Focused echocardiographic evaluation in resuscitation management: Concept of an advanced life support–conformed algorithm

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Emergency ultrasound is suggested to be an important tool in critical care medicine. Time-dependent scenarios occur during preresuscitation care, during cardiopulmonary resuscitation, and in postresuscitation care. Suspected myocardial insufficiency due to acute global, left, or right heart failure, pericardial tamponade, and hypovolemia should be identified. These diagnoses cannot be made with standard physical examination or the electrocardiogram. Furthermore, the differential diagnosis of pulseless electrical activity is best elucidated with echocardiography. Therefore, we developed an algorithm of focused echocardiographic evaluation in resuscitation management, a structured process of an advanced life support–conformed transthoracic echocardiography protocol to be applied to point-of-care diagnosis. The new 2005 American Heart Association/European Resuscitation Council/International Liaison Committee on Resuscitation guidelines recommended high-quality cardiopulmonary resuscitation with minimal interruptions to reduce the no-flow intervals. However, they also recommended identification and treatment of reversible causes or complicating factors. Therefore, clinicians must be trained to use echocardiography within the brief interruptions of advanced life support, taking into account practical and theoretical considerations. Focused echocardiographic evaluation in resuscitation management was evaluated by emergency physicians with respect to incorporation into the cardiopulmonary resuscitation process, performance, and physicians' ability to recognize characteristic pathology. The aim of the focused echocardiographic evaluation in resuscitation management examination is to improve the outcomes of cardiopulmonary resuscitation. (Crit Care Med 2007; 35[Suppl.]:S150–S161)

Key Words: emergency echocardiography; focused echocardiographic evaluation in resuscitation; resuscitation; cardiopulmonary resuscitation; algorithm; critical care ultrasound

In emergency and critical care medicine, the old and new American and European resuscitation guidelines of the American Heart Association, European Resuscitation Council, and the International Liaison Committee on Resuscitation (1–4) recommended identifying and treating correctable causes of cardiopulmonary arrest. Patients must be treated using algorithm-based management such as basic life support (BLS) and advanced life support (ALS). Time is an essential component for successful cardiopulmonary resuscitation (CPR) (5). Any diagnostic procedures and interventions must yield quick results to identify the underlying cause. "Point-of-care focused ultrasound" or "goal-directed ultrasound" in the evaluation of nontraumatic, symptomatic, undifferentiated hypotension in adult patients results in a narrower differential diagnosis and a more accurate physician impression of final diagnosis (6). These authors have shown that, in emergency rooms, the immediate application of sonography could result in improved patient outcome (6). Myocardial function during CPR is still underdiagnosed and remains a "black box" in most cases. Potentially treatable causes of sudden cardiac arrest, such as pericardial tamponade, cardiogenic shock, myocardial insufficiency (resulting from coronary or pulmonary artery thrombosis), or hypovolemia, should be detected or excluded as soon as possible, even on scene.

Important treatable causes of asystole are large, hemodynamically relevant pericardial effusions, which are regularly found after thoracic and cardiac surgery and in nontrauma in-hospital emergencies (7, 8). Another important issue is the differential diagnosis of pulseless electrical activity (PEA), which essentially requires echocardiography to either rule in or rule out critical findings (9–13). However, the new European Resuscitation Council 2005 guidelines recommend echocardiography in PEA or asystole after cardiotomy only, but they do not stipulate how it is to be performed (7). Furthermore, the new American Heart Association/European Resuscitation Council/International Liaison Committee on Resuscitation 2005 resuscitation guidelines set narrow time intervals for echocardiographic examination, due to potential detrimental effects and the requirement of rebuilding coronary perfusion pressure (14). Pauses in chest compression were recommended to be "brief interruptions" for adult ALS (4, 7) and of a maximum of 10 secs for pediatric ALS (15) to reduce the duration of no-flow intervals (NFIs), thereby limiting potential transthoracic ultrasound examinations. Unfortunately, there is a lack of recommendations regarding time frames of any interruptions,

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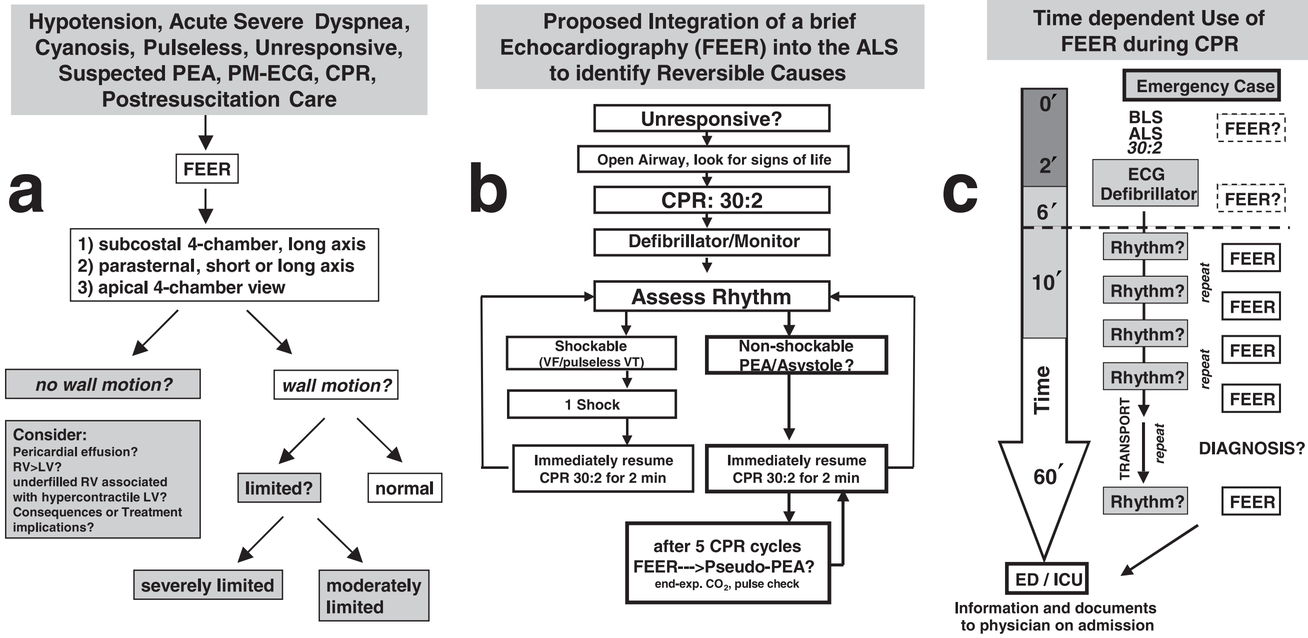

Figure 1. Focused echocardiographic evaluation in resuscitation management (*FEER*) in emergency and critical care medicine. Algorithm with indications and workflow (*a*); integration into advanced life support (*ALS*) (*b*); road map of repeated use of FEER during resuscitation stages (*c*). FEER has to be completed within 5 secs during pauses of cardiopulmonary resuscitation (*CPR*). *PEA*, pulseless electrical activity; *PM-ECG*, pacemaker–electrocardiogram; *RV*, right ventricle; *LV*, left ventricle; *VF/pulseless VT*, ventricular fibrillation/pulseless ventricular tachycardia; *end-exp. CO_2*, end-expiration CO_2; *BLS*, basic life support; *ED/ICU*, emergency department/intensive care unit.

and no specific time intervals are given for a maximum duration of rhythm analysis or other standard care interventions.

A major challenge is recognizing return of spontaneous circulation when no central pulse is palpable. New evidence is available that a "subclinical" return of spontaneous circulation (mechanical cardiac output) can be detected with the use of an echocardiogram (9, 12). We know that even health professionals are insecure and take too long in detecting a carotid pulse or respiratory effort (16–19). Standard measurements, including peripheral oxygen saturation with pulse curve or noninvasive blood pressure measurement, are unreliable in severe hypotension or shock, and it can take >10 secs to obtain such a critical result (2, 15). In fact, such measures have not been studied as independent markers during CPR. Only limited evidence is available on strategies using end-tidal CO_2 measurement (20).

Any CPR, regardless of the environment, is a relatively chaotic situation, potentially involving several health professionals. Consequently, a structured process for a focused echocardiographic examination and for recognition of relevant pathology during resuscitation management is mandatory. This type of echocardiography also has to conform to the universal ALS algorithm (1–3, 15). Therefore, we developed a simple algorithm of focused echocardiographic evaluation in resuscitation (FEER) to be performed in a time-sensitive manner (21) (Fig. 1, Table 1).

Focused Echocardiographic Evaluation in Resuscitation: Practical Considerations

The FEER examination is a ten-step procedure (Table 1). Its structure is designed to be executed simultaneously during CPR cycles to prevent any increase in the duration of the NFI and to reduce unwanted interruptions. It includes a practical approach that can be separated into four distinct phases. The practical approach of the FEER examination follows in more detail.

Preparation Parallel to CPR. In the first phase, high-quality CPR should be initiated (1–3, 15) by at least two rescuers according to the resuscitation guidelines. The preparation of the FEER examination starts with informing the rescue team that a qualified person, the emergency physician (EP) or intensivist (INT), is preparing to obtain an echocardiogram. Preparation includes removing clothes from the patient as needed, preparing the ultrasound device and ultrasound gel, and most importantly, the EP/INT themselves have to adapt to the patient's supine position. The probe should be loaded with transmission gel, be functionally tested, and be kept ready to start. These steps are important to minimize CPR interruption time. The preparation phase ends with signaling the team to be ready to perform an echocardiogram.

Obtaining an Echocardiogram Within Approximately a 5-sec Pause of CPR. In the second phase, one rescue team member should be selected to count down 10 secs and to palpate the carotid pulse simultaneously within the interruption. Thereafter, the examiner should give a concise command, "Interrupt at the end of this cycle for echocardiography," to the team. Parallel to the chest compressions, the examiner should palpate the patient's xiphoid and press the probe during the final chest compressions, about 2 cm, slightly to the right side lower in the subxiphoid region and in a flat angle (10 degrees) relative to the abdomen to obtain a glimpse of the ventricles. On discontinuation of chest compression, the probe must be positioned and calibrated as fast as possible to gain a complete four-chamber view from the subcostal window. The ventricles, atria, and valves should be visualized in one view (12). Ideally, a description of the real-time observation should be reported directly to

Table 1. Focused Echocardiographic Evaluation in Resuscitation (FEER) management examination in ten steps[a]

Phase	Step with Command, Element
High-quality CPR, preparation, team information	1) *Perform* immediate and accurate BLS and ACLS according to AHA/ERC/ILCOR guidelines, at least five cycles of chest compression/ventilation
	2) *Tell* the CPR team: "I am preparing an echocardiogram"
	3) *Prepare* portable ultrasound (let prepare) and *test* it
	4) *Accommodate* situation (e.g., best position of patient and doctor, removal of clothes), be ready to start
Execution, obtaining the echocardiogram	5) *Tell* CPR Team to count down 10 secs and to undertake a pulse check simultaneously
	6) *Command:* "Interrupt at the end of this cycle for echocardiography"
	7) *Put* the probe gently onto the patients subxiphoidal region during chest compressions
	8) *Perform* a subcostal (long axis) echocardiogram as quickly as possible. If you cannot identify the heart after 3 secs, stop the interruption and repeat again five cycles later and/or with the parasternal approach.
Resuming CPR	9) *Command* after 9 secs at the latest: "Continue CPR" and control it
Interpretation and consequences	10) *Communicate* (after continuation of chest compressions only) the findings to the CPR team (e.g. wall motion, heart is squeezing, cardiac stand still, (massive) pericardial effusion, no conclusive finding, suspected pulmonary artery embolism, hypovolemia) and *explain* consequences and follow-up procedure

CPR, cardiopulmonary resuscitation; BLS, basic life support; ACLS, advanced cardiac life support; AHA/ERC/ILCOR, American Heart Association (AHA), European Resuscitation Council (ERC), and the International Liaison Committee on Resuscitation (ILCOR).

[a]A practical approach is depicted. Because CPR interruption is limited to a maximum of 10 secs within the advanced life support, it is necessary to give *clear commands.* Note that the echocardiogram is undertaken after clear preparation only in step 8.

Table 2. Potential echocardiographic findings during cardiopulmonary resuscitation[a]

Possible Echocardiographic Findings	(Qualitative) Diagnoses
Wall movement	Circulation present
No wall movement in asystole, pulselessness, PEA, other rhythms	Proven cardiac standstill
Limited pump function Severely limited Moderately limited	Myocardial insufficiency
Wall motion, pulselessness, regular rhythm	Pseudo-PEA
No wall motion, pulselessness, regular rhythm	True PEA
Hypercontractile ventricular walls, underfilled right ventricle and atrium, hypotension, tachycardia, "kissing" trabecular muscles	Hypovolemia
Enlarged right ventricular cavum, "D-sign"	Suspected pulmonary artery embolism
Pericardial effusion (small or massive) and pericardial tamponade	Pericardial effusion (small or massive), with or without functional relevance, tamponade
No conclusive finding	No diagnosis

PEA, pulseless electrical activity.

[a]Note that the physician has to be trained to quickly recognize possible echocardiographic findings according to the Focused Echocardiographic Evaluation in Resuscitation (FEER) management examination to identify the corresponding diagnoses.

the rescue team. Statements may include, "heart is squeezing/contracting," "wall motion detectable," "heart is motionless/still," "enlarged right ventricle," "pericardial effusion," or "hypovolemia" (Tables 1 and 2). When the countdown is at 5 secs, the EP/INT must inform the rescuers to continue chest compressions.

Evaluation of the Echocardiogram While Continuing CPR. The third phase involves a continuation of high-quality CPR and evaluation or playback of the echocardiogram results. Ideally, the echocardiogram should not be repeated until compressions and ventilation have been restarted and allowed to continue for at least five more cycles, including rhythm analysis (Fig. 1, *b* and *c*). Depending on the device, the EP/INT may resume the video "loop" while CPR continues and show it to any colleague that may have arrived at the scene or discuss it later. One may reconsider the observation and come to a clear diagnosis or should state "no significant observation" or "bad quality" if no valuable result was found due to approach or quality of the image. Note that only a precise interpretation and documentation may be of use and will be supported by further specialist treatment.

Results, Follow-Up Information, and Consequences. In the fourth phase, the EP/INT should clearly communicate his or her findings and state follow-up consequences to the team. A decision should be made if and when to repeat FEER.

Scientific and Clinical Basis of ALS-Conformed Echocardiography

The most limiting factor in applying FEER within CPR is thought to be the danger of a prolonged NFI. With a strong emphasis on this issue, several questions have to be answered scientifically.

What Are the Indications for an Immediate "Emergency Echocardiography"? There are only a few indications to perform an emergency echocardiogram, which are listed in Table 3. One should perform an echocardiogram in preresuscitation care, during CPR itself or in post-resuscitation care, and once circulation has been established to optimize cardiac output by adapting vasopressors (22–24).

How Should an Echocardiogram During Resuscitation Management Be Performed? The standardized sequence to obtain a routine echocardiogram is normally parasternal-apical-subcostal in a patient who is turned on his or her left side. The subcostal window represents only an optional view. However, a patient undergoing CPR is normally in a supine position and artificial ventilation is likely. Because the heart is easier to access with artificial ventilation during inspiration, the FEER examination starts with the subcostal window (25). If this option fails,

Table 3. Indications for an immediate echocardiography in periresuscitation care

Preresuscitation care	Penetrating trauma, blunt trauma
	Postcardiotomy due to cardiac surgery
	Hypotension, shock of unknown origin
	Unconsciousness, unresponsiveness
	Acute severe dyspnea
	Syncope in young adults
	Vein thrombosis
	Acute myocardial infarction (AMI), mechanical complications of AMI
	"Atypical" chest pain: suspected aortic dissection, suspected aortic abdominal or thoracic aneurysm, nontraumatic cardiac rupture
	Iatrogenic complications because of invasive procedures (e.g. insertion of an artificial pacemaker, pulmonary artery catheter, electrophysiologic investigative procedures)
	Great-vessel disease
Resuscitation (CPR)	Pulseless electrical activity
	Suspected cardiac tamponade
	Early detection of ROSC
	Bradycardia-asystole, pacemaker-ECG
	Performance of CPR
	Effectiveness of chest compressions
Postresuscitation care	Hypotension, adaptation of vasopressors

CPR, cardiopulmonary resuscitation; ROSC, return of spontaneous circulation; ECG, electrocardiogram.

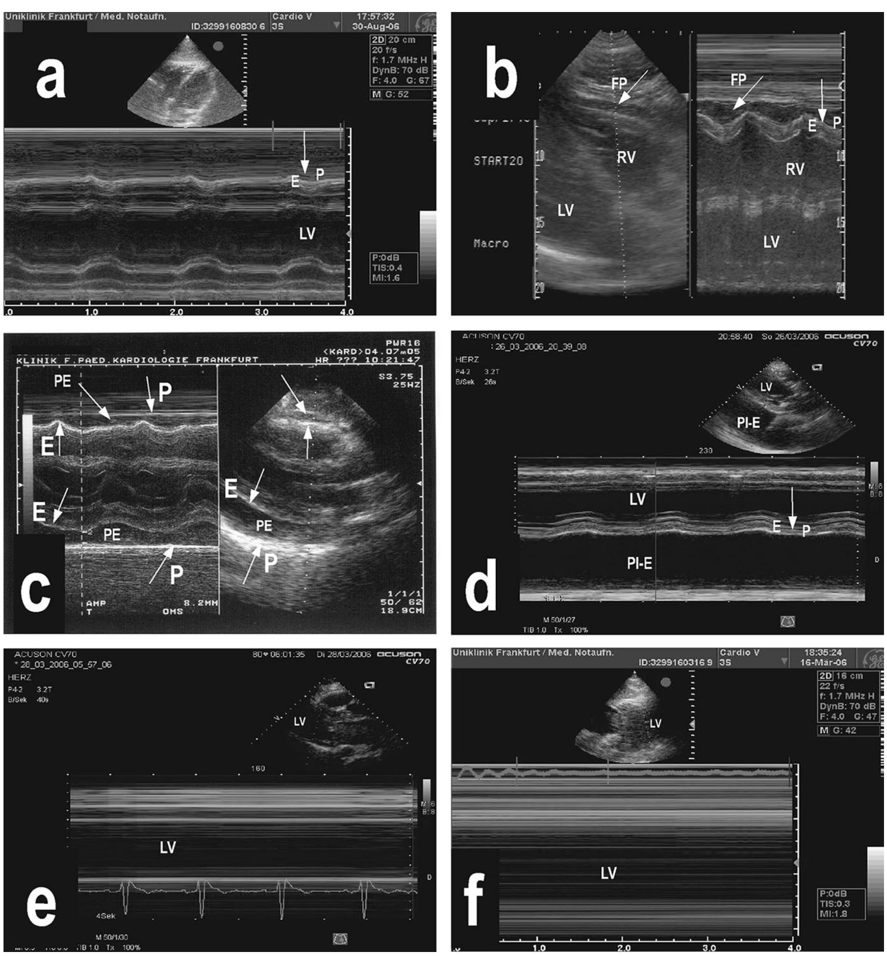

Figure 2. Use of M-mode in emergency echocardiography. *a* and *b*, Normal wall motion (subcostal window, long axis). *LV/RV*, left or right ventricular cavum; *FP*, anterior fat pad. Note that the pericardium (*P*) follows the epicardium (*E*) in waveforms and that E/P are tight together. *c–f*, Parasternal window, long axis. *c*, Pericardial effusion (*PE*); note that P and E are separated by the PE and that P is found as a flat line. *d*, Pleural effusion (*Pl-E*); the LV is clearly identified with unseparated posterior E and P. *e*, True pulseless electrical activity, regular electrocardiographic rhythm without wall motion. *f*, Cardiac standstill, no regular electrocardiographic rhythm or wall motion.

it uses the parasternal window, long-axis, or short-axis view and only later the apical four-chamber view if there is insufficient visualization. In addition, the FEER examination for nonexpert sonographers requires simplification in the context of a time-dependent investigation. It does not claim absolute quantitative accuracy. Therefore, it uses "eye-balling" (26), or a semiquantitative measurement of myocardial function with the educated eye.

How Should an Emergency Echocardiogram Be Documented? In principle, portable echocardiography has to fulfill the same image quality requirements as standard techniques (27). Any documentation must contain valid data with the option to be re-evaluated at a later time. It is important to show the valves clearly to provide a complete and standard view of the heart. Regarding bradycardia-asystole, with a suspected cardiac frequency down to 20 beats/sec, a record of an examination should contain a loop of video of >3 secs. Another option is to document an M-mode picture, which enables a *post hoc* analysis of wall movement, pericardial effusion, or enlarged right ventricle, all in only one picture (Fig. 2). A standard M-mode picture is normally obtained from the parasternal long-axis window. When an M-mode from the subcostal window is used, it has to show clear anatomic structures. This is best performed by a tiled B- and M-mode in one picture (Fig. 2). To document PEA findings, an M-mode echocardiogram containing the electrocardiographic stripe may be suitable.

When Should an Echocardiogram During CPR Be Performed? Does an ALS-Based Echocardiogram Interfere with Phases, Intervals, or Any Other Intervention During CPR? Is the Patient Harmed by Interrupting CPR? There are several limitations. Any pause in CPR is potentially harmful because it may decrease the probability of return of cardiac function (14). In principle, FEER could be applied during the BLS. The first diagnostic block with an approximate time frame of 10 secs mainly addresses "look, listen, and feel" (1–4, 15) for health professionals (Fig. 1*c*). No studies could be found supporting primary use of echocardiography to detect signs of life (signs of circulation), although it is assumed that it would be highly sensitive and specific and at least as good as checking for breathing or pulses (16–19). An echocardiogram could also be performed in parallel to rhythm analysis. Although, theoretically, there should be no electrical interference from either electrocardiography or ultrasound equipment, this possibility has not been well studied. Niendorff et al. (28) used emergency cardiac sonography stepwise after an initial assessment of the patient with suspected PEA during the next noticeable pause of the rescue team. Although look, listen, and feel also addresses the assessment of "signs of circulation" or "signs of life" in brief pauses in CPR, ALS-conformed echocardiography may be faster and more sensitive than any clinical observation. More conservatively, we actually apply FEER in ongoing CPR only after 6 mins, when high-quality CPR was initiated and rescuers performed CPR cycles regularly. Only after having performed a minimum of five additional CPR cycles (2 mins) after the last rhythm analysis is an interruption considered (1, 2, 4). Because there is no rule to terminate resuscitative efforts, one should continue CPR for 20–45 mins (or even longer if indicated) (29) when there may be some occasions to utilize FEER.

We analyzed typical phases and interruption intervals during BLS/ALS to identify relevant time windows for dummy-echocardiography and hypothesized that this intervention will not result in prolongation of sensitive time intervals during CPR. Eighteen groups of paramedics performed a two-rescuer CPR scenario (30). Equipment included: Resusci Anne (Laerdal, Stavanger, Norway), semiautomated defibrillator (Zoll Medical, Cologne, Germany), and a handheld ultrasound device. In a randomized fashion, a third person was allowed to use any interruption to apply dummy-echocardiography without disturbing CPR workflow. Prospectively, a protocol defined five regular phases within BLS and ALS. All sequences were recorded and analyzed in relation to specific time intervals within these phases. Here, only the "old" BLS/ALS algorithm was analyzed because the studies began before November 2005. BLS/ALS-related interruptions were (numbers are seconds ± SD): 1) BLS: 34 ± 3; 2) two breaths, 15 chest compressions (CPR cycle): 23 ± 12; 3) applying electrocardiography and analysis: 35 ± 8; 4) parallel airway management: 224 ± 67; and 5) rhythm analysis and three defibrillations: 40 ± 5. No non-ALS–based interruptions occurred in this model. The results also showed that there were no differences in the number and duration of NFIs with or without dummy-echocardiography between the groups (Fig. 3).

Interestingly, dummy-echocardiography performed by a third person induced improved regularity of performance of the CPR cycles themselves. Taken together, several time windows exist for a third person to perform echocardiography during a two-rescuer scenario. A prolongation of CPR cycles, other phases, or increased NFIs seemed to be unlikely in this model. Nevertheless, these preliminary results have to be reconfirmed in ongoing work regarding the effect of the new 2005 resuscitation guidelines to markedly reduce the NFIs (Fig. 3, *lower bar*). Salen et al. (9) and Niendorff et al. (28) both recently published results of ALS-based echocardiography. However, besides Bocka et al. (12), who initially admitted 5-sec interruptions to obtain echocardiograms during CPR, only Niendorff et al. (28) precisely mentioned the real time frame of seven valid examinations. In this study, for rapid cardiac ultrasound of inpatients with PEA arrest by nonexpert sonographers, average emergency sonography was 19.6 secs, although it was planned not to last longer than 10 secs (28). One may also keep in mind that the median time of interruption in cardiac massage necessary to fix an additional tool in CPR (e.g., Lifestick) was 20 secs (31).

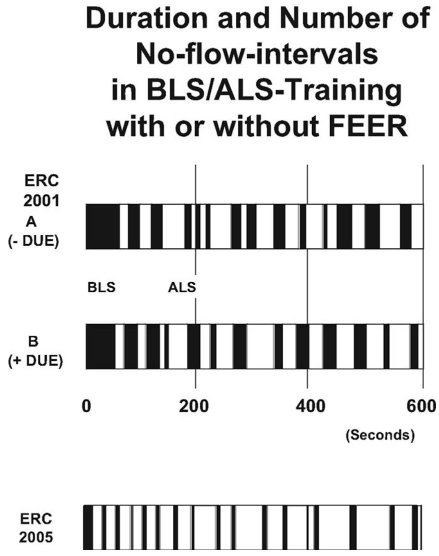

Figure 3. Comparison of duration of the no-flow intervals during advanced life support (*ALS*) training according to the European Resuscitation Council (*ERC*) 2001 (*upper two horizontal bars*) and ERC 2005 (*lower bar*) guidelines. No-flow intervals are all *black separations of the bar*. A randomized interruption with dummy-echocardiography (*DUE*) did not induce a prolongation of distinct phases or the duration or number of no-flow intervals. *BLS*, basic life support.

Does the Application of ALS-Based Echocardiography Result in Any Consequences? Tayal and Kline (8) demonstrated that pericardial effusion, detected by a bedside emergency echocardiogram in hospitalized nontrauma patients receiving CPR, is encountered more frequently than expected (8). The study by Niendorff et al. (28) presented only very low case numbers. In contrast, Blaivas and Fox (13) proposed that nontrauma patients with an initial proven cardiac arrest by echocardiography may not survive the emergency department, regardless of the electrical rhythm (13). Echocardiography seemed to serve as an independent prognostic marker (13). However, earlier studies revealed a higher percentage of visible myocardial wall motion when an electrical rhythm was present, so the term *electromechanical dissociation* was considered to be a misnomer (12). Low case numbers may limit the generalization of the implication from these studies. In a recent publication, Salen et al. (9) demonstrated that all patients undergoing CPR with suspected PEA and subsequent echocardiographically proven wall motion seemed to get return of spontaneous circulation. In this study, the length of CPR was not predictive for outcome, whereas echocardiography in PEA was suggested to be predictive for survival to hospital admission (9). In an ongoing prospective, observational trial we tested a) the capability of FEER to differentiate PEA states and b) the feasibility of FEER in an out-of-hospital setting using a mobile, battery-powered ultrasound system. Trained EP/INT conducted the FEER examination as described in prehospital cardiac arrest patients who were being resuscitated. A total of 77 out-of-hospital CPR cases (men, n = 54; women, n = 23; age, 67 ± 18 yrs) were included in the FEER protocol. At arrival of the EP on the scene, neither carotid pulse was palpable, nor were peripheral oxygen saturation or blood pressure measurable in any one of these patients. PEA was suspected in 30 of 77 cases. However, in 19 of 30 suspected PEA cases, cardiac wall movement was detected, and correctable causes such as pericardial tamponade (n = 3), poor ventricular function (n = 14), and hypovolemia (n = 2) were noted or treated. In 13 of 19 true pseudo-PEA cases, patients survived to hospital admission. In contrast, 11 of the 30 PEA cases, with true cardiac standstill on echocardiogram, died. On the scene, FEER-based changes in therapy were induced in 24 of 30 cases. In addition to differentiating PEA states, FEER has the ability to identify a pseudo-PEA state, allowing the continuation of CPR and further treatment of the underlying disorder on the scene if possible (32). Regarding the ability of echocardiography to differentiate PEA, our data are consistent with the results of Salen et al. (9), Tayal and Kline (8), and Blaivas and Fox (13).

What Level of Quality of Echocardiograms Can Be Expected During CPR? Quality of ultrasound image in the abovementioned PEA patients was considered to be good in 11 studies, sufficient in 21, and poor in five and was determined to be most feasible from the subcostal window (n = 23 of 39). The study characterized that the quality of mobile echocardiography is limited and had a lower diagnostic accuracy (33, 34).

Does Emergency Echocardiography Improve Outcome? This crucial question cannot yet be answered. To date, no study has been performed to prospectively evaluate the utility of primary echocardiography and its effect on outcome as the main variable. An evidence-based positive effect on patient outcome may be the most important element required for broad acceptance of the concept or method. If the implications, reported by Salen et al. (9), to improve outcome while detecting pseudo-PEA could be extended, it would have to be demonstrated in a larger study population. The numbers required to treat or diagnose will be approximately 1,000 CPR cases, to show or disprove a benefit of echocardiography on patient outcome. Is this an academic question only? Who would finance an investigator-driven trial? It is regarded as common sense that emergency echocardiography is a valuable tool and sensitive in detecting certain pathology related to critical care medicine. Although documentation in the memory of the device will help to understand the initial finding, there is no reference method available to express sensitivity and specificity in a point-of-care setting. This reflects the current dilemma. We think it may be quite difficult to test for outcome in a clinical trial with sufficient statistical power, and we will only be able to test and interpret surrogate markers. Thus, this question may remain unanswered.

Educational Basis of ALS-Conformed Echocardiography

We set up a 1-day course program on focused echocardiography in emergency and critical care medicine (25) for EP/INT without previous knowledge in transthoracic echocardiography to answer a series of questions listed below. Trainees passed a precourse test within the first hands-on training session and received theoretical and practical training with selected lectures as an intervention. Finally a postcourse examination within the second hands-on training session was completed (Fig. 4).

Can EP/INT Learn to Apply an ALS-Based Echocardiogram Within 5 secs? We tested the hypothesis of whether EP/INT can obtain a correct subcostal four-chamber view, long axis, in a healthy individual within 5 secs. To evaluate the training progress, sequences of echocardiographic findings were recorded onto a DVD and analyzed by a cardiologist who was blinded to the participants. The success rate was defined as obtaining the correct picture within 30 secs and on holding the view for ≥3 secs. Up to four independent tests were performed. The time utilized is depicted in Figure 4*a*. We found an improving success rate, although not every EP/INT was successful. Instructors were able to achieve the correct view in <5 secs. Furthermore, in a 21-item multiple-choice questionnaire, participants improved their theoretical basis (Fig. 4*d*). Although we did not test the hypothesis in actual patients with artificial ventilation, these preliminary results supported the hypothesis.

Can EP/INT Interpret a 5-sec Echocardiogram-.mpeg Movie at a Glance? To answer this question, we performed an experiment by developing an automated computer program, Emergency Echocardiography Simulation Test (Die Infographin, Frankfurt/Main, Germany). This program was built with Macromedia Director (Adobe Systems, Mountain View, CA) with QuickTime implementation (Apple Computer, Cupertino, CA) and contained 15 echocardiography video clips on normal and pathologic findings, such as pericardial effusion, reduced ventricular function, cardiac arrest, PEA, hypovolemia, and normal loops, all with a maximum length of 5 secs. Clips were randomly included in the program. A total of 12 trainees were included and had never seen the clips before. They could view the loops only once without replay and had to give free statements and a multiple-choice answer on their own, with time limitation. In essence, this experiment (Fig. 4*b*) demonstrated that EP/INT are able to learn to identify some simple pathologic findings as very short video clips.

Can EP/INT Learn to Perform the FEER Algorithm in an 8-hr Course? Uninformed participants were involved in two rescuer ALS training sessions (30). Regular CPR was begun and EP/INT trainees were then told to perform echocardiography with a mobile ultrasound device. The result of the echocardiogram was given as "wall motion" directly after finishing the sonogram. After completing the first hands-on training session, the ten-step algorithm FEER (Table 1) was taught on-site. In a second hands-on training session, the same system was applied, and the learning curve was observed and analyzed by an objective structured clinical examination checklist (35, 36). The test results were confirmed by *post hoc* analysis of videotapes. Attendants demonstrated a relatively high knowledge and imagination of how to process information, preparation, and performance. However, they could improve their practical skills in the distinct parts of FEER (Fig. 4*c*).

Taken together, our data show that FEER has to be taught both by practical and theoretical means. Similar to such a training concept, a high success rate to learn limited echocardiography for nonexpert residents was shown (37).

What Are the Corresponding Findings of Suspected Diagnoses with Which an EP/INT Has to Be Familiar?

In addition to understanding emergency echocardiography as a valuable tool for time-dependent diagnosis, an EP/INT must be familiar with the indications, differential diagnoses, and possible findings (Table 3). Therefore, a brief description of the most important findings is provided.

Preresuscitation Care: Acute Severe Dyspnea, Undifferentiated Hypotension, Shock of Unknown Origin, Atypical/Typical Chest Pain. In preresuscitation care in emergency cases, echocardiography can detect whether acute severe dyspnea (38) has a cardiogenic origin. Other issues are undifferentiated hypotension, shock of unknown origin to rule out a cardiogenic origin or to adapt vasopressors, and typical or atypical chest pain to identify or rule out thoracic or abdominal aortic aneurysm or dissection. Jones et al. (6, 39, 40) have provided good supportive data in several articles.

Myocardial Insufficiency. There are several quantitative methods to detect myocardial insufficiency and reduced ejection fraction. EPs can accurately determine left ventricular function in hypotensive patients (41, 42). Visually estimated left ven-

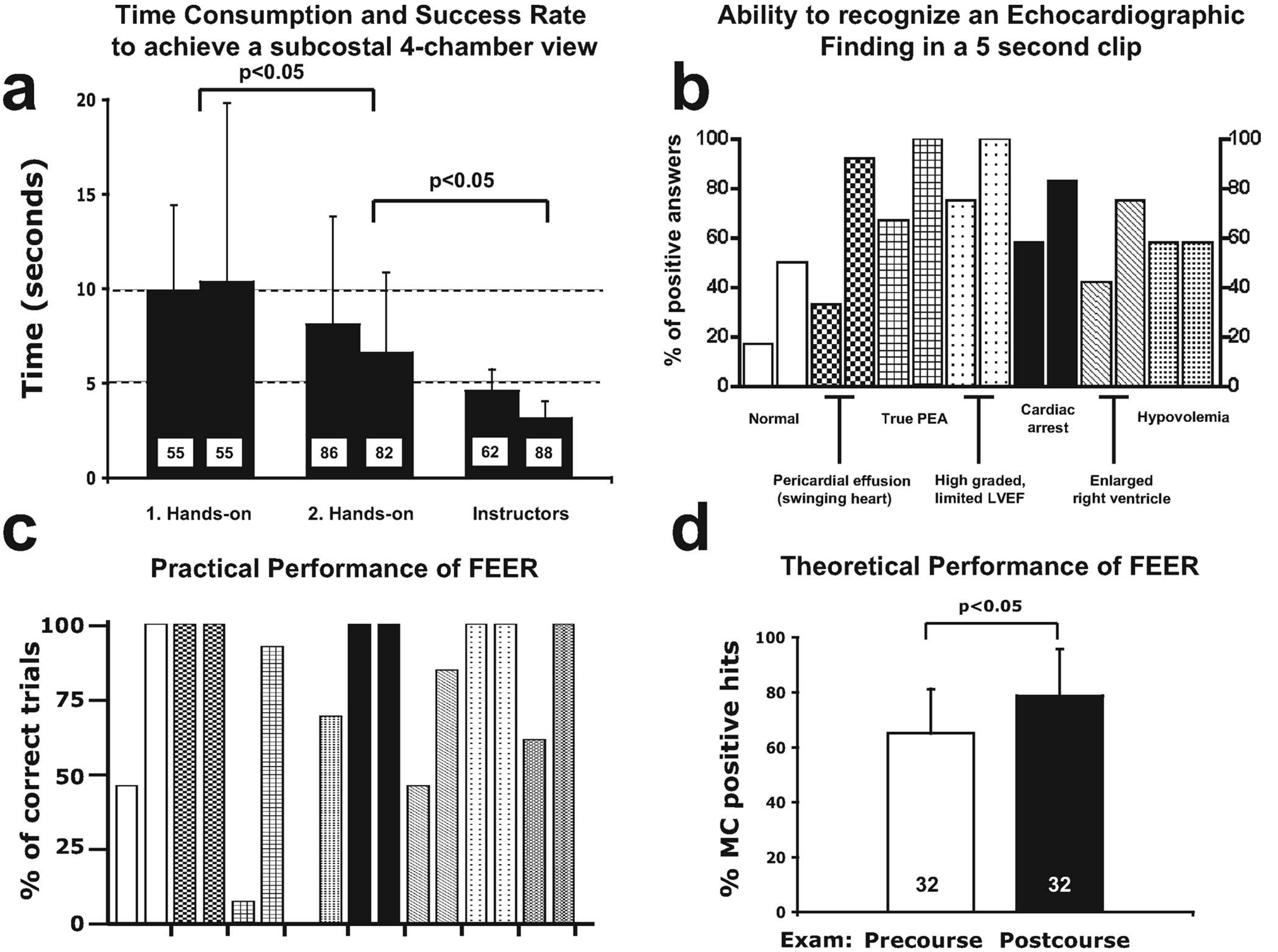

Figure 4. Results of the training course on the focused echocardiographic evaluation in resuscitation management (*FEER*) examination for emergency physicians and intensivists. *a*, Significant decrease of time consumption (mean, SD) of trainees within the two hands-on training sessions (*left four bars*) and compared with the instructors (*black bars*). The success rates, as percentages of successful trials by all trainees, are given as numbers in the *bars*. *b*, Recognition skills tested by movie clips in a 5-inch screen with a maximum length of 5 secs. The pairs of *bars* with the same pattern depict the pretest (*left*) and posttest (*right*) percentages of correct answers per question/pathology. *c*, Improvement of practical skills to learn the FEER examination. Pairs of *bars* with the same pattern show pretest (*left*) and posttest (*right*) percentages of correct trials checked by objective structured clinical examination (from the left): information, preparation and testing, count-down announcement, correct interruption, pulse check, positioning of the probe parallel to cardiopulmonary resuscitation, control to continuing cardiopulmonary resuscitation, and follow-up information. *d*, Theoretical gain in 32 participants (mean, SD), measured by multiple-choice (*MC*) questionnaires. *PEA*, pulseless electrical activity; *LVEF*, left ventricular ejection fraction.

tricular ejection fraction by echocardiography is closely correlated with formal quantitative methods (26). To understand graded ventricular function, one has to undertake structured training (37, 41, 43) with expert supervision. In addition, one should obtain video loops from numerous patients and discuss it with a coaching cardiologist until discriminating normal, low-grade, or high-grade limited ventricular function (Fig. 1*a*).

Pericardial Effusion and Tamponade. Two-dimensional echocardiographic signs of tamponade in pericardial effusion contain right atrial or right ventricular diastolic collapse and noncollapsible inferior vena cava and hepatic veins. More impressive is the pendulum movement of the heart within a large effusion, the "swinging heart." Although this diagnosis seems to be relatively simple (Fig. 5) and is only of interest in emergency medicine when the effusion is huge, EP/INT should be able to differentiate small or massive effusions and signs of functional relevance (Fig. 5*d*) and tamponade. They should train to confirm their findings in all approaches (subcostal, parasternal, apical) and combine it within the context of the clinical findings.

The detection and evaluation of a pericardial effusion must take into account the clinical setting. One has to consider whether there is a history of pacemaker insertion or cardiac surgery, especially those involving cardiotomy and cases of postcardiotomy syndrome. Further considerations include cases of penetrating injury or acute severe or atypical chest pain and other nontraumatic medical situations with respect to the practical consequences of an immediate pericardiocentesis (Table 3). However, differential diagnoses include small effusions that can be physiologic (Fig. 5*a*). With the M-mode echocardiogram, only systolic separations are normally visible (Fig. 2). Thus, any diastolic separation may be a pathologic finding. The pericardial fat pad is mainly located adjacent to the anterior wall or ventral to the right ventricle, and it can be misinterpreted as an effusion (Figs. 2*b* and 5*b*) (44). In the presence of a pleural effusion (Fig. 2*d*), the parasternal long axis allows distinction be-

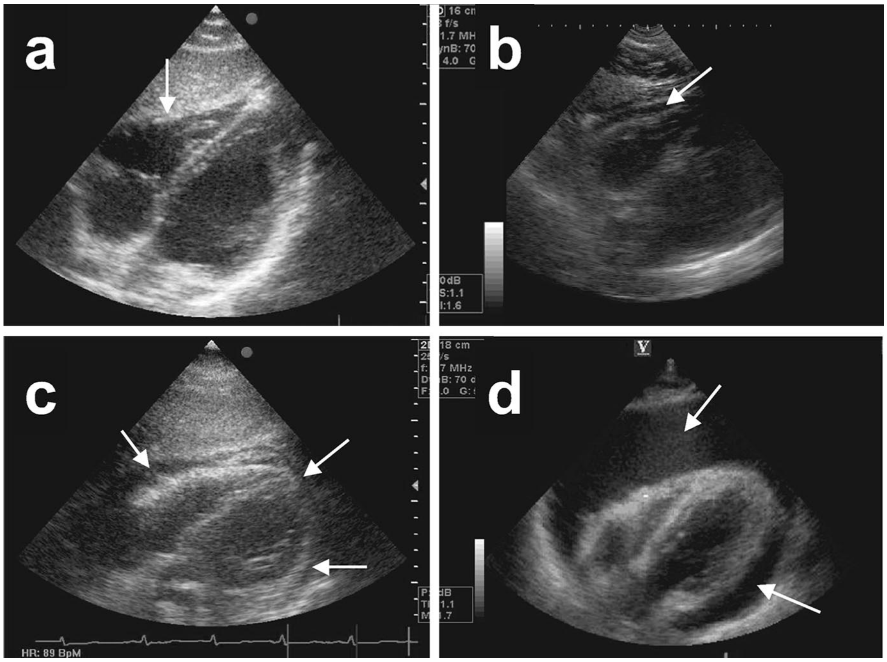

Figure 5. Differential diagnosis in emergency echocardiography of pericardial effusion. In the subcostal window, long axis, *arrows* indicate physiologic pericardial fluid (*a*), anterior fat pad (*b*), small effusion (*c*), and massive effusion (*d*) with functional relevance.

tween pleural or pericardial effusion because the descendant aorta and left atrium are separated in a pericardial effusion. Because the frequency of occurrence is rare (8, 12, 45) and has not been studied systematically, as echocardiography is not routinely used in CPR, we are unaware how often this diagnosis is missed.

PEA States. PEA is frequent in CPR (8, 9, 13, 28, 46) and leads rescuers to perform the look, listen, and feel. True PEA (Fig. 2*e*) is defined as "clinical absence of cardiac output despite electrical activity" (10) or as "continued electrical rhythmicity of the heart in the absence of effective mechanical function" (11). This finding is correlated with poor outcome (12, 13). In contrast, any PEA is classified as a pseudo-PEA when cardiac output was visualized by echocardiography. However, pseudo-PEA is a severe form of a cardiogenic shock with low or very low pump function. Which type of assessment has the best sensitivity for differentiating theses types of PEA? In line with the various guidelines, "any PEA patient with Doppler detectable blood flow should be aggressively treated" (4) because of *improved* outcome (46). The clinical diagnosis of PEA combining rhythm and pulse check is not precise; a true PEA/ electromechanical dissociation (no wall motion) cannot be firmly diagnosed without echocardiography (12). Unfortunately, when no pulse is detected, one assumes regularly that cardiac arrest is present and continues chest compressions. This is an area of conflict during CPR; on the one hand, one must ensure more frequent chest compressions, whereas on the other, frequent pulse checks are necessary to make a decision to continue or to discontinue CPR. This uncertainty may cause a prolongation of the NFI during PEA.

The absence of cardiac wall motion may indicate a very poor (13) but not futile prognosis (47). A decision to terminate CPR in this situation is very difficult. Since our emergency system has utilized prehospital ultrasound in our ground and helicopter emergency services (48), we have noted remarkable cases.

Another special issue addresses patients with artificial pacemakers and cardiac standstill that have a regular electrocardiogram and a suspicion of a PEA. The echocardiogram may show very limited regional wall motion or "twitching" only, which represents only passive movements because of pacemaker action. This finding leads to the diagnosis of a true PEA.

Asystole, Cardiac Standstill. In every patient with asystole, pericardial effusion has to be excluded as the underlying cause of arrest. An echocardiogram during asystole with cardiac standstill (Fig. 2*f*) or true PEA (Fig. 2*e*) should show no wall motion. Valvular motion (e.g., of the mitral valve (49)) seems to not be sensitive for a true cardiac standstill during pauses of chest compressions. When good chest compressions have been performed, passive blood flow may occur and can be further induced by ventilation alone because of cyclic elevation changes of intrathoracic pressure (50).

Varriale and Maldonado (51) used echocardiography without interfering with thoracic compressions during CPR (51) and showed that cardiac arrest results in a gel-like mass within the ventricles. This phenomenon may disappear after return of spontaneous circulation. It was further suggested that the echocardiogram could signal earlier return of spontaneous myocardial contractions during CPR, as this event was not always associated with a restored palpable pulse or conscious state (12). Although ventricular fibrillation is typically an electrocardiographic diagnosis, fine ventricular fibrillation can be misinterpreted as asystole. In this context, echocardiography may show atrial motion to be present and also show "quivering" of the ventricles (12). Echocardiography in CPR may also assess the effectiveness of thoracic compressions (52) by demonstrating that chest compressions are suboptimal during CPR (46, 53).

Hypovolemia. Echocardiographic signs of a suspected diagnosis of hypovolemia are an underfilled right ventricle, hyperkinetic left ventricular wall motion, and close ventricular walls, or "kissing trabecular muscles." Hypovolemia can be detected by measuring left ventricular end-diastolic volume or area (54) and is therefore a clinical variable used to assess preload. In pigs with graded hypovolemia after bleeding, left ventricular end-diastolic area correlated well with blood loss ($r = 0.96$) and was significantly reduced after 5 mL/kg blood loss (55). In patients undergoing cardiac surgery who were subjected to stepwise venesection, left ventricular end-diastolic area was significantly reduced after only 1.75 mL/kg blood loss and continued to decrease with further venesection (56). In pediatric patients, left ventricular end-diastolic area also significantly decreased in response to graded hypovolemia after cardiac surgery (57). In those studies, the left ventricular end-diastolic area was derived from the short-axis view of the left ventricle at the level of the midpapillary muscle (54). Finally, the diameter of inferior vena cava, either measured in the subcostal window, short axis, at the diaphragm using the liver as an acoustic window, or at the position of the right renal vein, is an

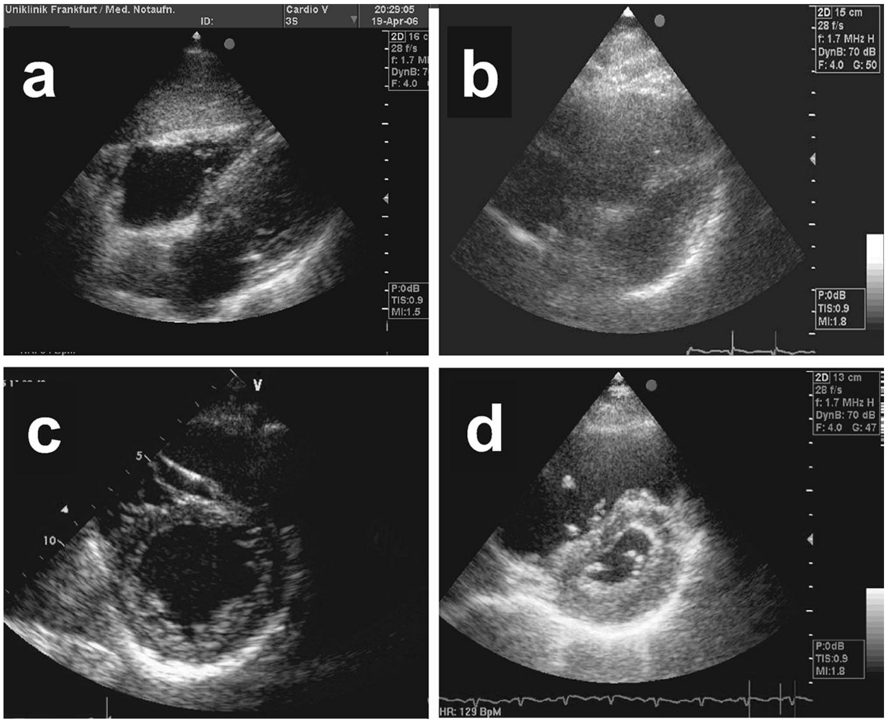

Figure 6. B-mode echocardiogram in acute right heart failure due to pulmonary artery embolism. Subcostal window, long axis, normal finding (*a*); enlarged right ventricle that can quickly be identified (*b*); parasternal, short axis, normal finding (*c*); paradoxic septal movement "D-sign" with impression of the left ventricle due to increased right ventricular pressure (*d*).

accurate variable to estimate hypovolemia in the emergency department (58) and may be a useful extension to the FEER examination.

Although the inferior vena cava is mainly visualized in the longitudinal plane, as a theoretical concern, caution has to be given to those views, for they can show in a paramedian plane (59) and incorrect anterior-posterior diameter. Therefore, a transverse plane may be easier and more accurate to obtain within a 5-sec examination time.

Pulmonary Artery Embolism. Transthoracic echocardiography can detect right ventricular dilation (Fig. 6), right ventricular hypokinesis/dysfunction, or pulmonary hypertension. Proximal and distal embolism can rarely be detected directly. An acute cor pulmonale is associated with a paradoxic septal wall motion (D-sign) and is of high diagnostic value (Fig. 6). Echocardiography may also detect free-floating right-heart thrombus in <10% of patients (60). Given these limitations (especially visualization of left pulmonary artery), only transesophageal echocardiography may be routinely used in the diagnosis of proximal pulmonary embolism and is a powerful diagnostic tool. It is recommended mostly for intensive care unit populations (60). However, one should be cautious because in massive pulmonary embolism, this was only present in 61% of echocardiograms in a retrospective study (60). Jackson et al. (61) demonstrated that right ventricular dilation was present in <50% of cases with pulmonary embolism and concluded that positive findings in the bedside transthoracic echocardiogram increase the suspicion for pulmonary embolism in an individual patient but are not yet strong enough for a definite diagnostic or to rule out pulmonary artery embolism.

Additional Remarks. In addition to the FEER examination, in CPR, a chest sonogram may be of value to detect or to rule out a suspected ventral pneumothorax or tension pneumothorax (62, 63). The B- and M-mode sonogram, performed by a trained physician, can be obtained within 3 secs (D. Lichtenstein, Paris, France, personal communication). Although a suspected tension pneumothorax is generally established as a clinical diagnosis, in patients with a specific history or bradycardia and hypotension, it may be helpful to identify the correct hemithorax to be punctured. This also is in line with an ALS-conformed use to identify reversible causes by ultrasound.

Discussion

Is There a Potential for Echocardiography in Emergency and Critical Care Medicine and in CPR? The American College of Emergency Physicians provided a clear strategy and suggested that "ultrasound imaging enhances the physician's ability to evaluate, diagnose, and treat emergency department patients and is often time-dependent in the acutely ill or injured patient. The EP is in an ideal position to use this technology. Focused ultrasound examinations provide immediate information and can answer specific questions about the patient's physical condition. Such bedside ultrasound imaging is within the scope of practice of EP" (64) or INT (65).

Diagnostic Gaps in Resuscitation Management: "Among the Blind, the One-Eyed Man Is King" (Erasmus of Rotterdam). The most prominent thesis of this review is that the most used standard care interventions do not give enough direct information of cardiac responses in CPR and PEA states. The lack of a standardized emergency echocardiography in the periresuscitation complex is a significant gap in our health system.

In our prehospital observational trial, we unexpectedly encountered several cases with hypotension because of a pericardial effusion or tamponade. One of these cases illustrated the need for emergency echocardiography. A 14-yr-old child who was well 6 wks after open heart surgery suddenly deteriorated, with agitation and hypotension progressing to unconsciousness. The trained EP used FEER to diagnosis a massive pericardial effusion. On transportation to the pediatric intensive care unit, there was a cardiac arrest with a PEA state. With the foreknowledge of the pericardial effusion, the EP decided to perform pericardiocentesis *before* starting chest compressions. The child survived and now attends the same school class without neurologic deficit (K. Rimbach, Darmstadt, Germany, personal communication). We believe that without detecting the pericardial fluid by echocardiography, the child probably would have died.

The next challenge for the American Heart Association/European Resuscitation Council/International Liaison Committee on Resuscitation guidelines may include reinforcing methods to identify treatable causes of arrest during resuscitation. Unfortunately, the suggestion of echocardiography use disappeared in

2005, except in special circumstances, in which the practitioner should "actively seek and exclude reversible causes of cardiac arrest" (7). Such circumstances include postcardiac surgery patients and mainly relate to in-hospital care in the immediate postsurgical phase (7). However, in blunt or penetrating trauma "ultrasound is a valuable tool in the evaluation of possible cardiac tamponade" (7). Prehospital emergency service by EPs or paramedics or in hospital rescue (at least in Germany) does not routinely include an ultrasound evaluation (48). However, new technical solutions on mobile ultrasound (weighing <2 kg of weight) are readily available for rescue teams of the emergency department, intensive care unit, or prehospital trauma support at the patient's bedside (8, 26, 28, 48, 63, 66–68). It has been established as a primary basic diagnostic procedure for the emergency department (68). Furthermore, cardiac abnormalities are quite frequent in medical intensive care unit patients (69). Thus, emergency echocardiography, based on mobile techniques, may be used in a qualitative approach as a "third eye" in resuscitation. We should consider its limitations and should implement these tools not only as a guide for terminating resuscitation efforts, but rather as a guide for improving effectiveness of resuscitation (32, 46, 47). With the simple use of ALS-conformed echocardiography, some of the diagnostic gaps in emergency and critical care medicine can be closed.

Education and Training. Jones et al. (37) demonstrated that a focused 6-hr echocardiographic training course significantly improved EP residents' written and practical examinations in a prospective, observational, educational study for goal-directed echocardiography performance and interpretation. Unresolved debate between the American Society of Echocardiography and the Society of Academic Emergency Medicine questions who should do the examination (EP, INT, or cardiologist?) and how many examinations are necessary to ensure quality control (47, 70). Nevertheless, a limited, goal-directed use of hand-carried echocardiography, as a point-of-care diagnostic, is only appropriate when one has passed a user-specific training session (American College of Emergency Physicians level II at a minimum) (43, 71). It is essential that EP/INT take full responsibility for their findings to ensure the most accurate acquisition, interpretation, and use of the data (26). This clear statement may encourage EP/INT to use only structured methods such as the FEER examination.

Summary and Conclusions

Because of the diagnostic pressure during CPR to identify and treat reversible causes, there is a demand for a structured process when using echocardiography. The simple FEER examination mainly enables an ALS-conformed algorithm to assess myocardial wall motion with the educated eye parallel to brief pauses of CPR within a few seconds. FEER may differentiate PEA and identify pericardial effusion without a major prolongation of the NFIs. Thus, it is suggested as an extension to standard advanced cardiac life support interventions. Educational training for the FEER examination is essential by theoretical and practical means and can be learned in an 8-hr course by nonexpert sonographers.

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