



Clinical paper

Focused echocardiographic evaluation in life support and peri-resuscitation of emergency patients: A prospective trial^{☆,☆☆}

Raoul Breitkreutz^{a,e,*}, Susanna Price^b, Holger V. Steiger^c, Florian H. Seeger^d, Hendrik Ilper^e, Hanns Ackermann^f, Marcus Rudolph^g, Shahana Uddin^h, Markus A. Weigandⁱ, Edgar Müller^j, Felix Walcher^k, from the Emergency Ultrasound Working Group of the Johann Wolfgang Goethe-University Hospital, Frankfurt am Main¹

^a Department of Anaesthesiology, Intensive Care and Pain Therapy University of the Saarland, Medical Faculty, D-66421 Homburg (Saar), Germany

^b Adult Intensive Care Unit, Royal Brompton & Harefield NHS Foundation Trust, London, United Kingdom

^c Department of Cardiology, Kerckhoff Heart Center, Bad Nauheim, Germany

^d Department of Cardiology, Johann Wolfgang Goethe-University Hospital, Frankfurt am Main, Germany

^e Clinics of Anaesthesiology, Intensive Care and Pain Therapy, Johann Wolfgang Goethe-University Hospital, Frankfurt am Main, Germany

^f Institute for Bioinformatics and Statistical Analysis, Johann Wolfgang Goethe-University Hospital, Frankfurt am Main, Germany

^g Department of Anaesthesiology and Intensive Care Medicine, Klinikum Ludwigshafen/Rhein, Germany

^h Department of Anaesthesia, Barts & the London NHS Trust, London, United Kingdom

ⁱ Department of Anaesthesiology, Intensive Care and Pain therapy, Justus-Liebig-University, Giessen, Germany

^j Emergency Medical Service of the Darmstadt Hospital, Germany

^k Trauma Surgery, Johann Wolfgang Goethe-University Hospital, Frankfurt am Main, Germany

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ABSTRACT

Purpose of the study: Focused ultrasound is increasingly used in the emergency setting, with an ALS-compliant focused echocardiography algorithm proposed as an adjunct in peri-resuscitation care (FEEL). The purpose of this study was to evaluate the feasibility of FEEL in pre-hospital resuscitation, the incidence of potentially treatable conditions detected, and the influence on patient management.

Patients, materials and methods: A prospective observational study in a pre-hospital emergency setting in patients actively undergoing cardio-pulmonary resuscitation or in a shock state. The FEEL protocol was applied by trained emergency doctors, following which a standardised report sheet was completed, including echo findings and any echo-directed change in management. These reports were then analysed independently.

Results: A total of 230 patients were included, with 204 undergoing a FEEL examination during ongoing cardiac arrest (100) and in a shock state (104). Images of diagnostic quality were obtained in 96%. In 35% of those with an ECG diagnosis of asystole, and 58% of those with PEA, coordinated cardiac motion was detected, and associated with increased survival. Echocardiographic findings altered management in 78% of cases.

Conclusions: Application of ALS-compliant echocardiography in pre-hospital care is feasible, and alters diagnosis and management in a significant number of patients. Further research into its effect on patient outcomes is warranted.

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Abbreviations: ALS, Advanced Life Support; GCS, Glasgow Coma Scale; ECG, Electrocardiogram; FEEL, Focused echocardiographic evaluation in life support; VF, Ventricular fibrillation; PEA, Pulseless electrical activity; EP, Emergency physician.

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* Corresponding author at: Department of Anaesthesiology, Intensive Care and Pain Therapy University of the Saarland, Medical Faculty, D-66421 Homburg (Saar), Germany.

E-mail address: raoul.breitkreutz@gmail.com (R. Breitkreutz).

¹ www.notfallsono.de.

1. Introduction

Pulselessness or severe shock of unknown origin is generally initially managed according to Basic and Advanced Life Support guidelines.^{1–3} Emergency echocardiography has been proposed as a basic diagnostic tool for the haemodynamically unstable critically ill patient, for acute severe dyspnoea, and during cardio-pulmonary resuscitation.^{4–8} Further, early echocardiography is now recommended in guidelines relating to the diagnosis of suspected pulmonary embolism or pericardial effusion.^{9,10} Focused

echocardiographic evaluation in life support (FEEL) has been developed to be used by cardiologists and non-cardiologists alike, as an adjunct to resuscitation in an ALS-compliant manner.^{11–13} The aim is to use FEEL to diagnose/exclude some of the potentially treatable causes of cardiac arrest, including tamponade, massive pulmonary embolism, severe ventricular dysfunction, and hypovolaemia as well as fine ventricular fibrillation missed by surface ECGs thereby optimizing peri-resuscitation care. Hence the use of FEEL is to improve resuscitative efforts but not to terminate resuscitation. The purpose of this study was to evaluate the feasibility of FEEL in pre-hospital resuscitation, the incidence of potentially treatable conditions detected, and the influence on patient management.

2. Methods

2.1. Study design

Ethical approval was obtained from the Institutional Ethics Committee for Human Studies, University Hospital, Frankfurt am Main, Germany. A prospective observational study with data acquisition controlled using STARD criteria for diagnostic trials and abbreviated Utstein-style data sets was performed.^{14,15}

2.2. Study setting

Patients were enrolled between August 2002 and December 2007. Four emergency medical systems (EMS) were involved: Frankfurt (urban), Darmstadt (urban and rural) and Raststatt (suburban). The EMS included paramedic-crewed ambulances with staff trained to perform standard cardio-pulmonary resuscitation (CPR) and an emergency physician (EP) trained in peri-resuscitation echocardiography, having undergone the standard FEEL training programme.¹² These EPs were able to independently obtain win-

dows, interpret peri-resuscitation emergency echocardiography pathologies and act independently on echocardiographic findings. The EP was a specialist in cardiology, internal medicine, surgery, anaesthesiology or paediatrics with an additional subspecialisation in pre-hospital emergency medicine. A modified hand-held ultrasound device (modified Tringa by Esaote, Wiesbaden, Germany) was used with a 3.5–5 MHz ultrasound probe¹⁶ (Frankfurt & Raststatt) and a standard ultrasound device (SonoSite i-Look 15, SonoSite GmbH, Erlangen, Germany) with a curved array probe (Darmstadt).

2.3. Study entry criteria

Patients with symptoms either of profound hypotension and/or severe dyspnoea/tachypnoea where judged by the EP to be in a peri-resuscitation state, and patients undergoing CPR were recruited. Patients were excluded if they refused echocardiography.

2.4. Protocol

On arrival of the EMS, patient assessment and management was as clinically directed by the resuscitation team, and peri-resuscitation echo implemented by the EP as per the FEEL protocol. Peri-resuscitation echocardiography was implemented during an ALS-conformed interruption of CPR of fewer than 10 s. Echocardiographic findings were documented from images taken from one of three standard echocardiography views (subcostal, parasternal or apical). Features noted were; cardiac motion (present or absent), ventricular function (normal, moderately impaired, severely impaired, absent), right ventricular dilatation or pericardial collection. In addition, the impact of echocardiographic information on management was documented, together with patient outcome. The form used for data collection is provided as online [supplementary material](#).

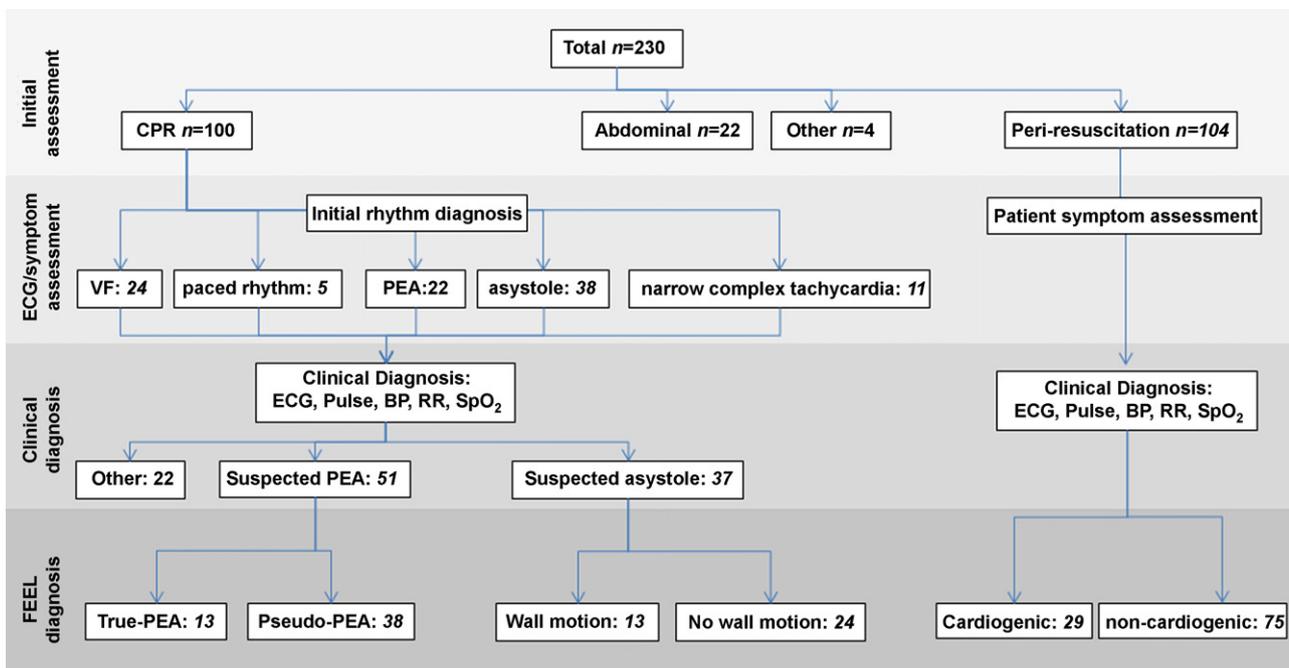


Fig. 1. The study profile is shown, comprising four stages: initial assessment, ECG/symptom assessment, standard clinical diagnosis, and diagnosis after performance of peri-resuscitation echocardiography (FEEL). CPR: cardio-pulmonary resuscitation; VF: ventricular fibrillation; paced rhythm: permanent pacemaker in situ and the only rhythm detectable on surface electrocardiogram was the presence of pacing spikes; PEA: pulseless electrical activity; ECG: electrocardiogram; BP: blood pressure; RR: respiratory rate; SpO₂: oxygen saturations; True-PEA: electrical activity on surface ECG with no cardiac motion detected on echocardiography (synonymous with electromechanical dissociation); Pseudo-PEA: electrical activity on surface ECG with cardiac motion detected on echocardiography but no palpable pulse; cardiogenic: cardiac cause for peri-resuscitation state diagnosed on echocardiography; non-cardiogenic: either no cardiac cause for peri-resuscitation state found on echocardiography, or another non-cardiogenic cause found (i.e. pneumothorax).

Table 1

Outcome of patients undergoing CPR undergoing ALS-compliant peri-resuscitation echocardiography. FEEL: focused echocardiographic evaluation in life support; PEA: pulseless electrical activity; Pseudo-PEA: electrical activity on surface ECG with cardiac motion detected on echocardiography but no palpable pulse.

Pre-FEEL diagnosis	Post-FEEL diagnosis	Survived to admission	Died on scene
Suspected PEA (n=51)	–	22 (43%)	29 (57%)
	Pseudo-PEA (n=38) (wall motion present)	21/38 (55%)	17/38 (45%)
	True-PEA (n=13) (no wall motion present)	1/13 (8%)	12/13 (92%)
Suspected asystole (n=37)	–	13/37 (35%)	24/37 (65%)
	Wall motion present (n=13)	9/37 (24%)	4/37 (11%)
	No wall motion present (n=24)	4/37 (11%)	20/37 (54%)
Pooled suspected PEA and asystole (n=88)	–	35/88 (40%)	53/88 (60%)
	Wall motion present	30 (34%)	21 (24%)
	No wall motion present	5 (6%)	32 (36%)

2.5. Data analysis

The data variables collected and analysed were: date, dispatch details, vital signs on arrival (blood pressure, oxygen saturation, Glasgow Coma Score (GCS), expired carbon dioxide, initial rhythm, presence of palpable central pulse), scan results (subcostal, parasternal and/or apical views), duration, timing and number of scans, and the influence of the scan on patient management. Categorical data are shown as absolute values, together with frequency distribution and range where appropriate. Continuous data are shown as mean \pm standard deviation and range.

3. Results

A total of 230 patients (male 141, female 84; age: 65 ± 19 years) were enrolled in the study (Fig. 1). CPR was required in 100 patients and performed according to the ALS guidelines. Peri-resuscitation echocardiography was performed in all of these cases according to the FEEL protocol. Echocardiography was used in an additional 104 cases where the patient was judged to be in a peri-resuscitation state (but not currently requiring CPR). In 26 cases ultrasound was used additionally for abdominal or vascular studies.

3.1. Findings in CPR (n=100)

The initial GCS was 3 in all but 5 patients requiring CPR, and no central pulse was palpable in 97 patients. ECG on arrival showed: asystole (n=38), ventricular fibrillation (n=24), PEA (n=22) sinus rhythm (n=8), supraventricular tachycardia (n=3), or paced rhythm (n=5). In 51% of patients undergoing CPR with an initial diagnosis of PEA, there was echocardiographically demonstrable cardiac motion in 38 (75%) suggesting “pseudo-PEA” (PPEA) (Fig. 1). In the remaining 13 (25%) there was no demonstrable wall motion, leading to diagnosis of “true-PEA” (TPEA), or electromechanical dissociation, EMD). In those with wall motion (PPEA), abnormalities recorded were reduced left ventricular function (22 patients, 59%), pericardial tamponade (5 patients, 9.8%), and a significantly dilated right ventricle (4 patients, 7.8%, Fig. 2). Hypovolemia as assessed by a low left ventricular end diastolic volume or inferior caval vein diameter was detected in 2 patients (3.9%). PPEA was associated with increased survival to hospital admission when compared with TPEA (Fig. 2).

In 37 patients where the initial ECG diagnosis was asystole, echocardiography demonstrated wall motion in 13 (35%), which correlated with increased survival to hospital admission (Table 1). Patients with true asystole (ECG + echo diagnosis) had low survival rates to hospital admission (Table 1).

3.2. Findings in peri-resuscitation care (n=104)

A peri-resuscitation state was diagnosed when at least one of the following criteria were found: severe hypotension, acute severe

dyspnoea, impaired consciousness with a reduced Glasgow Coma Score, cyanosis or SpO₂ of less than 92%, heart rate higher than 100/min or less than 60/min. Of 104/130 emergency patients fulfilling these criteria (Fig. 1), symptomatic hypotension was the main finding in 20% (n=29), acute severe dyspnoea in 36% (n=37), cyanosis in 2% (n=2), and impaired consciousness in 29% (n=30). None of the patients were undergoing mechanical CPR at the time of the scan. In this subgroup almost half of the patients had a cardiogenic and/or a treatable condition diagnosed using echocardiography (Table 2 and Fig. 3d).

3.3. Pericardial tamponade or effusions

The total number of pericardial collections detected was 5.4% in the overall study population. In the subset of cases undergoing CPR haemodynamically relevant collections were detected in a small but significant number of patients (PPEA 5/38; 13%, asystole 3/37; 8%). These collections were not demonstrated by ECG or other standard peri-resuscitation investigations. In the subset of PPEA cases with pericardial tamponade, return of spontaneous circulation (ROSC) was gained successfully after pericardiocentesis, with patients surviving to hospital admission (Fig. 2).

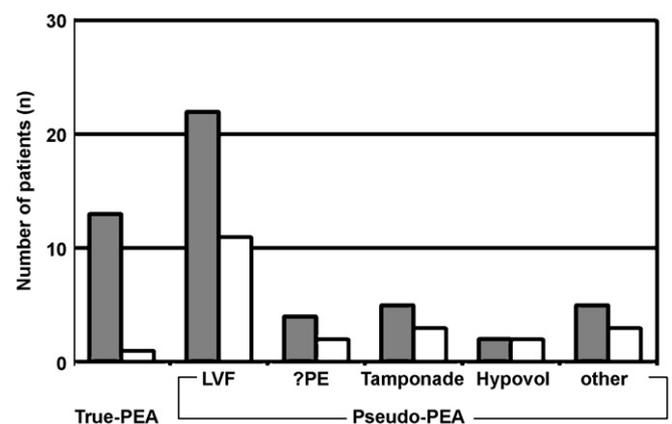


Fig. 2. The correlation between the echocardiographic diagnosis of cardiac arrest, and survival to hospital admission. On the x-axis is shown the diagnosis, and on the y-axis the number of patients. The total number of patients in each diagnostic category is shown in solid bars, and the number surviving to hospital admission in clear bars. Suspected pulmonary embolism indicates FEEL-related findings of acute right heart dilatation, paradoxical septal movement or septal flattening. Pericardial tamponade was identified as a combination of pericardial effusion by echocardiography and CPR. Others indicate subarachnoid hemorrhage (n=2), initial asystole changing to PEA associated with acute myocardial infarction (n=3). True-PEA: electrical activity on surface electrocardiogram with no cardiac motion detected on echocardiography (synonymous with electromechanical dissociation); Pseudo-PEA: electrical activity on surface ECG with cardiac motion detected on echocardiography but no palpable pulse; LVF: left ventricular failure; ?PE: probable pulmonary embolism; Hypovol: severe hypovolaemia.

Table 2

Clinical and echocardiographic features of patients in the peri-resuscitation arm of the study. The numbers indicate cases in which the FEEL exam identified or ruled out a cardiogenic cause or specific treatable cause of the peri-arrest state. In seven cases more than one pathological finding was detected. Inconclusive findings were noted in four cases.

Peri-resuscitation symptom	Cardiogenic cause	Non-cardiogenic cause
Acute severe dyspnoea	12	10
Syncope	2	3
Chest pain	7	14
Acute severe hypotension	6	5
Cyanosis	2	0
Total	29	32
Specific question/diagnosis (treatable conditions)	Ultrasound findings rule out	Ultrasound findings rule in
Pericardial effusion	10	4
Pulmonary embolism ^a	8	5
Hypovolemia ^b	2	8
Pleural effusion ^c	7	8
Pneumothorax	0	2
Total	27	27

^a Signs for pulmonary embolism included septal flattening, paradoxical septal motion or dilatation of the right ventricle.

^b Hypovolemia was assessed both by eye-balling of the ventricles and inferior cava vein diameter and collapsibility.

^c Lung ultrasound was formally not included into the FEEL procedure.

Analysis of the peri-resuscitation cases revealed additional 4 with a pericardial collection (Table 2), of which two were judged to be haemodynamically significant, requiring on-site pericardiocentesis. In 2 cases pericardial effusion was suspected from QRS alternans on the surface ECG, but were excluded using echocardiography.

Pericardiocentesis was performed in a total of 7 cases, however, drainage of the pericardial collection was unsuccessful in three of these cases because of the lack of adequate equipment.

3.4. Integration into ALS management and consequences of the use of FEEL

In patients undergoing CPR, FEEL was implemented by the EP after initiating standard ALS interventions (Fig. 2a). In peri-

resuscitation FEEL was performed after the ECG as a means to complement ECG analysis (Fig. 2b). The findings from FEEL performed both as part of CPR or as part of the management of the peri-resuscitation state were perceived by the treating EP to warrant a change in therapy in 89% and 66% of cases respectively (Fig. 3c and d), including initiation of pericardiocentesis, administration of fluid or initiation of inotropic therapy. In addition to directly resulting in an alteration in medical therapy, the findings from FEEL resulted in a change in the choice of destination hospital in a significant number of patients (Fig. 3c and d).

3.5. Imaging quality in CPR and peri-resuscitation

In all cases undergoing CPR, at least one echocardiographic window was successful in imaging the heart and providing diagnostic

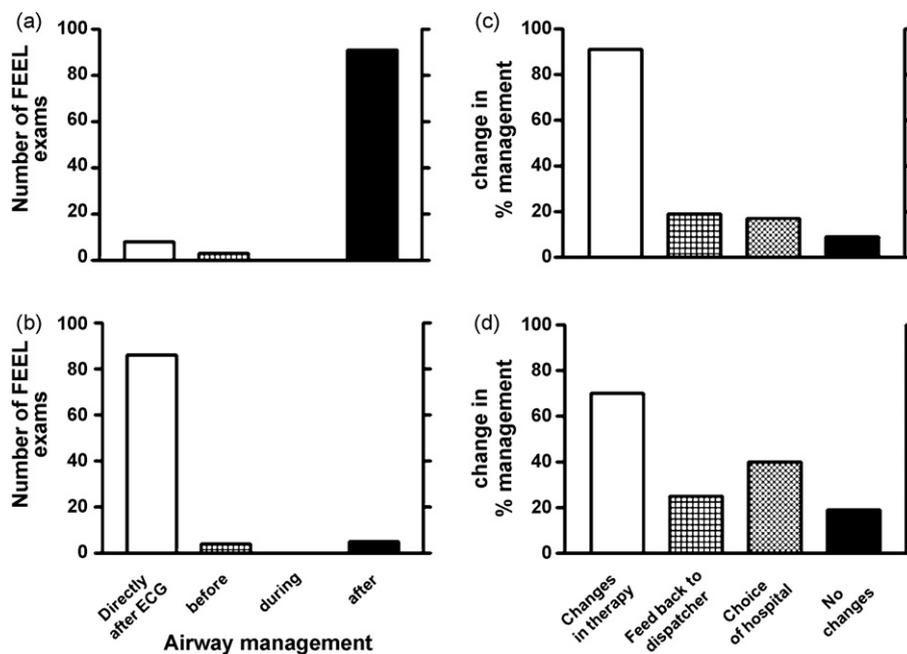


Fig. 3. Time-point for the application of the FEEL exams (a and b) and influence of the echocardiographic findings upon subsequent patient management (c and d). (a) CPR: emergency physicians were requested to apply FEEL in an ALS-compliant manner. FEEL was predominantly applied after intubation/airway management was judged to be complete. (b) Peri-resuscitation: FEEL was predominantly applied directly after ECG analysis. (c) Peri-resuscitation: emergency physicians recorded whether the results from the echocardiographic examination had altered management at the scene. (d) Peri-resuscitation: emergency physicians recorded whether the results from the echocardiographic examination had altered management at the scene. Changes in therapy mainly included medical therapy but additionally pericardiocentesis (see text for details).

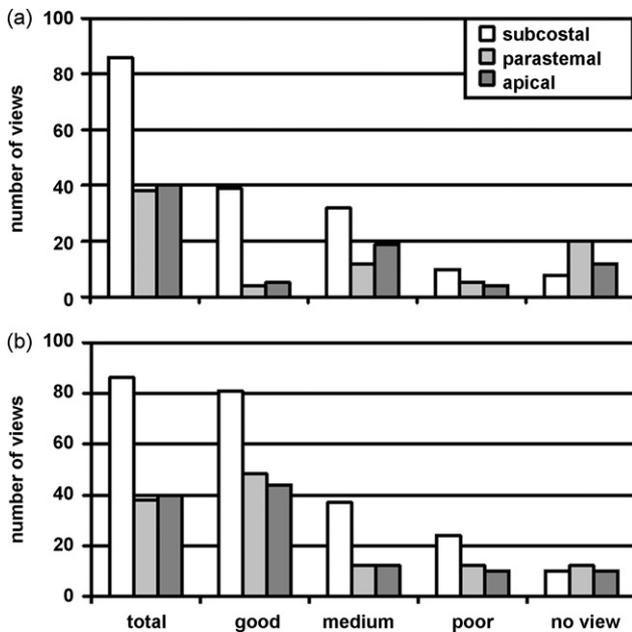


Fig. 4. Evaluation of the image quality obtained using FEEL. Patients were imaged in the supine position (a) during CPR, and (b) in the peri-resuscitation state. The best image quality was obtained predominantly using the subcostal window, which only rarely did not provide a view of the heart adequate for diagnosis. Both graphs show absolute numbers of views in 100 CPR cases and 104 peri-resuscitation cases with one or more exam per patient.

information. In this group the total number of echocardiographic views obtained was 154 (subcostal $n=86$, parasternal $n=38$, apical $n=40$) (Fig. 4a). The subcostal view was predominantly used, providing a higher success rate in comparison to the other views and with better imaging quality (Fig. 4a). In the non-CPR group, EPs achieved successful cardiac imaging using FEEL in 95 cases. Unlike studies performed during CPR, more than 50% of the findings were also obtainable from the parasternal and apical approach (Fig. 4b).

4. Discussion

The concept of ALS-compliant echocardiography using the FEEL algorithm is gaining acceptance.^{11–13,36} This study demonstrates that FEEL can be performed in the pre-hospital setting, resulting in the diagnosis of a significant number of potentially treatable underlying conditions and subsequent alteration in patient management.

The use of echocardiography or ultrasound by novice practitioners has been shown to be feasible in the emergency setting, with success in obtaining images and interpretation leading to a reduction in the differential diagnosis.^{4,16,17,25} Further, focused echocardiography has been shown to improve the diagnostic accuracy of shocked patients even when undertaken by relatively inexperienced practitioners. In this study, specialised EPs trained in BLS/ALS and ALS-compliant peri-resuscitation echocardiography were able to perform studies successfully in the pre-hospital setting, obtaining interpretable images in the majority of patients, and to use this data to inform patient management. Concerns have been raised regarding the image quality of portable US machines confounded by suboptimal lighting in the pre-hospital setting. These concerns were not supported in the current study, as adequate images were obtainable in all patients undergoing CPR and 91% of cases in the non-CPR group. This study did not aim to determine the accuracy of images as echocardiograms were obtained by competent practitioners and these studies have been published elsewhere. The concept of accuracy of interpretation in this patient population raises the question as to what should be regarded

as the gold standard; interpretation by an expert echocardiographer (cardiologist/sonographer) who is not necessarily trained in peri-resuscitation echocardiography, nor experienced in the investigation and management of the critically ill, or interpretation by an expert in peri-resuscitation management including interpretation of peri-resuscitation echocardiography.

Peri-resuscitation echocardiography provides an immediate bedside assessment of whether the patient has cardiac arrest, or merely a catastrophically low cardiac output. Further, the use of ALS-compliant peri-resuscitation echocardiography additionally provides the resuscitation team with the tools to diagnose/exclude some of the potentially treatable causes of cardiac arrest listed in the Resuscitation guidelines.^{1–3} Detection of cardiac output during cardiac arrest is generally performed by palpating central pulses and/or non-invasive blood pressure measurement. Both of these measures may be inaccurate or unhelpful.^{26–29} Up to 45% of health-care professionals may erroneously detect potentially palpable central pulses, resulting in prolonged periods of no chest compression and premature cessation of resuscitation efforts.^{27,29,35} Further, non-invasive blood pressure measurements at pressures <80 mmHg are unreliable, and may take significantly longer than the recommended 10 s maximal interruption of chest compressions during CPR.^{28–32} It is well-recognised that focused echocardiography can be used to identify the presence/absence of cardiac kinetic motion during CPR,^{6–8,19–21} however the prognostic significance remains unknown.^{7,8,22,23} Using ALS-compliant peri-resuscitation echocardiography we demonstrated that 35% of patients with an ECG diagnosis of asystole had ongoing co-ordinated cardiac motion (associated with a survival benefit to hospital admission). The ECG performance and interpretation were by experienced practitioners, and this therefore raises questions regarding the accuracy of an ECG diagnosis of asystole in the pre-hospital setting.^{7,8,22,37}

Echocardiography in the peri-resuscitation setting may have a further role in determining whether the patient has “pseudo-PEA” (co-ordinated electrical activity, no palpable pulse, but with co-ordinated cardiac activity) or “true-PEA” (electrical activity but no detectable cardiac motion and no palpable pulse).^{6,18,20} The latter could now with accuracy be labelled electromechanical dissociation (EMD), and the former PEA. The relevance of this differential has yet to be determined, however, the potential relevance may be inferred from the outcome data and findings in the critical care setting. Thus, EMD confers a poor prognosis with only 8% surviving to hospital admission. By contrast, PEA (co-ordinated electrical activity, no palpable pulse, but with co-ordinated cardiac activity) confers a better prognosis with 55% surviving to hospital admission. This survival benefit was further improved where a potentially treatable cause was found on echocardiography. An analogous scenario is the critical care setting, where patients have invasive arterial blood pressure monitoring thereby negating the requirement for palpation of an arterial pulse. Here, where pulse pressure is low, a potentially treatable cause is sought whilst providing appropriate titrated cardiovascular support to the patient. Thus, the echocardiographic distinction of EMD vs PEA may prove relevant in the future with respect to prognostication and also optimisation and more tailored administration of peri-resuscitation drug therapy.

4.1. Influence on patient management

The ALS-algorithm suggests practitioners should seek potentially treatable conditions for cardiac arrest, but do not yet suggest how this might be performed.^{1–3,26} Peri-resuscitation echocardiography addresses these requirements to some extent, with potential diagnoses of tamponade, profound hypovolaemia, myocardial insufficiency (severe left and/or right ventricular dysfunction) or thromboembolism (pulmonary or cardiac).^{11,12,36} Some would also

suggest that the diagnosis of tension pneumothorax may also be made,^{38–40} although it is generally regarded a clinical diagnosis and to date no study has been performed to determine whether peri-resuscitation US is more or less sensitive and/or specific than clinical assessment in this scenario. Our data, in line with that from others^{19,20,25,38} suggest that there is a relatively high frequency of pericardial collection, which can be demonstrated by an EP in the peri-resuscitation state. It has been shown that EPs or intensivists with brief and specific training in focused echocardiography can assess left ventricular function relatively accurately.^{33,34} In the current study in patients undergoing CPR with ongoing cardiac motion in addition to those with tamponade as a diagnosis, 59% were found to have reduced LV function, 8% to have a significantly dilated RV, and 4% to be significantly hypovolaemic as the primary echocardiographic finding. Although the total numbers are small in this study, the potential implications if performed routinely during CPR as part of the ALS-algorithm are clear. In the peri-resuscitation setting shock due to a cardiac cause is thought to have an adverse outcome and therefore recognition of the diagnosis and exclusion of potentially treatable causes is key where possible.^{4,24,25} In both studies,^{4,25} >50% were found to have a cardiogenic and/or a treatable cause for their shock state, and in the latter patient management was directly altered as a result of echocardiographic findings in 51% of cases.²⁵ If this is translated into a survival benefit then the potential implications for the implementation and use of peri-resuscitation echo in the pre-hospital setting are clear. Ongoing challenges include training and education, and provision of appropriate equipment for diagnosis and potential interventions. Currently peri-resuscitation echocardiography is being taught to doctors from acute specialties and resuscitation officers.^{12,21,36,41} Wider implementation and further research should determine whether its application improves outcomes in the peri-resuscitation setting.

4.2. Limitations

The present study was not randomised due to local ethical constraints, and the study was not designed to determine image interpretation or survival beyond hospital admission. The main emphasis of the present study was concerning the feasibility of performing the FEEL exam within the pre-hospital setting. The lack of gold standard in comparison of echocardiography findings in the pre-hospital emergency setting, together with the technical limitations imposed by equipment meant that not all images were later independently reviewed. All EPs were trained in a standardised manner in performance and interpretation of peri-resuscitation echocardiography.^{11,12} An interesting future avenue for research would include the use of telemedicine to allow real-time or later evaluation of echocardiographic findings determine the added value of interpretation by a senior echocardiographer.

Future studies are needed to determine the accuracy of diagnosis in this setting, to establish a gold standard of peri-resuscitation echocardiography interpretation, and the effects on patient outcomes. In addition, further research is needed into the implications of the various echocardiographic findings upon optimal patient management during resuscitation.

5. Conclusion

Out-of-hospital echocardiography using FEEL is feasible, and can be performed by EPs. The findings of this study call into question some of the peri-arrest diagnoses that are made, and demonstrate that echocardiography can be used in the pre-hospital setting to diagnose many of the potentially reversible causes of cardiac arrest, not identifiable by any other means, thereby changing patient

management. The potential to improve patient outcome, and the implications upon fine-tuning the management of cardiac arrest remain to be evaluated.

Conflict of interest

There are no conflicts of interest to declare.

Author contributions

RB, FHS, FW designed the study. HVS, FS reviewed results for the study protocol. EM, FHS and FW performed data collection. RB, HS, HI, HA, EM, FW analysed the data. RB, MAW, SU and SP prepared and revised the manuscript. RB, HVS, EM and FW take responsibility of the results and the paper as a whole.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.resuscitation.2010.07.013.

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