Joint British Societies' guideline on management of cardiac arrest in the cardiac catheter laboratory

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ABSTRACT

More than 300 000 procedures are performed in cardiac catheter laboratories in the UK each year. The variety and complexity of percutaneous cardiovascular procedures have both increased substantially since the early days of invasive cardiology, when it was largely focused on elective coronary angiography and single chamber (right ventricular) permanent pacemaker implantation. Modern-day invasive cardiology encompasses primary percutaneous coronary intervention, cardiac resynchronisation therapy, complex arrhythmia ablation and structural heart interventions. These procedures all carry the risk of cardiac arrest.

We have developed evidence-based guidelines for the management of cardiac arrest in adult patients in the catheter laboratory. The guidelines include recommendations which were developed by collaboration between nine professional and patient societies that are involved in promoting high-quality care for patients with cardiovascular conditions. We present a set of protocols which use the skills of the whole catheter laboratory team and which are aimed at achieving the best possible outcomes for patients who suffer a cardiac arrest in this setting. We identified six roles and developed a treatment algorithm which should be adopted during cardiac arrest in the catheter laboratory. We recommend that all catheter laboratory staff undergo regular training for these emergency situations which they will inevitably face.

INTRODUCTION

More than 300 000 procedures are performed in cardiac catheter laboratories in the UK each year. The variety and complexity of procedures undertaken in the cardiac catheter laboratory have increased substantially over the last 30 years. Invasive cardiology has grown from a largely diagnostic specialty focused on elective coronary angiography to one that treats a wide spectrum of cardiovascular problems through many different types of interventional procedures, often in urgent or emergency situations. The majority of myocardial revascularisation procedures, for example, are now performed by percutaneous coronary intervention (PCI), and over a quarter of these are undertaken in the setting of acute ST elevation myocardial infarction. Pacemaker implantations have evolved from mostly right ventricular procedures to treat bradycardias to encompass biventricular pacing to deliver cardiac resynchronisation therapy for patients with left ventricular dysfunction and/or implantable cardioverter defibrillators (ICDs) for patients at risk of ventricular arrhythmia. Complex arrhythmia ablation procedures have become more common as their indications and success rates have increased. Recent years have seen a large increase in structural heart interventions driven by transcatheter aortic valve implantation (TAVI) to treat aortic stenosis, adding a further level of complexity to procedures undertaken in the catheter laboratory. Percutaneous interventions on the mitral valve are increasing in number while the tricuspid valve and heart failure syndromes are targets for interventional technology development. Not only have procedures become increasingly complex, they are often undertaken in patients who are elderly and comorbid, with limited cardiorespiratory reserve.

Invasive procedures undertaken in the catheter laboratory all carry the risk of complications which lead directly or indirectly to cardiac arrest. Careful assessment of the risks and benefits of the procedure is required for each patient. In many cases, the risk of cardiac arrest is low. In others, such as primary PCI, the risk is appreciable. The incidence of cardiac arrest during PCI is approximately 1.5%.[1 2] The chance of successful resuscitation is higher than in other in-hospital cardiac arrest situations,[3] especially for elective procedures. The catheter laboratory benefits from the presence of an expert team which is present at the time of cardiac arrest, the reason for the cardiac arrest may be known, and it may be reversible through an intervention in the catheter laboratory. Other specialists are usually readily available to assist, if required. Nevertheless, there is variation between catheter laboratories, for example, whether they are based in a cardiac surgical centre or in a district general hospital and in the number of practitioners and the roles which they undertake in the catheter laboratory. Furthermore, the intervention to achieve restoration of spontaneous circulation (ROSC), such as PCI, may take some time to perform. Rescuers who are used to 10–15 min cardiac arrest scenarios may need to become familiar with prolonged cardiac arrest scenarios which involve mechanical cardiopulmonary resuscitation (CPR), the administration of drug infusions, consideration of every aspect of the patient's physiology, and treatment akin to

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that of a critically ill patient on an intensive care unit (ICU). In undertaking invasive procedures in the catheter laboratory, our expectation should be for successful resuscitation after a cardiac arrest. In aiming to achieve the best possible outcomes, a consistent approach to the arrested patient in the catheter laboratory is needed. For this reason, we have developed evidence-based guidelines for the management of cardiac arrest in the catheter laboratory.

SCOPE AND METHODS

This guideline covers adult patients undergoing any invasive procedure in the catheter laboratory, including coronary angiography, PCI, structural heart interventions including TAVI and mitral valve procedures, pacemaker and ICD implantation, arrhythmia ablation, atrial appendage occlusion, and pacing system extraction. We did not consider patients who suffer a cardiac arrest and are then brought to the catheter laboratory as these patients have recently been considered in a position paper by the European Society of Cardiology (ESC).[4]

The guideline was developed by a collaboration between nine stakeholder organisations: the British Cardiovascular Society (BCS), the British Cardiovascular Intervention Society (BCIS), the British Heart Rhythm Society (BHRS), the British Association for Nursing in Cardiovascular Care, the British Society of Echocardiography, the Association for Cardiothoracic Anaesthesia and Critical Care, the Cardiovascular Care Partnership UK, the Society for Cardiothoracic Surgery in Great Britain and Ireland, and the Resuscitation Council UK.

These guidelines were developed in accordance with The Resuscitation Council UK 2021 guidelines development process.[5] We used the ESC 2018 practice guidelines recommendations for grading the strength of recommendations and for assessing the levels of evidence in support of them.[6] It should be acknowledged that the literature surrounding cardiac arrest comprises mostly of papers which reported the findings of studies after either in-hospital or out-of-hospital cardiac arrest rather than after cardiac arrest in the catheter laboratory and that their findings were extrapolated to the catheter laboratory environment.

We undertook a comprehensive review of the literature and a Delphi expert consensus process in order to identify all of the situations in the catheter laboratory that potentially lead to cardiac arrest and to provide team-based solutions to their management. We propose these guidelines as the standard of care in this specialist area.

The International Liaison Committee on Resuscitation

According to international guidelines, resuscitation is governed by The International Liaison Committee on Resuscitation (ILCOR) which is a collaborative of seven world resuscitation councils which was founded in 1992. The full range of all recommendations in the area of resuscitation is reviewed and updated and a document of the 'best evidence' in resuscitation is created. The seven resuscitation councils then take this evidence and generate guidelines adapted to the needs of their own healthcare systems.

The American Heart Association guidelines

The 2015 American Heart Association (AHA) guidelines contain a two-page section entitled 'Cardiac Arrest During Percutaneous Coronary Intervention', although this was omitted from its 2020 guideline.[7] In 2015 the AHA concentrated mainly on a discussion on the use of automated CPR devices over manual compressions and the use of extracorporeal CPR (ECPR) devices. It did not come to any firm conclusion but stated that mechanical CPR devices and ECPR devices have been used as bridges to other interventions such as coronary artery bypass surgery, cardiac transplantation or longer-term mechanical devices. In the text of the guideline it is also noted by the authors that early defibrillation within a minute of cardiac arrest is associated with excellent outcomes. No other special considerations were discussed with regard to the management of cardiac arrest in the catheter laboratory.

The European Resuscitation Council guidelines

The European Resuscitation Council (ERC) published guidance regarding resuscitation in the catheter laboratory in 2021 in its document entitled 'cardiac arrest in special circumstances'.[8] It included a protocol diagram, and there was a strong emphasis on ensuring that catheter laboratory staff are adequately trained in resuscitation technical skills including team training, and specific protocols for the initiation of mechanical CPR, temporary pacing and pericardiocentesis, with the use of on-site emergency drills. The ERC also recommended the availability of resuscitation equipment and the use of checklists. Mechanical CPR was recommended due to the risk to staff from manual CPR during fluoroscopy, and the requirement to continue CPR during PCI.

The Australian and New Zealand guidelines

These guidelines discussed the use of mechanical CPR in cardiac arrest during PCI.[9] They also discussed cough CPR for which they found case reports regarding its use during electrophysiology (EP) procedures. They discussed treatment of cardiac tamponade during cardiac arrest by thoracotomy and pericardiotomy if pericardiocentesis fails with a class B recommendation. They noted that the interventionalist is heavily task burdened and, as such, is seldom in a good position to lead the resuscitation and that there may be tension between the requirement to perform CPR and the ability of the interventionalist to continue with the procedure, thus acknowledging two of the particular challenges faced by the catheter laboratory team during a cardiac arrest.

A NOVEL PROTOCOL FOR THE MANAGEMENT OF PATIENTS WHO SUFFER A CARDIAC ARREST IN THE CATHETER LABORATORY

We have developed a modified resuscitation protocol which is specifically designed for the specialist area of the catheter laboratory. Of note this does not apply to recovery areas but does apply to hybrid laboratories where TAVI or Mitraclip procedures are being undertaken. This protocol could also be used in hybrid laboratories performing thoracoscopic endovascular aortic repair (TEVAR). The full protocol is shown in figure 1 and the rationale for its development is discussed.

How should cardiac arrest be identified, defined and categorised?

In a catheter laboratory a cardiac arrest is identified much more quickly than other in-hospital arrest scenarios. Ventricular fibrillation (VF), pulseless ventricular tachycardia (VT) and asystole may be diagnosed immediately when a continuous intra-arterial blood pressure is displayed, without need for an added pulse check.

It is important to define what constitutes a cardiac arrest in a catheter lab. In contrast to the two pathways in the standard arrest algorithm we have separated the protocol into three pathways: VF or pulseless VT, asystole or extreme bradycardia, and pulseless electrical activity (PEA).

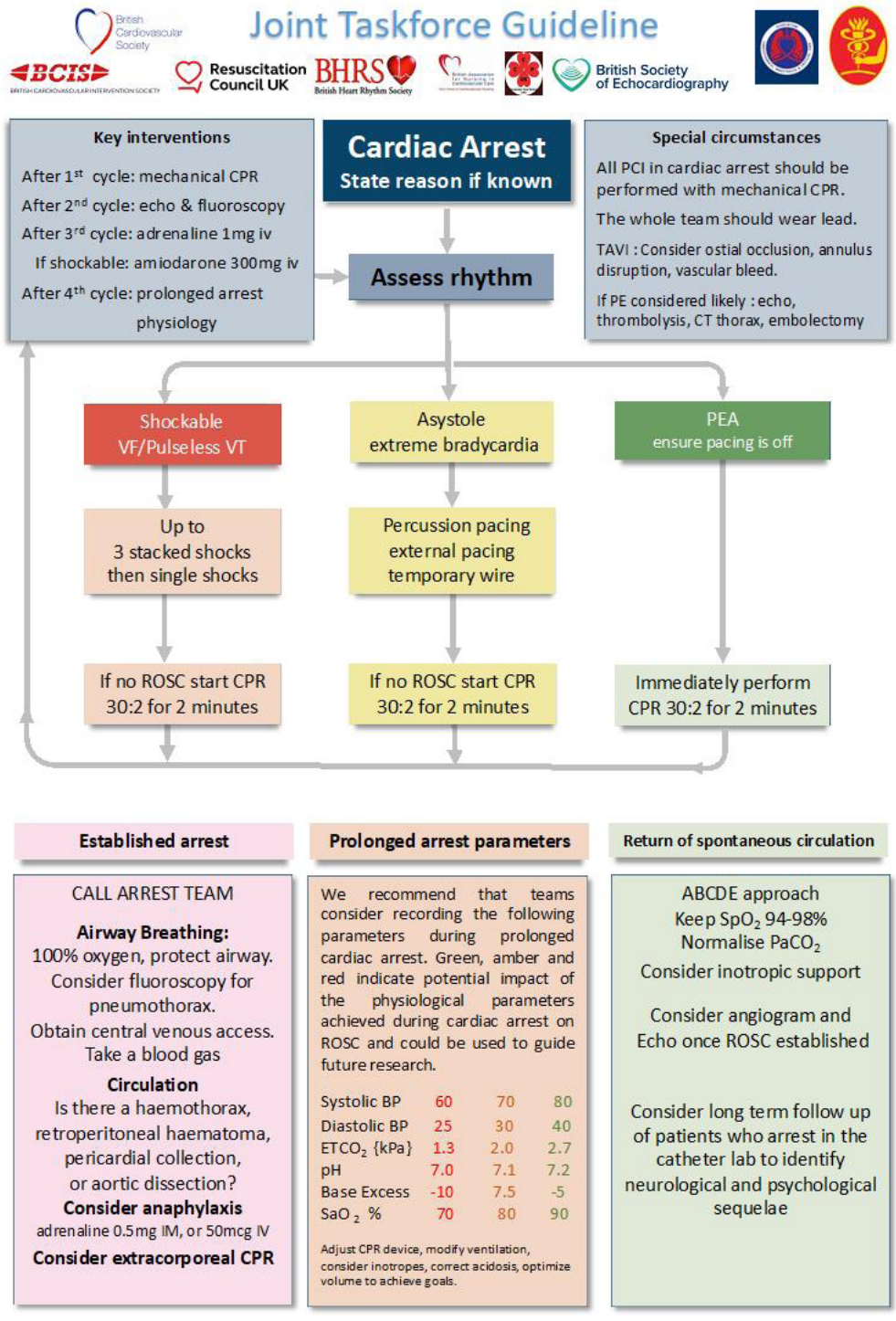

Figure 1 Protocol for resuscitation of patients who suffer a cardiac arrest in the catheter laboratory. BCIS, British Cardiovascular Intervention Society; BHRS, British Heart Rhythm Society; CPR, cardiopulmonary resuscitation; PCI, percutaneous coronary intervention; PE, pulmonary embolus; PEA, pulseless electrical activity; ROSC, restoration of spontaneous circulation; TAVI, transcatheter aortic valve implantation; VF, ventricular fibrillation; VT, ventricular tachycardia.

In VF or pulseless VT, the pulse oximeter and arterial trace will confirm the absence of a cardiac output. A cardiac arrest should be called and the operator should tell the team if they know the reason for the arrest (eg, vessel dissection or occlusion in PCI, occluded left main stem in TAVI or irritation of the ventricle in a pacing procedure for example). VF or VT is occasionally deliberately induced in EP labs and this should not trigger the arrest protocol.

Temporary asystole or extreme bradycardia (<30/min) may occur and can be anticipated during manipulation of ventricular pacing leads or EP catheters. A cardiac arrest should be called when the rhythm disturbance is unexpected and or prolonged. The pulse oximetry and any arterial transduction will show non-pulsatile traces, and percussion pacing, external pacing or temporary wire pacing may be attempted prior to chest compressions.

Many cases of PEA may be diagnosed by the absence of a pulsatile waveform on a continuous intra-arterial blood pressure display. Non-pulsatility or minimal pulsatility of the arterial trace and pulse oximetry in the presence of continuing electrical activity confirms the diagnosis. The operator should call it a cardiac arrest and inform the laboratory team of the likely cause.

Pulseless VT can be mistaken for PEA. A regular rhythm above 140/min should be considered as pulseless VT if the arterial trace and pulse oximetry have minimal or absent pulsation and the patient has lost consciousness. Similarly extreme bradycardia may be mistaken for PEA if the arterial trace is not being transduced. It may be necessary to feel the pulse for 10 s or alternatively (and optimally) to perform a rapid echocardiogram to identify a cardiac output.

Occasional patients will deteriorate in the catheter laboratory with support devices in place such as left ventricular assist device (LVAD), extra corporeal membrane oxygenation (ECMO) or Impella (Abiomed), where non-pulsatility does not equate with an absent cardiac output.

Should all members of the resuscitation team wear lead aprons?

All clinicians coming into an arrest in the catheter laboratory should wear lead aprons. Our protocol uses the members of the team present in the catheter laboratory in the initial stages of the arrest and, thus, it is strongly recommended that everyone entering the room should wear lead aprons as it is very likely that the cardiologist may need to perform fluoroscopy in many emergency situations.

We recommend that catheter laboratory team members are regularly trained in basic airway management to ensure a patent airway and good oxygenation for all patients, to ensure that the anaesthetic team have adequate time to put on protective lead before entering the laboratory. We recommend that an individual in the catheter laboratory team is allocated to manage the personnel coming into the arrest. They will be required to assist these personnel to put on lead, and as they do this, they will be able to brief these clinicians as to the arrest situation in the catheter lab.

Catheter laboratories must also ensure that lead aprons in a range of sizes are immediately available for emergency team members.

Recommendation	Class	Level
All clinicians entering a cardiac arrest situation in a catheter laboratory must first put on lead aprons prior to entry. Advance provision should be made for enough lead aprons to be available for this situation.	IIa	C

Should we defibrillate before external chest compressions?

In 2020 ILCOR published a literature review on this subject[10] and it was identified as a priority area for the Basic Life Support Taskforce. They found that in five randomised controlled trials (RCTs)[11 12 13 14 15] there was no difference in outcomes with a specified period of chest compressions (typically 1.5–3 min) before shock delivery compared with shock delivery as soon as possible with interim brief CPR while the defibrillator was readied for use. A meta-analysis of these studies (n=10 600 patients) also found no differences. Only when the arrest time was more than 5 min did any studies show an improvement with CPR before defibrillation.[16 17] The ERC 2021 guidelines[8] do not recommend the routine delivery of a prespecified period of CPR before rhythm analysis and shock delivery, and recommend shock delivery as soon as it can be applied. Deferring chest compressions until after shock delivery has been recommended in the ERC 2021 guidelines[8] in other highly monitored areas such as after cardiac surgery and these now state: 'If a patient has a monitored and witnessed cardiac arrest (eg, in the catheter laboratory, coronary care unit, or other monitored critical care setting in or out-of-hospital) and a manual defibrillator is rapidly available: Confirm cardiac arrest and shout for help. If the initial rhythm is VF/pVT, give up to three quick successive (stacked) shocks. Rapidly check for a rhythm change and, if appropriate, ROSC after each defibrillation attempt. Start chest compressions and continue CPR for 2 min if the third shock is unsuccessful'.

Recommendation	Class	Level
In ventricular fibrillation (VF) or ventricular tachycardia (VT) without a cardiac output, external chest compressions may be deferred in order to perform up to three stacked shocks immediately.	IIa	A

How many attempts at defibrillation should be performed prior to commencing external chest compressions?

Evidence was sought for the optimal number of attempts at external defibrillation for VF or pulseless VT prior to commencing external chest compressions. This has been subject to a literature review looking at the effectiveness of the numbers of defibrillation attempts in a range of scenarios including ICD insertions, electrophysiological studies, out-of-hospital arrests and animal studies.[18] When the data from all 15 papers are combined, the average success rate of sequential shocks declines from 78% for the first shock to 35% for the second shock and 14% for the third, and any subsequent shock will have less than a 10% chance of success. Thus, the likelihood of successful cardioversion declines dramatically from first to second shock and declines further from second to third shock.

Our guideline seeks to place a mechanical CPR device on the patient early in the pathway and it is important to consider how we modify the protocol to allow this. First, it may be possible to assess the rhythm while the mechanical CPR is ongoing. Our patients often have multi-lead ECG monitoring, and sometimes intracardiac ECG monitoring, and thus where the team leader is satisfied that there has been no change from the shockable rhythm, there is no need to pause the CPR device every 2 min. If the team leader is uncertain then a pause should be performed every 2 min for rhythm assessment. As there is no risk to a rescuer, charging and administration of a shock may be performed while mechanical CPR is ongoing. Finally, if multiple shocks have failed to cardiovert the patient and it is clear that a coronary occlusion is the cause of the arrhythmia, then mechanical CPR should continue uninterrupted until coronary flow is restored.

Recommendations	Class	Level
In ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT), up to three stacked shocks should be given without intervening external chest compressions.	I	B
Thereafter, a single attempt at defibrillation, if required, is performed every 2 min.	I	C
If the arrhythmia is due to an acute coronary artery occlusion, repeat shock administration can be deferred to facilitate percutaneous coronary intervention (PCI) to the occluded artery.	IIa	C
Shocks for known VF/VT should be administered while mechanical cardiopulmonary resuscitation (CPR) is ongoing.	I	C
If the patient is receiving mechanical CPR and it is possible to assess the rhythm while the CPR is ongoing then it may not be necessary to pause the CPR device.	IIa	C

Should we perform pacing in patients who undergo an asystolic arrest in the catheter laboratory prior to external chest compressions?

In an asystolic arrest in a catheter laboratory there is the potential to rapidly restore cardiac output with pacing and, as this is a witnessed arrest, if pacing is performed immediately then potentially there will be an immediate restoration of a spontaneous circulation. Furthermore, in the literature review on the effectiveness of external chest compressions in the early stages of an arrest[19] it was found that there was little evidence to suggest harm from delaying external chest compressions for a few minutes. Periods of asystole are not uncommon in pacing and electrophysiology (EP) laboratories and most cardiologists would use external, percussion or transvenous temporary wire pacing to address this as a routine part of their practice. We recommend that pacing should be attempted prior to the initiation of external chest compressions.

Percussion pacing may initially be attempted (see the section below for further details). For external pacing the pacing pads should be applied, and the amplitude of the pacing quickly increased to regain an output. Only if capture is not obtained with maximum amplitude with the pads well applied should external chest compressions be performed. If the cardiologist suspects that the arrest is due to an extreme bradycardia due to a conduction defect then transvenous pacing can be used if external pacing has been ineffective in achieving ventricular capture.

Recommendations	Class	Level
In a patient who arrests with asystole or extreme bradycardia with a rate of less than 30 bpm, external pacing or percussion pacing should be attempted prior to chest compressions.	IIa	C
If either external or percussion pacing is ineffective and the cardiologist feels that there is a persisting bradycardia as the cause of the arrest a temporary pacing wire should be inserted while chest compressions are performed.	IIa	C

Interventions to address PEA

Our protocol using three categories aims to ensure that the greatest number of patients possible may benefit from either immediate defibrillation or pacing prior to the institution of external cardiac compressions. In patients presenting with PEA efforts should be directed towards identifying the underlying causes and treating them rapidly. There are a number of possibilities to consider that are relevant to the catheter laboratory:

Hypoxia: There is an airway and breathing protocol with a person allocated to address these issues in an arrest.

Hypovolaemia: bleeding. Our recommendation ensures that the four most likely areas for bleeding in the catheter laboratory (haemothorax, retroperitoneal or vascular bleed, aortic dissection and tamponade) are investigated.

Hypo/hyperkalaemia, H^+ ion imbalance and electrolyte abnormalities are addressed by a recommendation to perform an early blood gas.

Hypothermia is unusual in a catheter lab, other than following prolonged out of hospital arrest

Tension pneumothorax may arise during procedures requiring vascular access in the thorax. This is addressed in the airway and breathing protocol and by fluoroscopy.

Tamponade: Where tamponade is a possibility immediate echocardiography should be performed. The clinical sign most suggestive of tamponade in a cardiac arrest is the inability to generate a systolic blood pressure of 70 mm Hg with external cardiac massage.

Toxins: One possible cause of a toxin-related arrest in a catheter laboratory is a drug error. We recommend that any syringe drivers or infusions should be stopped in the arrested patient to address this possibility. Careful consideration should also be given to contrast-induced or antibiotic-induced anaphylaxis. Look for supportive signs such as rash, wheeze or facial swelling. Our protocol recommends epinephrine 0.5 mg intramuscular or otherwise 50 mcg intravenous.

Thrombosis: coronary or pulmonary. In the catheter laboratory this would most commonly relate to acute coronary occlusion, either due to an acute myocardial infarction or a complication of PCI which in both circumstances would be treated by reopening of the vessels by PCI. Pulmonary embolism causing an arrest is far less common. In an arrest situation it can be very difficult to diagnose but is suggested by disproportionate right ventricular distention. If suspected, then thrombolysis or thrombectomy might be considered. This is considered in our protocol.

How deeply should we perform chest compressions?

The universal algorithm recommends compressing the chest to between 5 cm and 6 cm over the lower half of the sternum.[7 8] For those patients with an arterial trace being transduced, we recommend 'titrating' chest compressions to achieve a systolic pressure of 70 mm Hg. This allows more gentle external compressions to be performed, potentially reducing the chance of compression related injury, while still producing effective cerebral perfusion. Furthermore, the inability to generate an acceptable systolic pressure is suggestive of tamponade.

Recommendations	Class	Level
Chest compressions should be performed to a depth of 5–6 cm to the lower half of the sternum.	IIa	C
If the arterial trace is being transduced it is preferable to compress to achieve a systolic pressure of 70 mm Hg.	IIb	C

Should we perform a precordial thump?

The AHA guidelines[20] state that 'The precordial thump may be considered for termination of witnessed monitored unstable ventricular tachyarrhythmias when a defibrillator is not immediately ready for use (Class IIb, level of evidence (LOE) B), but should not delay CPR and shock delivery'. ILCOR produced a worksheet on this subject in 2021.[21] This documents that precordial thump is only effective in 2% of attempts and, in fact, rhythm deterioration is twice as common as successful cardioversion. Thus, our protocol does not recommend a precordial thump. A defibrillator should be immediately at hand in every catheter laboratory, and this is much more likely to successfully cardiovert the patient.

Recommendation	Class	Level
A precordial thump is not recommended for patients who suffer a cardiac arrest in the catheter laboratory due to ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT).	III (no benefit)	C

Is cough CPR an effective alternative to external chest compressions in the catheter laboratory?

The AHA stated in 2010 that 'cough' CPR may be considered in settings such as the cardiac catheterisation laboratory for conscious, supine and monitored patients if the patient can be instructed and coached to cough forcefully every 1–3 s during the initial seconds of an arrhythmic cardiac arrest. It should not

delay definitive treatment (Class IIb, LOE C). The AHA made no modifications to this recommendation in 2020.[7]

The longest documented case of a patient maintaining their own spontaneous circulation is 90 s and most reports were around 30 s, in both VF as well as asystole. These patients seem able to maintain consciousness in a manner similar to the mechanism proposed for external CPR, namely a compression of the pulmonary vascular bed increasing the pressure in the left atrium then ventricle and allowing blood to flow across the aortic valve.[22] There are case reports of its use for short periods of time in the catheter laboratory,[23] including prior to defibrillation[24 25] but the most effective use seems to be in patients with severe bradycardia who are periarrest. ILCOR performed a systematic review in 2021.[21] Their conclusion was as follows: 'We suggest cough CPR may only be considered as a temporising measure in an exceptional circumstance in a witnessed, monitored, in-hospital setting (such as a cardiac catheterisation laboratory) if a non-perfusing rhythm is recognised promptly before loss of consciousness (weak recommendation, very-low-certainty evidence)'.

If a bradycardic or asystolic cardiac arrest is very rapidly identified (while the patient is responsive), then it is reasonable to attempt to coach the patient to cough forcefully every 1–3 s if experienced clinicians choose to try this. This should not delay the commencement of the cardiac arrest protocol including the application of pads and defibrillating or pacing if necessary. Staff should be ready to perform CPR if the patient stops following the command to cough, and the arterial trace should be observed to monitor the effectiveness of cough CPR.

Recommendation	Class	Level
Vigorous cough cardiopulmonary resuscitation (CPR) every 1–3 s in the catheter laboratory may only be considered as a temporising measure if a non-perfusing rhythm is recognised promptly before loss of consciousness. It is likely to be most useful in bradycardia in order to maintain consciousness until more definitive reversal measures can be instituted.	IIb	C

Percussion (fist) pacing as an alternative to CPR in the catheter laboratory

ILCOR performed a systematic review on this subject in 2021.[21] The total number of cases reported in the literature is around 170 patients and in the largest series of 100 patients, 69 of these maintained consciousness and 90 had percussion pacing as an alternative to CPR.[26]

In a study performed in 1978[27] 19 healthy volunteers and 31 patients with paused pacing had a right heart catheter and the authors found reliable electrical impulses could be reproduced for up to 6 min when the left lower sternum was struck with the clenched fist from about 20–30 cm height, by causing the right ventricular pressure to rise by around 20 mm Hg with this action.

The ILCOR 2021 systematic review states that 'We suggest fist pacing may only be considered as a temporising measure in an exceptional circumstance in a witnessed, monitored, in-hospital setting (such as a cardiac catheterisation laboratory) if a non-perfusing rhythm is recognised promptly before loss of consciousness'.

The catheterisation laboratory is a highly monitored environment where bradycardia and asystole are common. There have been no studies comparing CPR to percussion pacing directly but percussion pacing has been shown to effectively induce cardiac contraction and maintain consciousness in patients immediately identified as having an asystolic arrest. Therefore, with close monitoring, we recommend that this could be a useful temporising method in the catheterisation laboratory, while preparations are made for external pacing or a temporary wire or the administration of chronotropic medications.

Recommendations	Class	Level
In monitored patients with onset of a non-perfusing rhythm such as asystole or extreme bradycardia (figure 1), percussion (fist) pacing may be deployed as an alternative to external pacing when successful perfusion is confirmed by a continuous arterial tracing, pulse oximetry and ECG.	IIb	C
Percussion pacing should be performed at a rate of 50–70 per minute and the ulnar side of a clenched fist should be used to strike the chest from 20–30 cm above the left lower sternal edge, in order to mechanically increase the right atrial pressure, if measured, by 15–20 mm Hg.	IIb	C

Active pad compression for defibrillation

In atrial fibrillation there are papers including the Ottowa AF Cardioversion protocol[28] and the 2014 AHA guidelines for the management of patients with atrial fibrillation[29] that mention using paddles to provide manual compression over the defibrillator pads as a method of increasing the success of cardioversion. The original citation as evidence in favour of this intervention was by Kerber *et al*[30] in 1981 looking at 44 cardioversion patients, although, interestingly, the only part of this paper that actually looked at active compression was a subreport of four dogs who were cardioverted with or without active compression.

Sirna *et al* in 1988 reported a 13% reduction in impedance with active compression when uniphasic defibrillation was being performed in 28 patients[31] and a similar result was found by Ramirez *et al* in 2016 with 11 participants where they concluded that 8 kg of pressure could reduce the impedance by about 10%.[32]

Thus, there is limited evidence from animal studies and case series, as well as a trial of cardioversion in atrial fibrillation, that active compression of the defibrillation pads using disconnected defibrillation paddles reduces intrathoracic impedance and improves shock efficacy. In the absence of any studies in ventricular arrhythmias in humans the routine use of active compression during defibrillation is not recommended. However, the use of disconnected defibrillation paddles to apply external compression to defibrillation pads may be considered in patients with arrhythmias refractory to cardioversion particularly where there is a risk of high intrathoracic impedance.

Recommendations	Class	Level
Active pad compression is not routinely recommended for defibrillation and the standard method of defibrillation should be via pads either in an anterior-lateral position, an anterior-posterior position or apex-posterior position.	III (lack of benefit)	C
In situations when initial attempts at cardioversion have failed, an expert clinician who feels that increased impedance may be a factor, such as in high body mass index (BMI), may elect to try active pad compression if paddles are also available to provide the compression.	IIb	C

Does epinephrine improve outcomes in resuscitation in the catheter laboratory?

ILCOR in 2015 reviewed the literature with regard to epinephrine including a large RCT by Olasveengen *et al*[33] where ambulances were randomised to Group 1: CPR and defibrillation with

iv cannulation and usual resuscitation medications versus Group 2: CPR and defibrillation alone. This RCT showed reduced survival to hospital discharge in Group 1 and this was felt to be due to the ineffectiveness of the drugs and also the delay in CPR in order to cannulate and administer the drugs. This paper, and a more recent meta-analysis[34] (demonstrating no benefit of epinephrine in cardiac arrest) led ILCOR to write: 'despite the widespread use of epinephrine during resuscitation, and several studies involving vasopressin, there is no placebo controlled study that shows that the routine use of any vasopressor at any stage during human cardiac arrest increases survival to hospital discharge. Current evidence is insufficient to support or refute the routine use of any particular drug or sequence of drugs. Despite the lack of human data, the use of epinephrine is still recommended, based largely on animal data'.

The PARAMEDIC-2 Study[35] randomised 8014 patients in an arrest situation across five ambulance services in the UK to receive either 1 mg of epinephrine every 3–5 min, or identical syringes containing 0.9% saline. The mean time for the ambulance to arrive was 6.6 min and the mean time to trial drug administration was 13 min after arrival. There was a large increase in the number of patients who had return of spontaneous circulation in the epinephrine arm (36% vs 11%), as well as the number who were transferred to hospital (50% vs 30%). The primary outcome measure was survival at 30 days and this was 3.2% in the epinephrine group and 2.4% in the placebo group which was significant, but the number of survivors with severe neurological impairment was 31% in the epinephrine group versus 18% in the control group, and thus the trial was negative in terms of survival with favourable neurological outcome (2.2% vs 1.9%). The triallists concluded that epinephrine significantly improved the chance of achieving the return of spontaneous circulation and the survival of the patient to hospital admission but that it led only to a greater proportion surviving with severe neurological disability.

In the light of this important study, we suggest that the current recommendations of giving epinephrine every 3–5 min at a dose of 1 mg is supported on the basis that it is unlikely to harm the patient and may be beneficial. We recommend that intravenous epinephrine (1 mg) is given after the third cycle. It may be acceptable to administer smaller doses of epinephrine if a senior clinician feels that there may be reactive hypertension on ROSC.

The guideline group also discussed the question of the administration of epinephrine in cases of a non-shockable rhythm. Current recommendations from the ERC are to give epinephrine at a dose of 1 mg as soon as possible but they do caveat this by saying that 'exceptions may exist where a clear reversible cause can be rapidly addressed'. In PEA and asystole in the catheter laboratory there are reversible causes that should be addressed, and for this reason the group concluded that we should recommend administering epinephrine at the same time as in a shockable rhythm to allow time for reversible causes to be addressed.

Recommendations	Class	Level
We recommend that for patients who arrest in a catheter laboratory the benefits of epinephrine which are mainly based on out-of-hospital arrest randomised controlled trials (RCTs) may also apply in terms of an increased return of spontaneous circulation.	I	A
We recommend that for patients who arrest with ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT) intravenous epinephrine 1 mg is given after the third shock cycle.	I	A

Table 1 Physiological parameters of interest.

Physiological parameters of interest			
The following parameters are suggested to encourage data collection and stimulate research in a cardiac arrest management. It should be noted that they are not known markers of improved clinical outcome.			
Parameter of interest	**Parameter targets**		
Systolic blood pressure (mm Hg)	60	70	80
Diastolic blood pressure (mm Hg)	25	30	40
Central venous pressure (mm Hg)	5	10	20
Coronary perfusion pressure (mm Hg)	10	15	20
End-tidal CO_2 (mm Hg)	10	15	20
End-tidal CO_2 (kPa)	1.3	2	2.7
PH	7.0	7.1	7.2
Base excess (mmol/l)	−10	−7.5	-5
Oxygen saturation (%)	70	80	90
Cerebral oximetry (Near infrared spectroscopy) (%)	25	30	40

Green, amber and red indicate potential impact of the physiological parameters achieved during cardiac arrest on restoration of spontaneous circulation (ROSC) and could be used to guide future research. Clinical decisions regarding cessation of resuscitation should not be based only on these parameters.

Recommendations	Class	Level
We recommend that for patients who arrest with a non-shockable rhythm intravenous epinephrine 1 mg is given after the third cycle of cardiopulmonary resuscitation (CPR) rather than immediately to allow time for reversible causes of cardiac arrest to be addressed	IIa	C

Waveform capnography in cardiac arrest

We recommend that waveform capnography is used for patients in established cardiac arrest. Not only does this prove that the airway is patent, and that there is reasonable air entry to allow the exchange of CO_2, but more importantly the level of exhaled CO_2 correlates with the cardiac output. Capnography can be used as a prognostic guide to the likely result of prolonged resuscitation. An end-tidal CO_2 more than 20 mm Hg (2.7 kPa) is a good prognostic indicator whereas an end-tidal CO_2 of less than 10 mm Hg (1.3 kPa) indicates a poor prognosis and may be used to indicate that further treatment is likely to be futile or that modifications are required to the CPR to improve this figure.

Goal-directed management during prolonged cardiac arrest in the catheter laboratory

A number of physiological parameters are associated with higher rates of ROSC. This has led to the hypothesis that higher rates of ROSC and better clinical outcomes might be achieved by goal-directed resuscitation techniques. This may be particularly relevant to the management of cardiac arrest in the catheter laboratory where resuscitation attempts may be prolonged and invasive monitoring is routine.[36 37 38] Physiological parameters of interest based on our literature review on this topic are listed in table 1. This concept was investigated in a series of 10 patients who underwent mechanical CPR and PCI to treat prolonged cardiac arrest in the catheter laboratory.[39] The average time of mechanical CPR was 43 min. Systolic blood pressures above 70 mm Hg and diastolic blood pressures above 40 mm Hg were targeted. A pigtail catheter was inserted into the right atrium via the femoral vein at the interventionists discretion to monitor CVP and to administer vasoactive drugs. The investigators aimed to keep the CVP below 25 mm Hg. If this was not achieved, echocardiography was performed to exclude cardiac tamponade, the mechanical CPR device was repositioned, and inotropes or vasoconstrictors were initiated. End-tidal CO_2 was measured following

insertion of an endotracheal tube or a supraglottic airway with a target of >15 mm Hg (>2 kPa). The SpO_2 was kept above 80%, and arterial blood gas measurement was used to guide 'normo' ventilation. Cerebral oximetry was also monitored. Vasoconstrictor infusions were used in favour of epinephrine boluses. For patients in VF, attention was directed towards opening the acutely occluded coronary artery in favour of repeated attempts at defibrillation. The protocol was simulated in training prior to its institution. Early experience identified difficulties measuring all of the parameters every 2 min during ongoing cardiac arrest. When the parameters were measured successfully, they regularly identified patients whose vital parameters were suboptimal.

In the AHA 'get with the guidelines registry' of 3023 monitored cardiac arrests and 6064 unmonitored in-hospital cardiac arrests, those who had a monitored arrest had a significantly better chance of survival based mostly on blood pressure and end-tidal CO_2 monitoring.[40] The AHA recommended keeping the end-tidal CO_2 above 20 mm Hg and the diastolic blood pressure above 25 mm Hg in their consensus statement on improving resuscitation outcomes.[41]

A group in Greece wrote a discussion document proposing the 'PERSEUS' protocol in 2019 aimed at prolonged physiological monitoring of patients in cardiac arrest.[42] They proposed mechanical CPR, and ventilating the patient with positive end expiratory pressure (PEEP) of zero, respiratory rate of 10 per min, tidal volume 6 mL//kg, 100% oxygen, inspiration:expiration ratio 1:2. In a previous observational study they had found higher airway pressure was associated with better outcomes, with a pressure of 40–45 mm Hg giving optimal outcome. They discuss the pitfalls of using end-tidal CO_2 to estimate cardiac output and discuss how positive pressure ventilation may be used to augment cardiac output during chest compressions. They suggested placing a CVP line with the aim being to keep the CVP below 25 mm Hg and advocated that if the CVP was low, a straight leg raise should be performed to assess volume status and then fluid be given as indicated. They suggested using optimal positioning of the mechanical CPR device and epinephrine infusions to keep the diastolic blood pressure above 40 mm Hg and that severe acidosis be treated immediately to prevent vasodilation and decreased central perfusion pressure.

Among over 1500 patients with out-of-hospital cardiac arrest in whom a venous blood gas was measured, adverse results were associated with a lower rate of survival. In particular, patients without ROSC had a mean pH of 7.11, pCO_2 of 9.7 kPa, base excess of −7 mmol/L, potassium of 4.5 mmol/L and a lactate of 7 mmol/L. Low pH, high pCO_2 and high plasma potassium concentration were predictors of poor outcome.[43]

A meta-analysis of goal-directed resuscitation identified mainly animal studies but did conclude that goal- directed CPR may be superior to standard CPR, especially when end-tidal CO_2 and blood pressure management were targeted.[44] It is important to emphasise that a low end-tidal CO_2 may reflect inadequate ventilation rather than low cardiac output, especially when a supraglottic airway is used, because of the higher airway pressures required during chest compressions and steps should be taken in these cases to place an endotracheal tube as soon as it is safe to do so.

Monitoring of the CVP allows an estimate of coronary perfusion pressure by subtracting the diastolic arterial pressure from the CVP. Ideally it should be kept above 20 mm Hg.

The catheter laboratory is a unique environment in which physiological parameters can be accurately monitored during circulatory arrest. These parameters can be used to assess the effect of interventions such as the adjustment of cardiac massage technique, intravenous administration of vasoactive medications, correction of acidosis, electrolytes, and volume status, and less conventional treatments such as head-up CPR, while prolonged revascularisation attempts are ongoing or preparation is made for ECPR. Whether or not goal-directed resuscitation improves clinical outcomes, or even increases rates of ROSC, is not yet clear so firm recommendations for setting physiological parameter targets during cardiac arrest cannot be made. Nevertheless, we recommend that teams consider recording physiological parameters during prolonged cardiac arrest (table 1). Green, amber and red indicate the potential impact of the physiological parameters achieved during cardiac arrest on ROSC and could be used to guide future research. Clinical decisions regarding cessation of resuscitation should not be based only on these parameters.

Recommendation	Class	Level
We recommend that physiological parameters are recorded at regular intervals during cardiac arrest in the catheter laboratory once mechanical cardiopulmonary resuscitation (CPR) has been instituted.	IIb	C

Is amiodarone of use in a VF arrest in the catheter laboratory?

We sought evidence as to whether amiodarone or lidocaine may be useful for VF/pulseless VT. There is good evidence in support of Amiodarone in four large randomised trials,[45–48] each demonstrating an improvement of the chance of successful cardioversion of about 10%. It must be noted that these studies are all in the out-of-hospital setting and thus there is less certainty that the results might be equivalent in the in-hospital setting or indeed in a catheter laboratory.

Amiodarone should be given as a bolus injection of 300 mg. A further dose of 150 mg may be given for recurrent or refractory VF/VT followed by an infusion of 900 mg over 24 hours. Lidocaine 1 mg/kg may be used as an alternative and may have a similar efficacy.[49] There is less robust evidence regarding alternatives such as procainamide.

Recommendation	Class	Level
After three failed cycles of defibrillation for ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT) without a cardiac output, a bolus of 300 mg of intravenous amiodarone should be administered.	I	A

The use of echocardiography during cardiac arrest

Echocardiography can help to identify the cause for the arrest and should be performed rapidly as an integral part of the resuscitation. It is important to exclude tamponade early in the resuscitative process and also to repeat the echo in a prolonged arrest if the effectiveness of CPR diminishes abruptly as this may indicate tamponade secondary to external cardiac massage or delayed onset of tamponade. Echocardiography has also been shown to reduce the time taken for pulse checks[50] by enabling visualisation of the presence or absence of organised contractions.

In patients who already have a transoesophageal echo (TOE) probe in place this has advantages compared with transthoracic echocardiography[51] in that it does not require interruptions of CPR, can be performed continuously with better images, can be used to identify ROSC quickly, to look for dissection of the ascending aorta and, if required, can aid placement of pacing wires or the initiation of ECPR. It is also better at monitoring the effectiveness of prolonged mechanical CPR. In addition, there may be clinicians experienced in its use available in the

catheter laboratory. Thus, if it is in place already it is preferred to transthoracic echocardiography, and if it is not in place then it should be considered, especially if prolonged arrest management is being planned, allowing for the risk of oesophageal damage in TOE placement of around 0.2%[51]

Recommendation	Class	Level
We recommend that echocardiography is performed early after cardiac arrest, particularly if immediate interventions, such as defibrillation or pacing, have failed to restore cardiac output. Transthoracic echocardiography is the most readily available modality and should generally be used first. If a transoesophageal echo (TOE) probe is in place, this should be used in preference to transthoracic echocardiography (TTE). In a prolonged arrest, teams may consider the placement of a TOE probe.	IIa	B

Fluoroscopy in order to identify a pneumothorax in an arrest in the catheter laboratory

A literature review was performed in an attempt to find cases of pneumothorax identified by fluoroscopy in a catheter laboratory and to gain an understanding of the incidence of pneumothorax causing cardiac arrest, particularly after pacing procedures, or transaxillary, transcarotid or subclavian arterial approaches.

Pneumothorax is not uncommon after attempted vessel puncture in the thorax, such as pacemaker and implantable defibrillator insertion, with an incidence of around 0.6%–1.0%.[25 52]

If a pneumothorax is suspected it is straightforward to diagnose in the catheter laboratory by fluoroscopy, which has also been used to guide chest drainage in such situations.[53]

In a cardiac arrest, one potential cause could be pneumothorax. Since there is immediate access to fluoroscopy, it is recommended that in a cardiac arrest with no clear cause identified, and especially if the patient is undergoing an intervention that is high risk such as pacemaker or ICD insertion, fluoroscopy is performed to exclude pneumothorax as a cause.

Recommendation	Class	Level
If a patient arrests without a clear cause, especially in a procedure that is high risk for a pneumothorax, (pacemaker or defibrillator insertion), it is recommended that fluoroscopy be used to investigate this as a cause.	IIa	C

How should the team balance chest compressions with attempts at percutaneous intervention in a cardiac arrest?

Interventions on the coronary arteries can be associated with occlusion, or reduced flow secondary to dissection or thrombus formation. Other complications can include no reflow and perforation. In the majority of these circumstances, a key part of the ongoing resuscitation effort will involve a further intervention to treat or reverse the underlying cause. In order to preserve cerebral perfusion until a spontaneous circulation is restored, external cardiac massage is required. Manual cardiac massage cannot be achieved at the same time as fluoroscopy due to radiation exposure for the rescuer and therefore a balance must be struck between the interventionalist and those performing external chest compressions.

The AHA, the ERC and the Australian Guidelines all address the issue of external cardiac massage in the catheter laboratory. The AHA recommend early transfer to automated CPR devices, the ERC recommend that external cardiac massage should not be interrupted for angiography and the Australian Guidelines discuss the tension between the rescuers performing external CPR and the interventionalist wanting to continue with angiography. These statements have not translated into an agreed protocol that can be followed by the resuscitation team.

We strongly recommend using only mechanical CPR devices to administer CPR while undergoing PCI during an arrest. It is reasonable to pause manual CPR in order to perform angiography to search for a cause for the arrest, but subsequent PCI should be performed with mechanical CPR.

Recommendations	Class	Level
If percutaneous intervention is required during cardiac arrest, this should be performed after mechanical cardiopulmonary resuscitation (CPR) is initiated.	I	C
It is acceptable to pause manual CPR for less than a minute to perform diagnostic angiography to search for the cause of the arrest.	IIb	C

Mechanical CPR devices

The use of mechanical CPR has been extensively investigated in at least nine randomised trials with over 12 000 patients in both out-of-hospital and in-hospital arrest.[54–56] Several meta-analyses exist and support the use of mechanical CPR for in-hospital patients, although the evidence is less strong for use in out-of-hospital patients.[56–60 61]

The AHA reviewed the feasibility of using mechanical CPR devices during PCI and identified papers where feasibility has been demonstrated in both animal[62] and human[63–66] studies. No comparative studies have examined the use of mechanical CPR devices compared with manual chest compressions during PCI procedures although, due to the inherent need to cease manual compressions during fluoroscopy, there is a clear benefit for mechanical CPR.

A number of case reports[62 63] and case series[65–68] have reported the use of mechanical CPR devices to facilitate prolonged resuscitation in patients who have a cardiac arrest during PCI. One study demonstrated that the use of a mechanical CPR device for cardiac arrest during PCI was feasible; however, no patients survived to hospital discharge.[65] Other studies have reported good patient outcomes, including ROSC and survival to discharge with good functional outcome.[62] Of note the length of time required to perform PCI with a mechanical CPR device was around 30 min (ranging from 12 min to 90 min), which highlights further the importance of a protocol that allows prolonged CPR while PCI is ongoing.

We are therefore strongly of the view that mechanical CPR devices are of major benefit to patients in the specialist environment of the catheter laboratory, for liberating rescuers from performing manual CPR and for the ability to perform uninterrupted CPR for at least 30 min while interventions are performed (Figure 2). In addition, we strongly advocate the immediate availability of these devices in the catheter laboratory and regular team-based training in order to be able to place these devices with a pause of less than 15 s.[69 70]

Recommendations	Class	Level
Mechanical cardiopulmonary resuscitation (CPR) is strongly recommended if simple measures do not succeed in resuscitating the patient. We recommend that mechanical CPR is commenced after the first cycle of manual CPR.	I	A
We recommend that all catheter laboratories have mechanical CPR immediately available in the catheter laboratory complex in case of arrest.	I	C

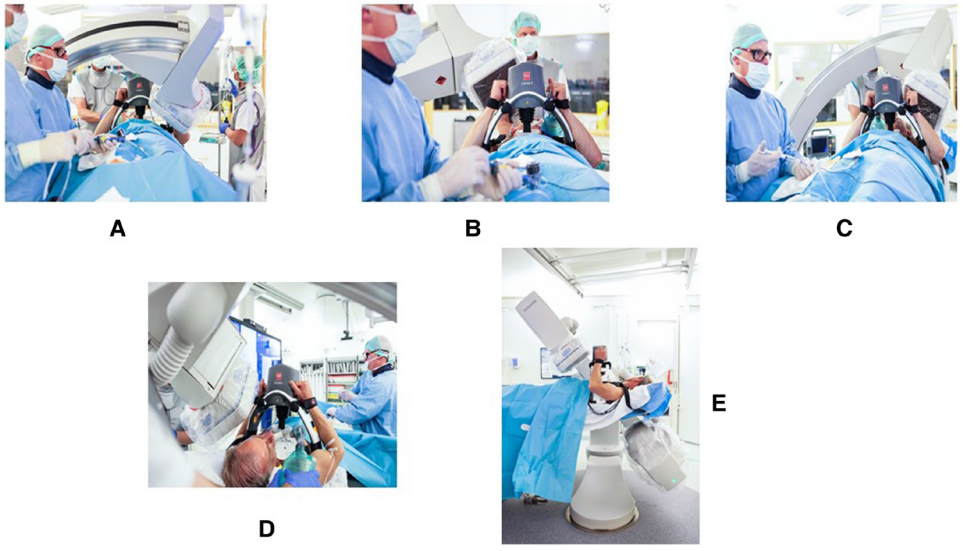

Figure 2 Fluoroscopic projections possible with the automatic external cardiac massage device in place. (A) Right posterior oblique; (B) Left anterior oblique; (C) Right anterior oblique; (D) Straight cranial; (E) Straight caudal (with permission from Stryker Corporation).

Recommendations	Class	Level
We recommend that teams undergo regular group training to ensure that the transfer from manual CPR to automated CPR is conducted in less than 15 s.	I	C

ECPR in the catheter laboratory

The AHA and the ERC both recommend the use of ECMO to provide ECPR. The AHA state that 'rapid initiation of eCPR or cardiopulmonary bypass is associated with good patient outcomes in patients with haemodynamic collapse and cardiac arrest in the catheter laboratory and also the use of eCPR is feasible and associated with good outcomes when used as a bridge to coronary artery bypass grafting' (AHA Class IIb, LOE C). The ERC are more equivocal, stating that very low quality evidence suggests that the use of extracorporeal life support can be considered as a rescue strategy if the infrastructure is available, and this should probably be preferred to the use of intra-aortic balloon pump (IABP) in such situations. The First RCT in this area called the ARREST Trial was stopped early due to the highly significant effects in favour of ECMO in out of hospital cardiac arrest (OHCA). Thirty patients were randomised and there were six survivors in the ECMO group compared with only one in the standard care group.[71] Furthermore, there are many case series reporting the efficacy of extracorporeal cardiopulmonary bypass[72–80] in the context of catheter laboratory based cardiac arrests. Bagai *et al* reported in 2011 on the use of extracorporeal cardiopulmonary bypass in 39 patients in a range of situations including cardiac arrest and cardiogenic shock in the catheter laboratory. The survival to discharge was 71%.[76] Van den Brink in 2018[80] reported the use of extracorporeal cardiopulmonary bypass in 12 patients of whom 11 were in cardiac arrest with a survival to discharge of 67% and a 1-year survival of 42%. Nine had out-of-hospital arrest and a further two had in-hospital arrest.

The Extracorporeal Life Support Organisation has published a position paper in 2018, advocating ECMO in arrests of longer than 15 min of duration, but centres offering ECMO are required to be looking after at least 30 patients a year and therefore will generally be located only in transplantation centres.[81]

Recommendation	Class	Level
It is recommended that units investigate the use of ECMO as a further means of supporting patients who do not recover after cardiac arrest in the catheter laboratory and have local protocols and training in place for its effective use if it is available.	IIa	B

IABP insertion in the arrest situation

The evidence for the insertion of an IABP in an arrest situation was reviewed. Of note the AHA have also reviewed this evidence and concluded that while IABP counterpulsation increases coronary perfusion, decreases myocardial oxygen demand and improves haemodynamics in cardiogenic shock states, it is not associated with improved patient survival. They state that the role of IABP in patients who have a cardiac arrest in the catheterisation laboratory is not known.

The IABP-SHOCK II Trial which randomised nearly 600 patients who were in shock from an acute myocardial infarction did not find an improvement in the 30-day survival after the intervention.[82] This landmark study followed 13 RCTs together with meta-analyses and a Cochrane systematic review which were all unable to detect a significant improvement in 30-day survival although other small improvements were sometimes reported.[83–90] It must be noted that although these studies were in patients with an acute myocardial infarction (rather than patients in cardiac arrest in a catheter laboratory) the IABP-SHOCK Trial has led to a significant reduction in the use of IABP in cardiogenic shock in catheter laboratories.

A further small RCT looking at IABP versus control in patients who suffered a cardiac arrest with an acute coronary syndrome also found no benefit.[91]

There are few studies looking at the insertion of IABPs in the arrest situation.[92 93] Without a spontaneous circulation to trigger the IABP, counterpulsation would be unlikely to be

successful. Thus, it is concluded that there is no indication to place an IABP acutely in the cardiac arrest period in the catheter laboratory.

Recommendation	Class	Level
The insertion of an intra-aortic balloon pump (IABP) during an arrest in the catheter laboratory or routinely in the acute postcardiac arrest period is not recommended.	III (lack of benefit)	A

Is an Impella pump useful in an arrest?

The ERC in 2015 stated in their section on cardiac arrest in the catheter laboratory that 'There is no evidence to recommend circulatory support with the Impella pump only during cardiac arrest' and in 2021 they changed this slightly to say that they may provide circulatory support while performing rescue procedures but require further evaluation. They provided a single reference to support this[94] which was a case series of eight patients who had an Impella device in an arrest, of whom four survived to hospital discharge. We identified a further paper documenting use in 7 patients in arrest, although only 1 survived,[95] and a multicentre study across four countries[96] of 35 patients having Impella insertion while in cardiac arrest with a 45% survival.

There have been case series and cohort studies of the use of the Impella in cardiogenic shock in adults and children[97] and in high-risk PCI cases[98–100] and there is an interesting ongoing RCT currently recruiting that aims to randomise 360 patients with shock post-myocardial infarction (MI) to standard therapy or Impella that will report in the coming years.[101]

The 2021 joint ERC and European Society of Intensive Care medicine guidelines for postresuscitation care state that 'the evidence about which type of mechanical device is superior appears inconclusive and thus their use should be decided on a case-by case basis'.[95]

Recommendation	Class	Level
The use of an Impella is not routinely recommended in cardiac arrest in the catheter laboratory	III (lack of benefit)	C

The identification and treatment of pericardial tamponade

Sethi *et al* reported the findings of the US National Inpatient Sample database from 2009 to 2013 which covers around 90% of all patients in the USA. They document 64 000 pericardiocentesis procedures and 57% of these were in unstable patients, 17% were in PCI cases, 13% in EP procedures and 14% in structural heart procedures. Thus, pericardiocentesis is performed in all types of catheter laboratory interventions.[102] As this was a database study they were unable to comment on the procedural success rate, although the inpatient mortality in the database overall was around one in four.

Tsang *et al* documented a 21-year experience with a thousand pericardiocentesis procedures at the Mayo clinic, including many patients with perforation in the catheter laboratory. They report a 97% procedural success for this procedure in all settings with only a 2% major complication rate. They also reported that they saw a significant increase in the rate that clinicians left a drain in situ during the period of the study from 25% to 75%.[103]

Cho *et al* confirmed these findings in a report of nearly 300 echocardiographically guided pericardiocentesis procedures, with approximately 40 during PCI. They reported a 99% procedural success with a 1% complication rate.[104]

A UK observational study of 270 329 PCI procedures in the context of acute coronary syndromes describes 1013 coronary perforations (0.37%).[41] Importantly, the adjusted ORs for all clinical outcomes were adversely affected by coronary perforation. The conclusion was 'Coronary perforation is an infrequent event during ACS-PCI but is closely associated with adverse clinical outcomes'.

The ESC position statement on the urgent management of cardiac tamponade[105] gives a class I indication for pericardiocentesis for tamponade, preferring echocardiographic guidance where possible although fluoroscopic guidance is an acceptable alternative. If unsuccessful, surgical drainage is recommended. Of note these guidelines are mainly for non-iatrogenic causes of the tamponade

It is extremely important that all catheter laboratories have immediate access to an echo machine in order to be able to confirm or exclude tamponade in an emergency. All cardiologists who perform interventional procedures should be trained in pericardiocentesis techniques, and all catheter labs should have a dedicated and easily accessible pericardiocentesis kit, which the team are familiar with. The emergency procedures for pericardiocentesis should be familiar to all catheter laboratory staff. The pericardiocentesis/perforation kit should be stored together and include drainage equipment, coils and covered stents. There should be an agreed unit protocol as to the method of distal embolisation technique as a wide variety of options are available.

In all cases of pericardial collection, repeat TTE should be performed within 2 hours of return to the ward and often again within the following few hours. This is particularly important in the case of distal wire perforations and any case in which a perforation has apparently sealed spontaneously.

Recommendations	Class	Level
Pericardiocentesis should be performed for all patients with pericardial tamponade and where possible this should be with echocardiographic or fluoroscopic guidance. Surgical drainage and repair should be performed if percutaneous drainage is not successful in relieving the tamponade.	I	B
An echocardiography machine should be immediately available in all catheter laboratories in case of patient deterioration or arrest.	I	C
We recommend that a repeat echocardiogram is performed to reassess the pericardial space after drain insertion to monitor for recurrence of a haemopericardium.	IIa	C

Treatment of pericardial tamponade if pericardiocentesis fails

A BCIS analysis from 2006 to 2013 of the complete UK PCI database reported a 0.3% perforation rate with PCI.[106] This comprised of 1762 patients of whom 14% developed tamponade (246 pts) and 3% required emergency surgery (52 patients). Thus, there are roughly 250 coronary perforations per year with around 35 associated episodes of tamponade and seven patients per year in the UK who require emergency surgery after coronary perforation.

This number is likely to have increased since 2013. Furthermore, this database does not include pacing procedures, EP or structural heart procedures. Thirty-seven per cent of coronary perforations occurred in a unit without surgical cover (589 coronary perforations in units without on-site surgical cover compared with 997 in units with cover). Coronary perforations can be classified using the Ellis Classification both in the arrest and the non-arrest situation according to the significance of the defect created in the artery.[107]

With regard to the perforation of cardiac chambers from non-PCI interventions, the National Cardiovascular Data Registry in the USA[108] documented 625 cardiac perforations in a 5-year

period, which was one perforation for every 700 implantations of an ICD. The BHRS has provided detailed guidance in their 2016 document entitled 'Standards for Interventional Electrophysiology and catheter ablation in adults'.[109]

We recommend that for coronary perforations consideration be given to heparin and antiplatelet reversal, a decision that must be balanced against the risk of producing stent thrombosis. An activated clotting time could be used to guide this decision.

We recommend there should be on-site availability and experience with covered stents, embolisation coils and the ability to perform distal embolisation. There should be an agreed unit protocol as to the method of distal embolisation technique as a wide variety of options are available.

For perforation of cardiac chambers we also recommend consideration of reversal of heparin, calling for senior colleague assistance, where relevant withdrawal of the lead or wire from the perforation and echocardiographic monitoring for a tamponade.

Recommendations	Class	Level
For coronary perforations, consideration should be given to reversal of anticoagulants, antiplatelet medications and glycoprotein IIb/IIIA inhibitors and an activated clotting time (ACT) should be performed.	IIb	C
There should be on-site availability and experience with covered stents, embolisation coils and the ability to perform distal embolisation. There should be an agreed unit protocol as to the method of distal embolisation technique as a wide variety of options are available.	IIa	C
For all cardiac perforations, even if the patient seems stable, a decision must be taken as to whether cardiac surgical colleagues should be consulted. The threshold for surgical discussion should be low. Failure to stop the underlying cause for the tamponade should mandate emergency consultation.	IIa	C

Surgical support

There should be access to emergency cardiothoracic surgery for all patients who have suffered a tamponade in the catheter laboratory. In units without cardiac surgical cover, an agreed written protocol must be in place in order to ensure that timely relief of a tamponade is possible. The time taken for a patient to sternotomy should be of a similar order to that possible with on-site surgical facilities where a surgical team is not on stand-by.

Options to achieve this may include rapid transfer to the cardiothoracic centre with surgeons ready to receive the patient, or using experienced on-site surgeons trained in emergency thoracotomy to commence relief of a tamponade while a cardiac surgeon travels to the local centre. We recommend that these protocols be documented and tested regularly to ensure equitable availability of potentially life-saving interventions in both centres with and without on-site cardiac surgical cover.

We furthermore recommend the notification of the on-call surgical team for all coronary perforations that cannot be sealed via percutaneous techniques, and all cardiac chamber perforations requiring a pericardiocentesis drain, even if they seem stable, so that the most appropriate management strategy can be agreed.

Recommendation	Class	Level
In units without cardiac surgical cover, an agreed written protocol must be in place in order to ensure that timely surgical relief of a tamponade is possible. The time taken for a patient to sternotomy should be of a similar order to that possible with on-site surgical facilities where a surgical team is not on stand-by.	IIa	C

The management of pulmonary embolus

We identified papers relevant to the management of either confirmed or suspected pulmonary embolus (PE) in cardiac arrest. In addition, the ESC have guidance on the treatment of PE[110] and the AHA and ERC both give recommendations in this area.

It may be difficult to determine PE as the cause of the cardiac arrest although in-hospital arrest teams have been able to identify PE up to 85% of the time.[111] Teams may identify factors precipitating the cardiac arrest before the actual arrest which may include a high-risk history such as malignancy, previous PEs or recent surgery, they may identify symptoms such as dyspnoea, tachycardia and chest pain, and there maybe signs on ECG or a distended right ventricle on echocardiography prior to the arrest.

Once the arrest has occurred, the arrest rhythm is more commonly PEA (63%) versus only 5% in VF.[112] Echocardiography during the cardiac arrest may identify a distended right ventricle with a flattened interventricular septum in cases of PE large enough to precipitate arrest,[113] although right ventricular dilatation in arrest should be interpreted with caution.[114]

In terms of the treatment of the PE in the cardiac arrest Li *et al* published a meta-analysis in 2006[115] of eight papers that demonstrated that thrombolytics administered during CPR did improve survival, although inevitably there was also an increase in bleeding complications. In an RCT of 1000 patients with out-of-hospital arrests randomised to thrombolytic therapy, no improvement in survival was seen but the percentage of patients who actually had PE may have been low in this study.[116]

The ERC recommend the use of fibrinolytics for patients suspected of arresting secondary to a massive pulmonary embolus.[8] They also recommend that CPR should then continue for 60–90 min and that a mechanical compression device may therefore be required for this. In addition, if there is return of spontaneous circulation then particular attention should be paid to identification of bleeding complications thereafter and in centres where this is available ECPR could be considered.[117–122]

The AHA gives a class IIb indication for echocardiography during cardiac arrest stating that 'if a qualified sonographer is present and use of ultrasound does not interfere with the standard cardiac arrest treatment protocol, then ultrasound may be considered as an adjunct to standard patient evaluation'. The AHA recommend thrombolysis with a class IIb strength of recommendation in addition to systemic anticoagulation. The AHA also mention the possibility of percutaneous mechanical thrombectomy although many units would not have access to this as it requires specialist equipment. One case series reported a successful outcome of percutaneous mechanical thrombectomy during CPR in six out of seven patients.

We also discussed whether in an arrest where PE is suspected in the catheter laboratory pulmonary angiography should be performed, but technically this was felt to be difficult to perform.[123]

Recommendation	Class	Level
In confirmed or suspected acute massive pulmonary embolus in the catheter laboratory, we recommend thrombolysis and systemic anticoagulation. Cardiopulmonary resuscitation must then continue for 60–90 min. Echocardiography may assist in making this diagnosis.	IIb	B

Return of spontaneous circulation

Once there has been a return of spontaneous circulation a full airway, breathing, circulation examination should be performed. Angiography and echocardiography should be considered where appropriate. If the patient has not neurologically recovered sufficiently or their gas exchange is unfavourable it is often safer to intubate and ventilate. Appropriate vascular access with a central line and an arterial line will allow cardiac monitoring and vasoactive drug use as necessary. It is important that such patients are treated in an intensive care area environment if ventilated and at least a high care area otherwise. If there has been a prolonged period of arrest then targeted temperature management has been extensively investigated especially in out-of-hospital arrests[124] and may help a patient who has had a prolonged arrest. However there have been no in-hospital studies to demonstrate benefit and the target temperature has not been established and therefore routine early cooling is not recommended.

Perhaps more importantly the possible longer-term effects of arresting in the catheter laboratory should be considered. If the patient makes a good physical recovery, they should be fully counselled as to the events that occurred in the arrest and consideration of additional or prolonged follow-up should be given to make sure that they suffer no neurological or psychological sequelae. The ERC and the European Society of Intensive Care Medicine have written detailed guidance in 2021 for post-resuscitation care which addresses many of these issues[125] and in addition to this there is excellent patient support at the website www.suddencardiacarrest.org.

THE OPTIMAL CONFIGURATION FOR THE CARDIAC ARREST TEAM

In order to carry out emergency protocols efficiently, whether they be in an arrest situation or with a deteriorating patient, it is vital for all team members to know their roles and responsibilities. There may be a wide variety of staff numbers and skill mixes available in the catheter laboratory area depending on the size of the institution and also the time of day or night. Therefore, there will clearly also have to be some flexibility and also additional roles that might be allocated, but we propose these six key roles to allow a structure for people to work towards (Figure 3). In addition, it is optimal that the staff members will know in advance the role that they would be expected to take in an emergency, and that this could be documented on a communication board at the start of a shift.

The operator

While the cardiologist takes the lead in the catheter lab, the main aim of our protocols is to free this person up of responsibility for resuscitation in the cardiac arrest or the emergency situation. The cardiologist should stay scrubbed at the side of the patient. They are often the person to see the emergency first, and thus must declare this early to the team but thereafter an emergency team leader should be allocated.

The cardiologist is best placed to perform the specialist interventions that may resolve the situation. They should concentrate on this aspect of the pathway and coordinate with the other staff addressing resuscitation via the team leader.

Role 1: The emergency leader

We recommend that someone other than the operating cardiologist organise the team to achieve the best outcome for the patient. We do not mandate who this person should be in terms of their discipline or qualifications, and in fact we are of the opinion that everyone who works in a catheter laboratory should be trained to be able to carry out each of the six key roles, although often in the day there might be another senior cardiologist who will be available to perform this role.

The role is to coordinate the protocols highlighted above as the leader of the group addressing all the components of the arrest response. The leader is encouraged to have the protocol to hand on a flip chart or on a poster.

The emergency leader must make sure personnel are allocated to all required roles and will also allocate tasks to additional people, outside of the six key roles

Role 2: Airway and breathing

If there is any acute emergency and especially in an arrest, the scrubbed personnel will be dealing with the circulation, so

Figure 3 The six key roles. BCIS, British Cardiovascular Intervention Society; BHRS, British Heart Rhythm Society; CPR, cardiopulmonary resuscitation.

another member of staff should go straight to the head of the patient to take responsibility for airway and ventilation. For a person who is not breathing they must immediately get a bag/valve/mask at 100% oxygen and place this on the patient's face and attempt to ventilate the patient. If they are successful, then the chest will rise on both sides, and water vapour may be seen in the mask. If they are unsuccessful then an airway obstruction issue must be considered. Attempt airway manoeuvres—jaw thrust, chin lift, Guedel airway and perhaps ask another person to help with squeezing the bag so you can use two hands to form a good seal around the patient's nose and mouth. We do not recommend that staff who are not fully trained in the technique attempt intubation. In most instances simple airway manoeuvres and airway adjuncts will suffice. A supraglottic airway is a recommended alternative to intubation. Emergency call-out for anaesthetic support is mandatory in this situation.

Once air entry is established in an arrest you must coordinate 30:2 with the person performing massage or the automated CPR device. Your role also requires you to feel the trachea to see if it is central or displaced and then ask everyone to stop massage and bag forcefully while listening bilaterally to see if you can hear a difference in breath sounds.

It is mandatory to perform these assessments in every critically ill catheter laboratory patient if you do not know the cause of their deterioration, and you must communicate that you have done this to the team leader. It is not always easy to, but if you are getting air entry from bagging but it is more difficult than you would expect, if the trachea is not central and if you bag vigorously but cannot hear breath sounds on one side then a pneumothorax or haemothorax should be suspected and this must be communicated to the team leader. We also recommend that fluoroscopy is performed for every arrested patient without an obvious cause for the arrest.

If a tension pneumothorax is suspected, for example, oxygen saturations dropping and the patient complaining of being short of breath before becoming periarrest or arresting during a pacing procedure, then needle thoracocentesis should be performed followed by a drain or a thoracostomy.

Role 3: Defibrillation and pacing

We recommend that a single person is always allocated to this role and stays beside the defibrillator at all times, even if the rhythm is not shockable. The person fulfilling role 3 should place pads on the patient wherever it is most convenient. Often they will be draped and therefore access will be limited but this will have been practised in simulation so should not be an issue. Anterior-lateral position, an anterior-posterior position or apex-posterior positions are all acceptable.

Where the rhythm is shockable we recommend immediate three-stacked shocks. Once the first shock has been delivered, external cardiac massage should not be recommenced, but the rhythm assessed while the defibrillator is being charged for the next shock. If there is no ROSC and the rhythm remains shockable, up to two further shocks should be delivered in rapid succession. The defibrillator operator is responsible for communicating to the team when the defibrillator is charging and before each shock.

If the third shock fails then further shocks may be given at 2 min intervals as determined by the resuscitation leader and the operating cardiologist. Most defibrillators when turned on, activate a timer, so the defibrillator operator is often the best person to time the CPR cycles.

Role 3 is also important in the two other rhythm disturbances. In asystole or extreme bradycardia without a pulse, external pacing may rapidly resolve the situation. We recommend that percussion pacing is attempted while pads are placed on the patient, and it is also important that defibrillators cannot pace and sense from the same pads and thus it is mandatory that ECG leads are placed on the patient and connected to the defibrillator prior to attempting external pacing. We recommend that external cardiac massage is withheld until the pacing is attempted. When the pacing is activated on the defibrillator it usually defaults to the minimum amplitude, and therefore this will have to be increased to achieve capture. If capture is not achieved at maximum amplitude then it is unlikely to work unless the pads are poorly placed and the attempt can cease. If it is felt likely that the asystole or extreme bradycardia could be resolved with pacing, and both percussion and external pacing were unsuccessful then the final option would be a temporary wire to be placed in an arrest situation by the cardiologist.

Defibrillation is not required in PEA arrest but the defibrillator operator should ensure that underlying VF or asystole is not mistaken for PEA in patients with either a temporary or permanent pacemaker in place. We are aware of three cases when this occurred and although rare, if there is a temporary wire with pacing this can be paused to check, or if there is a permanent pacemaker then a relatively narrow QRS complex with a regular rate should raise this suspicion.

Role 4: Manual chest compressions

One person should be allocated to perform CPR. If there are very limited numbers of people in the room at night then either the cardiologist or the scrub nurse could do this but it is an important role and having an allocated person is preferable.

CPR is withheld if the arrest is VF or asystole until shocks have been administered or the external pacing has been commenced, but if this has failed then CPR must be commenced. The person performing CPR will most likely need to be on the opposite side of the table to the cardiologist, and if the table is fairly high they may need a step to stand on. Hands should be linked together and elbow straight and CPR is performed on the lower half of the sternum.

Recommendations	Class	Level
Ventricular fibrillation (VF), pulseless ventricular tachycardia (VT) and asystole may all be diagnosed immediately based on the monitoring in the catheter lab (figure 1). There is no need to routinely look, listen and feel for 10 s.	I	C
Many cases of pulseless electrical activity (PEA) may also be diagnosed by the absence of pulsatile traces but if in doubt then either look, listen and feel or use echocardiography to look for a cardiac output.	IIa	C
If a patient has circulatory collapse with a rate less than 30/min then we define this as extreme bradycardia as this may respond to percussion, external or temporary wire pacing and thus we recommend following the asystole pathway.	I	C
If a patient has an arrhythmia above a rate of 140/min without a discernible cardiac output then we recommend following the pathway for VF/pulseless VT as this may respond to defibrillation.	IIa	C

The general algorithm recommends a depth of 5–6 cm and there are devices available to measure whether you are compressing adequately, but if your patient has an arterial line in place then in fact this can function as a direct measure of the quality of your CPR. In this situation you should compress the chest hard enough that you achieve a systolic pressure of

70 mm Hg. It is also important to note that if you have a well-functioning arterial line and you are compressing as hard as you can but you are unable to achieve a systolic pressure of 70 mm Hg this implies that there is a mechanical cause to the arrest such as a tamponade or a bleed, as it indicates either that the heart is compressed by tamponade and cannot fill with blood to eject, or that the heart is empty of blood due to blood loss. The inability to maintain a systolic pressure of above 70 mm Hg requires you to immediately notify the team leader and cardiologist.

Role 5: Mechanical CPR, drugs, timing and vascular access

Some smaller centres or primary PCI sites in the middle of the night will not have six people in the catheter laboratory, but in the day-time many busy catheter laboratories will have sufficient numbers of people immediately available. Therefore we considered protocols from four to eight allocated members and propose six roles here The role of having a person in charge of mechanical CPR, drug administration, vascular access and timing we would regard as highly desirable assuming there is adequate personnel available. This person's first role would be to immediately obtain the mechanical CPR device, turn it on and prepare it for placement after the first cycle of CPR. Then this person can stand by the person allocated to airway and breathing and give mediations as per protocol.

There are some key drugs that this person would need to have immediately available. Epinephrine in an arrest should be given at a dose of 1 mg every 3–5 min. We mandate its administration after the third cycle in the protocol for all arrest rhythms. It should then be given every other cycle which is again in line with the general algorithm unless the arrest is likely to be prolonged in which case the team leader will determine whether an infusion or a vasoconstrictor may be better.

If the arrest is due to a resolvable mechanical issue such as a tamponade that needs draining, it may be best to withhold the epinephrine to avoid its proarrhythmic effects and potential hypertension once the tamponade is removed which may risk further bleeding from the vessel that caused the tamponade in the first place.

The second drug in VF arrest is amiodarone. It has been shown to have a 10% increased change of defibrillation being successful in several RCTs and is recommended in all algorithms after the third cycle.

The third drug to mention in cardiac arrests is atropine. It was removed from the universal algorithm in 2015 due to lack of efficacy in the arrest situation and therefore it does not appear in our arrest algorithm. It is important to remember that it is still an important medication in bradycardia with a pulse when the patient has not arrested and it is recommended at a dose of 600 mcg, repeated up to 3 mg so long as the patient has a pulse. This issue has caused some confusion in the past.

Finally it is useful to mention that in cases of oversedation naloxone at a dose of 400 mcg repeated every 3 min up to 10 mg will immediately reverse the effects of morphine and fentanyl, and intravenous flumazenil at 200 mcg repeated every 30 s up to 3 mg will equally effect a rapid reversal of midazolam and other benzodiazepines and that in a prolonged arrest infusions and bicarbonate may be required.

Role 6: Resource coordinator

There are often many members of the team available to help in an emergency situation and on simulations and observations of real-world emergencies it is clear that there has to be a great deal of organisation behind the actual arrest or acute emergency. The emergency team leader needs to be by the patient and coordinating everything in the room but there have to be advanced lines of communication between the catheter lab, the coronary care unit (CCU), the arrest team, the ICU, echocardiographers and also other clinicians in the other catheter labs.

Therefore we feel this line of communication is sufficiently important to have a specific allocated role. If other personnel arrive, such as anaesthetists and surgeons then the resource coordinator can hand them lead aprons (and remind them that they must be worn) and while they are being put on then they can brief the person as to the case and what the nature of the emergency is. They may also be able to direct them to look at the communication board and to go and see the emergency leader rather than going into the room and immediately talking to the cardiologist.

It is possible that this role may fall to the radiographer who is a key member of the team and will most usually be at the foot of the table.

TEAM TRAINING AND VISUAL AIDS

The ERC 2021 guidelines[8] strongly recommended that all clinicians and staff who work in the catheter laboratory be adequately trained in protocols specific to this environement. The ERC state that 'protocols for specific emergency procedures (initiation of mechanical CPR, emergency pacing, pericardiocentesis, ventricular assist devices) should be established. On-site emergency drills should be considered to facilitate implementation and familiarisation of the staff'.

Training in simulated catheter lab emergencies is provided at the annual meeting of the BCS (www.bcs.com) and there is a well-established group who can assist in this training called the Cardiac Advanced Resuscitation Education group (C.A.R.E.—www.csu-als.org).

We recommend that catheter laboratory specific training be performed in every unit. ILCOR recommend the use of cognitive aids to augment the quality of the specialist resuscitation.[126] ILCOR also recommend debriefing stating that data-driven, performance-focused debriefing of rescuers after in hospital cardiac arrest (IHCA) for both adults and children is recommended.[91]

Recommendations	Class	Level
Specific catheter laboratory focused training should be given to all staff working in this area, including training in the protocols contained in this document, and emergency drills for mechanical cardiopulmonary resuscitation (CPR), emergency pacing, pericardiocentesis and ventricular assist devices.	I	C
Cognitive aids may be used in the catheter laboratory to assist with the conduct of emergency protocols including the cognitive aids provided in this document.	IIb	C
After an unexpected cardiac arrest or a prolonged emergency situation we recommend that the senior clinician leads a debrief with his team on the same day as the emergency situation in which aspects of performance are analysed.	IIb	C

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