n [%]	17 [81]	N/A
Presenting Rhythm ED		
- Asystole — n [%]	5 [24]	1 [8]
- Pulseless Electrical Activity — n [%]	7 [33]	1 [8]
- Pulseless Ventricular Tachycardia — n [%]	1 [5]	1 [8]
- Ventricular Fibrillation — n [%]	0	2 [17]
- Perfusing Rhythm [Post Arrest] — n [%]	6 [28]	10 [83]
- Unknown — n [%]	2 [28]	0
Mechanical CPR — n [%]	15 [71]	3 [25]
Initiation of VA ECMO [ECLS] — n [%]	4 [19]	3 [25]
Time ED arrival to TEE image in Intra-arrest Mean [Min–Max]	12 [3–30]	18 [13–26]
Aerodigestive injuries in patients who survived to admission — n [%]	0	0

mellitus (DM) and history or STEMI. We also did not find a correlation between type of CPR (mechanical vs manual) and location of AMC over LV *vs.* LVOT/Aortic root. There was no statistically significant difference between ROSC, survival to ED or survival to hospital discharge, and initial position of AMC. Table 5 with results of the exploratory analysis for predictors of AMC over the LV and RV dilation intraarrest, is provided as supplemental material.

Overall, TEE was found to have diagnostic, therapeutic or prognostic clinical impact, defined by change in management, in 32 of the 33 cases (97%).

Assessment of CPR physiology

Assessment of the position of aortic (AV) and mitral (MV) valves during ongoing chest compressions was possible in 16 out of the 21 intra-arrest cases. In 100% of these cases, we found the AV open and MV closed during compression phase, and AV closed and MV open during decompression phase. These findings are consistent with the cardiac pump model of CPR physiology.[9]

Ventricular fibrillation or pulseless ventricular tachycardia (pVT) was identified at some point during resuscitation in 7 cases. In all these cases, patients received external defibrillation, with TEE probe remaining in place and being held by the physician sonographer. Neither physician electrical injuries, nor device malfunction or damage were observed. No aerodigestive injuries were reported in patients that survived and were admitted to the hospital.

On review of TEE images, no significant discrepancies were found between the real-time interpretation provided by the EP performing TEE, the findings documented in the procedure note, and the impression of the reviewers. Detailed TEE findings for all 33 subjects and corresponding change in management are summarized in Tables 3 and 4.

Discussion

In this prospective cohort study, we found that EP-performed resuscitative TEE is feasible, safe, and clinically impactful. Management changes based on TEE findings during resuscitation occurred in 97% of patients. This work extends prior descriptions of the use of TEE in resuscitation in the ED[3,10] by its prospective systematic collection of longitudinal data during arrest that allows for identification of decision making that occurred based on the TEE findings.

One of the main limitations of TTE during resuscitation of cardiac arrest is the difficulty of obtaining adequate views. This is due to multiple factors, some patient related (e.g. gastric insufflation preventing subxyphoid view, emphysema or obesity impeding transthoracic views, etc.), and some specific to the resuscitation environment (e.g. defibrillator pads, chest compressions etc.). It is likely that the combination of these factors contribute to the finding of longer CPR pauses associated with ultrasound.[11,12] We found that TEE reliably obtains high-quality images without interfering with other resuscitation interventions. The reasonably brief time to TEE and the 100% protocol completion rate (all 4 core views were obtained), demonstrates the feasibility of TEE in this setting. In addition to providing the same diagnostic and prognostic information as TTE, TEE offers continuous feedback on the quality of CPR during resuscitation, and guides management after ROSC. To our knowledge, this is the first prospective observational study to describe the systematic use of TEE during intra- and post-arrest evaluation of OHCA patients.

The systematic use of echocardiography in cardiac arrest resuscitation over the past decade, has led to further characterization of PEA. Several prospective studies in prehospital, ED and intensive care settings have demonstrated that patients with organized electrical activity, who are pulseless but yet have ventricular wall motion visualized in echocardiography, have significantly better survival.[13–15] Furthermore, in one large study in the ED setting, it was the variable most associated with survival at all time points including hospital discharge.[16]

In contrast to the traditional approach of classifying patients on the basis of presence or absence of cardiac activity, due to the high-quality of the images obtained with TEE and the ability to perform multiple serial assessments during resuscitation, a wide range of cardiac activity was identified during the study (Table 3). We believe the ability to assess the type of cardiac activity during PEA may have therapeutic implications. Patients with pseudo-PEA that are treated with continuous infusion of pressors may lead to better outcomes.[17] The current study was insufficiently powered to make correlations between type of cardiac activity and outcomes, but it is hoped that future studies might explore how the dynamic physiologic and anatomic information available from TEE could be used for prognostic and therapeutic decision-making. The availability of TEE, providing serial real-time assessments of the cardiac activity, could make possible a protocol in which PEA is further stratified and resuscitation therapy is tailored to the degree of ventricular function.

While the role of echocardiography is mainly for non-shockable rhythms, the high definition of images has also allowed the detection of fine VF in patients with suspected asystole. The finding that certain cases of VF, may be indistinguishable from asystole, or that the arrhythmia might be misdiagnosed due to artefact, has led to the proposal of echocardiography as a tool to enhance recognition of this rhythm.[18] In this cohort we found that 4 (12.2%) cases with suspected asystole, had VF visualized on TEE. Early differentiation of fine VF from asystole may make a difference in survival, since such patients might otherwise follow an inappropriate ACLS pathway.

The evaluation of RV dilation, a sign suggesting PE as a reversible cause of cardiac arrest, has been proposed in several algorithms.[19,20] However, RV dilatation has been described as a common finding during cardiac arrest, challenging the assumption that RV dilatation during resuscitation is indicative of PE. In this cohort, 57% (12/21) of intraarrest cases and only 8% (1/12) of postarrest had echographic signs of RV dilation on TEE at arrival, defined as RV/LV ratio equal or greater than 0.6. While our data do not include the results of follow-up testing for PE, it is unlikely that such a high proportion of the cohort had acute PE.

Regarding the association between bystander CPR and presence of intraarrest RV dilation, patients who received bystander CPR, had an odds ratio of 0.77 of having RV dilation. Although this finding is not statistically significant (p = 0.6 95% CI 0.23–2.5), this signal would be consistent with the theory that RV dilation intraarrest is due to prolonged no flow or low flow period of arrest.

Regarding ED presenting rhythm as a predictor of intra-arrest RV dilation, we found no statistically significant correlation between asystole and PEA, but the odds ratios were 4 (p = 0.25) and 2.5 (p = 0.35) respectively. A perfusing presenting rhythm (ROSC), was found to be a negative predictor of intra-arrest RV dilation with

Table 3 – Patient characteristics, clinical findings and influence in management with TEE of intraarrest cases.

Age /sex	Presenting ECG rhythm ED	Type of CPR	Time to TEE [min]	Outcome	TEE findings	Change in management
74 F	ROSC	Mech	3	ROSC	AMC LVOT/Ao Root Intra-cardiac thrombus and PE	Optimized AMC, Diagnosis of underlying etiology (thrombus), Assessment of Intervention (Thrombolysis)
77 M	PEA	Mech	10	No ROSC	AMC LVOT/Ao Root, RV dilation	Optimized AMC, Decision to Discontinue Resuscitation
58 M	PEA	Mech	21	No ROSC	RV dilation	Decision to Discontinue Resuscitation
63 M	PEA	Mech	14	Survived ED	AMC LVOT/Ao Root, Fine VF	Optimized AMC, Defibrillation
43 F	Unknown	Mech	N/A	ROSC	Normal LV	Allowed identification of normal cardiac activity after inadequate TTE windows due to severe emphysema (Respiratory Arrest)
63 M	Asystole	Mech	9	ROSC	AMC LVOT/Ao Root, RV dilation, Fine VF	Optimized AMC, Defibrillation, Anticipated rearrest, Diagnosis of PE, Assessment of Intervention (Thrombolysis)
96 F	ROSC	Mech	6	ROSC	RV dilation, cardiogenic shock in post arrest	Anticipated episodes of rearrest, identification of cardiogenic shock and initiation of pressors in post arrest
60 M	PEA	Mech	10	ROSC	AMC LVOT/Ao Root, RV dilation	Optimized AMC
29 M	Asystole	Mech	10	No ROSC	RV dilation, cardiac standstill	Decision to Discontinue Resuscitation
71 M	VF	Mech	3	Survived ED	RV dilation, cardiogenic shock in post arrest	Identified cardiogenic shock and prompted initiation of pressors and VA ECMO post arrest
59 M	Asystole	Manual	14	No ROSC	Cardiac standstill	Decision to Discontinue Resuscitation
89 F	ROSC	Manual	30	Survived ED	AMC LVOT/Ao Root, cardiogenic shock in post arrest	Identified cardiogenic shock and prompted initiation of pressors post arrest
89 F	PEA	Mech	4	ROSC	AMC LVOT/Ao Root, RV dilation, Fine VF	Optimized AMC, prompted defibrillation (fine VF), led to diagnosis of PE, provided real time assessment of intervention (Thrombolysis)
89 M	Asystole	Manual	13	ROSC	RV dilation, pseudo PEA	Identification of pseudo PEA and initiation continuous infusion of pressors
64 M	Asystole	Manual	3	Survived ED	AMC LVOT/Ao Root, RV dilation	Optimized AMC, identification of pseudo PEA and prompted initiation of pressors
57 M	ROSC	Mech	19	Survived ED	Rearrest, RWMA, cardiogenic shock in post arrest	Anticipated episodes of rearrest, identified regional wall motion abnormality and cardiogenic shock, led to initiation of pressors post arrest
78 F	Unknown	Manual	29	No ROSC	AMC LVOT/Ao Root, RV dilation,	Optimized AMC
59 M	PEA	Manual	11	ROSC	Pseudo PEA	Identified pseudo PEA prompting initiation of pressors
50 F	ROSC	Mech	8	Survived ED	RWMA, cardiogenic shock in post arrest	Identification of Regional Wall Motion Abnormality, and cardiogenic shock, initiation of pressors post arrest
44 F	PEA	Mech	N/A	Survived Hospital DC	RV dilation, obstructive shock	Anticipated episodes of rearrest, Identification of pseudo PEA, Diagnosis of PE, Assessment of Intervention (Thrombolysis) and initiation of VA ECMO post arrest
65 M	ROSC	Mech	N/A	ROSC	Cardiogenic shock in post arrest, Appropriate unloading of LV in ECMO	Identification of cardiogenic shock and initiation of pressors and VA ECMO in post arrest

OD = 0.7 (p < 0.05 95% CI 0.006–0.82). Taken together, these findings would support the hypothesis that OHCA patients that present with better cardiac output (e.g. ROSC vs asystole), are likely to have RV dilation as an intra-arrest finding. Further research is needed to establish if there are any other echographic findings that can improve the specificity of TEE to diagnose PE during intraarrest phase of resuscitation.

The American Heart Association Advanced Cardiovascular Life Support guidelines have prioritized external chest compressions to maintain coronary perfusion pressure. Prior recommendations identified the middle of the lower half of the sternum as the optimal site for compressions.[21] Despite recommendations for midsternal compressions in line with the nipples, chest compressions are often performed in the incorrect location, obstructing stroke volume and subsequently precluding adequate coronary perfusion.[22,23] Furthermore, animal studies randomizing compressions delivered with AMC over the LV compared to aortic root, have demonstrated not only that AMC

Table 4 – Patient characteristics, clinical findings and influence in management with TEE of post arrest cases.

Age /Sex	Presenting ECG rhythm ED	Type of CPR	Outcome	TEE findings	Change in management
39 M	Sinus	Manual	Survived ED	Normal LV EF but underfilled. SVC D variation > 40%. No RV failure	Ruled out cardiogenic and confirmed distributive shock, initiated pressors and guided fluid therapy
81 F	Asystole	Mech	Survived ED	Global hypokinesis of LV, without RWMA. No RV failure	Identification of cardiogenic shock after inadequate TTE (emphysema), prompted initiation of pressors
37 M	Sinus	N/A	Survived ED	Normal LV function, under filled LV. SVC D variation > 50%	Suggested hypovolemia and not cardiogenic etiology of shock post arrest. Guided fluid therapy
69 M	Sinus	N/A	Survived Hospital DC	Normal LV function, no RWMA. Displaced pacemaker lead	Suggested mechanical cause as likely arrest etiology from displaced pacemaker lead as opposed to MI
42 F	Sinus	Manual	Survived ED	Cardiogenic shock with RWMA	Prompted initiation of VA ECMO in refractory cardiogenic shock (STEMI), and decision to take to cardiac cath lab
63 F	Sinus	Manual	ROSC	Normal LV function. SVC D variation > 40%	Guided fluid therapy and pressor support after inadequate TTE (obesity)
71 M	Sinus	N/A	Survived ED	Global hypokinesis of LV, without RWMA	Guided initiation of pressor therapy despite normal BP, anticipated re-arrest episode
41 F	pVT	Manual	Survived Hospital DC	Normal LV function, no RWMA, SVC D variation > 40%	Ruled out cardiac etiology, guided fluid therapy, assisted cannulation for ECMO given refractory VF
60 F	Sinus	Mech	Survived Hospital DC	Severe biventricular systolic dysfunction EF 5%	Supported diagnosis of cardiogenic shock, ruled out RV failure, prompted initiation of VA ECMO and guided decision-making regarding need for LV unloading (Impella)
39 F	Sinus	N/A	Survived ED	Cardiogenic shock with RWMA	Prompted initiation of VA ECMO in refractory cardiogenic shock with RWMA in absence of STEMI, guided decision to take to cath lab where LAD occlusion was found
47 M	Sinus	Mech	Survived ED	Biventricular systolic dysfunction with significant RV dilation	Identified cardiogenic shock despite normal BP in immediate post arrest, diagnosed RV failure, guided hemodynamic management
51 M	Sinus	N/A	Survived ED	Decreased LV EF but underfilled. SVC D variation > 40%. No RV failure	Identified mixed shock physiology, cardiogenic and hypovolemic (hemorrhagic) components, prompted initiation of pressors, guided fluid therapy and prompted imaging that eventually identified GI bleeding as likely trigger

RWMA: Regional wall motion abnormality, EF: Ejection fraction, SVC D: Superior vena cava diameter.

over LV provides consistently higher coronary perfusion pressures, but also that only animals receiving chest compressions over LV achieve ROSC.[24,25] Our study confirms the finding that in many cases compressions are actually preventing cardiac flow by occluding the aortic outflow tract with each compression. Further study is needed to determine whether there is any position for compressive force on the chest that provides ventricular compression and avoids outflow tract obstruction for all patients, or whether each patient's anatomy is idiosyncratic in this respect, requiring TEE optimization of AMC on a case-by-case basis for all patients during resuscitation.

Lastly, in our cohort TEE was used in 21% (7/33) cases to assist cannulation and successfully initiate veno-arterial extracorporeal circulation (VA ECMO) during ECLS. A common problem during initiation of ECMO intra-arrest is the difficulty distinguishing between femoral artery and vein, even under transcutaneous ultrasound guidance, due to the typically high venous pressures and low arterial pressures during cardiac resuscitation. As previously described,[26] we used TEE to visualize venous guidewire and then cannula placement to the RA-SVC junction, as well as arterial guidewire positioning in the descending thoracic aorta. TEE clips demonstrate visualization of venous and arterial guidewires during cannulation for ECLS during cardiac arrest.

Limitations

Our study has several important limitations. Firstly, our work represents a relatively small, single-institution study, limiting the generalizability of our findings. We included a convenience sample of OHCA patients, enrolled only when TEE was available as part of resuscitation care. All TEE examinations in this study were performed by a group of 7 emergency physicians, 5 of which are study investigators (FT, AD, NP, AZ, WC). Thirty out of the 33 cases were supervised by the clinician who leads the resuscitative TEE program at our institution and is the lead study investigator (FT), representing a potential source of investigator bias.

Conclusion

The performance of TEE during intra-arrest care by EPs is feasible and clinically useful during the management of OHCA in the ED. Resuscitative TEE allows characterization of the type of cardiac activity, identification of reversible causes of arrest, optimization of the quality of chest compressions during CPR, guidance of invasive procedures for ECLS, and post-ROSC cardiac and hemodynamic

monitoring. Intra-arrest optimization of AMC represents a promising tool for patient-centered thoracic compressions as well as a possible pathway to elucidation of long-standing and fundamental questions about the mechanism of external cardiac massage. Larger prospective studies are needed to further understand the role of resuscitative TEE and its impact in clinical outcomes.

Conflict of interest

The authors declare that they have no competing interests.

Acknowledgements

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2019.02.013.

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