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AHA SCIENTIFIC STATEMENT

Cardiac Catheterization Laboratory Management of the Comatose Adult Patient With an Out-of-Hospital Cardiac Arrest: A Scientific Statement From the American Heart Association

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ABSTRACT: Out-of-hospital cardiac arrest is a leading cause of death, accounting for ≈50% of all cardiovascular deaths. The prognosis of such individuals is poor, with <10% surviving to hospital discharge. Survival with a favorable neurologic outcome is highest among individuals who present with a witnessed shockable rhythm, received bystander cardiopulmonary resuscitation, achieve return of spontaneous circulation within 15 minutes of arrest, and have evidence of ST-segment elevation on initial ECG after return of spontaneous circulation. The cardiac catheterization laboratory plays an important role in the coordinated Chain of Survival for patients with out-of-hospital cardiac arrest. The catheterization laboratory can be used to provide diagnostic, therapeutic, and resuscitative support after sudden cardiac arrest from many different cardiac causes, but it has a unique importance in the treatment of cardiac arrest resulting from underlying coronary artery disease. Over the past few years, numerous trials have clarified the role of the cardiac catheterization laboratory in the management of resuscitated patients or those with ongoing cardiac arrest. This scientific statement provides an update on the contemporary approach to managing resuscitated patients or those with ongoing cardiac arrest.

Key Words: AHA Scientific Statements ■ cardiac catheterization ■ cardiopulmonary resuscitation ■ coma ■ extracorporeal membrane ■ heart arrest ■ out-of-hospital cardiac arrest ■ oxygenation

Approximately 350 000 people each year experience an out-of-hospital cardiac arrest (OHCA) in the United States, with a survival rate of 6% to 10%.[1] As such, OHCA is a leading cause of death, accounting for 15% to 20% of all natural deaths and 50% of all cardiovascular deaths.[2,3] Whereas overall survival to hospital discharge is low, reported survival in patients with a witnessed collapse and shockable rhythm approaches 30%.[1] Survival with favorable neurologic outcomes is highest among patients who present with a witnessed shockable rhythm (ie, ventricular tachycardia or fibrillation), receive bystander cardiopulmonary resuscitation (CPR) or automated external defibrillation, achieve return of spontaneous circulation (ROSC) within 15 minutes of arrest, and have evidence of ST-segment–elevation (STE) on initial post-ROSC ECG.[1,4] The implementation of a coordinated systems of care approach with emergency access to the cardiac catheterization laboratory and incorporating extracorporeal membrane oxygenation (ECMO) in select patients have been shown to positively affect survival.[5,6]

The main initial focus of management of the resuscitated comatose patient with OHCA and ROSC is 2-fold: minimizing neurologic damage and treating the underlying condition that led to the arrest to prevent further hemodynamic or electrical deterioration. Therefore, immediate recognition of cardiac arrest and initiation of effective CPR in the field, with early defibrillation when indicated,

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and subsequent rapid transfer of the individual to a hospital capable of delivering state-of-the-art postresuscitation care, is warranted.[5] Interventions, including performing primary percutaneous coronary intervention (PCI) in patients with STE on ECG, implementing evidence-guided targeted temperature control, and providing multidisciplinary care including neurologic prognostication by neurologists with postresuscitation care expertise, are crucial to achieving optimal outcomes after ROSC.

The cardiac catheterization laboratory is an important link in the coordinated Chain of Survival for individuals with OHCA. The catheterization laboratory can provide a useful setting to resuscitate and stabilize patients with sudden cardiac arrest from many different cardiac causes, but it has a unique importance in the treatment of OHCA resulting from underlying coronary artery disease.[6–8] Over the past few years, numerous trials have clarified the role of the cardiac catheterization laboratory in the management of resuscitated patients or those with ongoing cardiac arrest. This scientific statement provides an update on the contemporary approach to managing resuscitated patients or those with ongoing cardiac arrest, incorporating current data and guidelines.

EPIDEMIOLOGY AND RISK FACTORS

The incidence of OHCA treated by emergency medical services (EMS) among the adult population in the United States is ≈66 per 100 000 annually, with <20% of patients presenting with an initial shockable rhythm.[1] Survival to hospital discharge varies by sex, race and ethnicity, and arrest location, with the highest survival observed among White men and lower survival among Black or Hispanic men and women.[1] Over the past 3 decades, survival rates in individuals with OHCA have increased by nearly 2-fold, with the greatest gains noted during the first 2 decades, with no notable improvement over the past 10 years.[9]

Atherosclerotic coronary artery disease is the most important risk factor for OHCA; in accordance, the incidence of OHCA increases with age and the coexistence of established risk factors, such as diabetes, hypertension, dyslipidemia, and tobacco use.[10] The incidence of OHCA is ≈3-fold to 4-fold higher in men compared with women, but this disparity may be decreasing.[11] Additional cardiac and noncardiac risk factors for OHCA include atrial fibrillation, underlying cardiomyopathies, primary electrical disorders, chronic kidney disease, substance abuse, and obstructive sleep apnea.[10]

PATHOGENESES

Sudden cardiac arrest attributable to primary cardiac causes may arise as a result of several different underlying mechanisms. These can be divided into 3 broad categories: ischemic, structural, and electrical (Figure 1). The most common pathogenesis, accounting for as many as 70% of sudden cardiac arrests, is atherosclerotic coronary heart disease. Sudden cardiac arrest may be the initial manifestation of obstructive coronary disease in >50% of cases.[12] Whereas coronary artery disease is the most prevalent risk factor, the proportion of OHCA as a result of an ischemic cause has decreased substantially over the years.[9] For this reason, focusing on this risk factor with regard to causality or for therapeutic purposes is not warranted in every case.

INITIAL ASSESSMENT

The initial assessment of the patient resuscitated after cardiac arrest should focus on the clinical history, physical examination, and accompanying ECG and laboratory findings, with the aim of identifying and reversing the precipitating cause, especially if the arrest is a result of an acute STE myocardial infarction (STEMI). Identifying the likelihood of an acute ischemic trigger is important, because this will guide the decision to selectively use urgent invasive angiography. Several evaluation tools are useful in determining arrest cause and selecting patients for coronary angiography and other invasive procedures.

History

A targeted medical history focusing on cardiac risk factors, previous cardiac diagnoses, family history of sudden cardiac arrest or sudden death, prescribed and recreational drug use, and symptoms preceding arrest is one of the most important aspects of ascertaining the underlying pathogenesis of cardiac arrest. In addition, when possible, the clinician should attempt to determine the time from collapse to initiation of CPR, and the time from collapse to ROSC, as well as the adequacy of CPR, as these metrics will aid in further decision-making surrounding care. A family history of cardiac arrest or sudden death in a young patient with OHCA would favor a genetic cause (ie, hypertrophic cardiomyopathy, long QT syndrome, Brugada syndrome, arrhythmogenic right ventricular dysplasia, anomalous coronary arteries). A history of established coronary artery disease, previous myocardial infarction or revascularization, or numerous coronary heart disease risk factors would raise the suspicion for an ischemic cause. Prearrest chest discomfort and a history of myocardial infarction is associated with 5-fold higher odds of acute coronary lesions.[13] A history of limited mobility or immobile state (eg, recent orthopedic surgery, prolonged hospitalization, extensive car or airplane rides) accompanied by prearrest dyspnea and an initial rhythm of pulseless electrical activity may be indicative of an acute pulmonary embolism. In many cases of OHCA, a detailed medical history and description of presenting symptoms are lacking, and therapeutic decisions must be made on the basis of other information.

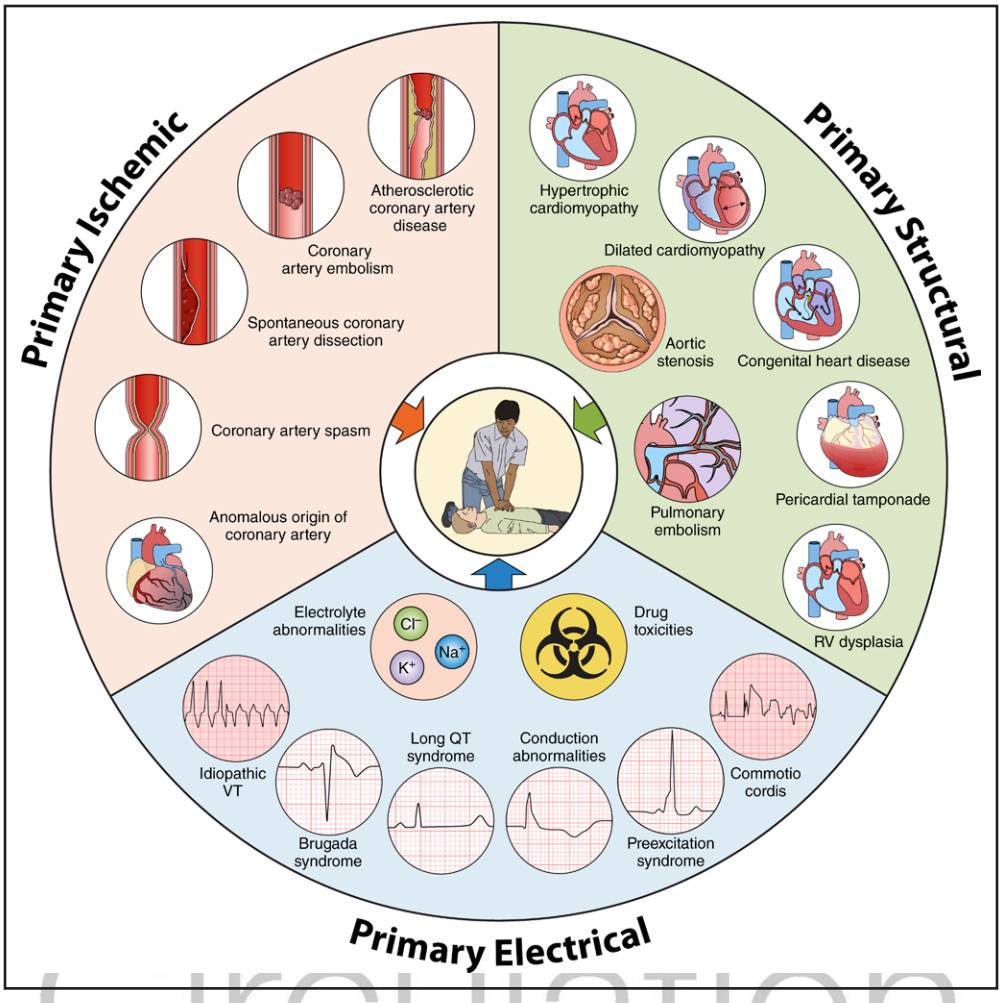

Figure 1. Cardiac pathogeneses of sudden cardiac arrest.
Cardiac pathogeneses are grouped into 3 general categories: ischemic, structural, and electrical. RV indicates right ventricle; and VT, ventricular tachycardia.

Electrocardiography

The post-ROSC ECG is an important tool in assessing the likelihood of an ischemic substrate and is recommended by American Heart Association (AHA) guidelines.[14] However, the post-ROSC ECG has limitations. In the setting of global myocardial ischemia after cardiac arrest, the post-ROSC ECG is notably insensitive and nonspecific for acute coronary occlusion.[15,16] STE on post-ROSC ECG has an 85% positive predictive value and 65% negative predictive value for an acute or presumed recent acute coronary artery lesion.[16] Among patients without STE on ECG, studies have shown a wide range (3%–58%) who manifest angiographic findings suggestive of acute coronary occlusion or culprit lesions on coronary angiography.[17–19] In addition, ECGs obtained immediately after ROSC lack specificity. Time to post-ROSC ECG will affect the accuracy of a STEMI diagnosis. In 1 series, false-positive abnormalities consistent with STEMI were present in 18.5% of ECGs performed within minutes of ROSC, 7.6% of ECGs performed between 8 and 33 minutes after ROSC, and 5.8% of ECGs performed >33 minutes after ROSC.[20] Metabolic abnormalities, such as hyperkalemia and acidemia, and intracranial processes, such as subarachnoid hemorrhage, may also cause ECG abnormalities that mimic ischemia. Low perfusion index has been shown to correlate strongly with likelihood of a false-positive ECG, with the postulated mechanism being hypoperfusion-mediated transmyocardial ischemia that is independent of acute thrombotic coronary artery occlusion.[21] With this in mind, when there is ambiguity regarding the implications of the post-ROSC ECG, serial ECGs performed >30 minutes after ROSC can provide additional information regarding the accuracy of the ST changes, which can help guide the decision to proceed with immediate or delayed coronary angiography.

Hemodynamic Assessment

A broad spectrum of hemodynamic presentations among individuals with OHCA exists, ranging from complete hemodynamic stability to stage E cardiogenic shock (CS).

Studies have shown that ≈50% to 60% of patients with cardiac arrest have concomitant shock.[22] Shock after cardiac arrest can result from myriad causes, including impairment of myocardial contractility related to a direct ischemic insult from an acute coronary syndrome, diffuse ischemia caused by inadequate coronary perfusion during the arrest, or CS related to baseline myocardial disease, including severe aortic stenosis, left ventricular dysfunction, or dynamic outflow tract obstruction. Hypotension also can be present because of profound vasoplegia after the arrest or from septic or hemorrhagic shock. Testing for electrolyte abnormalities, as well as lactic acid, pH, and hemoglobin levels, is important in all individuals with OHCA, but it is especially pertinent when assessing patients with hemodynamic compromise after ROSC. In addition, point-of-care ultrasound imaging of the heart can help elucidate the primary cause of hypotension (see Imaging).

Neurologic Assessment

The initial neurologic examination is notoriously inaccurate for predicting eventual neurologic outcome after OHCA and should be interpreted with caution. Survival to discharge with relatively few deficits has been reported in some patients initially presenting with absent pupillary reflexes or myoclonus.[23] On the other hand, the finding of a Neurological Pupil Index score ≤2, which has been shown to predict poor outcome with 100% specificity (95% CI, 98%–100%),[24] combined with diffuse cerebral edema on computed tomography (CT) indicates a dismal prognosis. Given the limitations of early neurologic assessment in most cases, determination of neurologic prognosis should be delayed >72 hours after ROSC, should be performed using a multimodal approach, and should not be the sole reason influencing early decisions around coronary angiography or initiation of mechanical circulatory support (MCS).[23]

Imaging

Point-of-care ultrasound or echocardiography is valuable in assessing OHCA pathogenesis, and can provide useful information in patients with hemodynamic compromise to assess for right or left ventricular dysfunction, valvular or structural abnormalities that can result in outflow obstruction, or hemodynamically significant pericardial effusion, as well as to estimate intravascular status. In addition, regional wall motion abnormalities can be a valuable clue to support an ischemic cause for the arrest, although the literature is limited. An observational study of 146 individuals with OHCA demonstrated 3.7-fold higher odds of ≥70% coronary stenosis among patients with regional wall motion abnormalities on transthoracic echocardiography.[25] In situations in which the diagnosis is uncertain, echocardiographic findings may aid in assessment to guide the decision for catheterization laboratory activation.

CT is sometimes used in OHCA to evaluate coronary anatomy and identify alternative pathogeneses. In an observational study of individuals with OHCA who underwent both CT and invasive coronary angiography, diagnostic accuracy for >50% coronary stenosis was 0.93 (95% CI, 0.77–0.98).[26] Among 104 patients, early whole-body CT identified 39% of OHCA causes and identified critical diagnoses (including life-threatening CPR-related injuries and intracranial hemorrhage) in 43 out of 44 (98%) patients with an underlying critical diagnosis.[27] Although further research is needed, early whole-body CT (with or without coronary imaging) after OHCA is a promising diagnostic tool. The usefulness of whole-body CT with intravenous contrast should be balanced by the potential for acute kidney injury in this at-risk population, particularly when there is evidence of baseline renal dysfunction and when performing this test in settings with inadequate experience to handle cardiac emergencies.

Clinical Prediction Tools

Prediction risk tools aid in determining prognosis on the basis of prearrest, intra-arrest, and postarrest characteristics.[28–36] These tools can provide additional information that may influence the decision to proceed with emergency angiography or initiation of MCS, in the context of other clinical factors. The ideal predictive tool for assessing the absence of a favorable neurologic or clinical outcome is one that is easy to use, incorporates readily accessible variables at the bedside, and remains a reliable predictor for unfavorable neurologic outcome. Prehospital and laboratory variables are often not available at the time a patient presents to the emergency department, thereby limiting the practical use of risk scores. In addition, these scores are at times insensitive or nonspecific. For example, scores predicting an unfavorable prognosis with 95% specificity will have a limited (40%) sensitivity.[37] Table 1 highlights some of the currently available clinical risk tools. The CAHP score (Cardiac Arrest Hospital Prognosis), derived from the Sudden Death Expertise Center Registry (Paris, France), in which 41% of patients had evidence of STE on their post-ROSC ECG, was designed to assess neurologic outcomes after OHCA. In the validation cohorts, a high CAHP score (>200) was associated with an unfavorable neurologic outcome (CPC score [Cerebral Performance Category] >2) in 96% to 100% of patients, with a positive predictive value and specificity of 96% to 100%.[30] The targeted temperature management score[36] identified clinical and demographic variables and arrest characteristics associated with a poor outcome (CPC >2) in a post hoc analysis of 933 patients enrolled in the Targeted Temperature Management trial. This trial included patients resuscitated from OHCA with a Glasgow Coma Scale score ≤8 and a presumed cardiac cause for the arrest. Patients with unwitnessed asystole as the initial

Table 1. Clinical Risk Prediction Scores for Outcomes After OHCA

Tool	Components	End point Score cutoff	Sensitivity, %/specificity, %	PPV/NPV, %	AUROC
CAHP score[30]	Age (y) Arrest setting Initial rhythm VF/VT No flow interval (min) Low flow interval (min) pH Epinephrine (mg)	Unfavorable neurologic outcome (CPC >2) on discharge from ICU >200	46/96	96/48	0.91
OHCA score[31]	Initial rhythm VF/VT No flow interval (min) Low flow interval (min) Serum creatinine Arterial lactate	Unfavorable neurologic outcome (CPC >2) on discharge ≥32.5	80/85	94/56	0.69
NULL-PLEASE score[32]	Nonshockable rhythm Unwitnessed arrest Long no-flow period (no bystander CPR) Long low-flow period (CPR >30 min) Blood pH <7.2 Lactate >7 mmol/L End-stage renal disease Age ≥85 y Ongoing CPR Extracardiac cause	In-hospital mortality ≥3	74/90	92/68	0.88
rCAST score[33]	Initial rhythm Witness until ROSC time pH Lactate mmol/L GCS motor score	Unfavorable neurologic outcome at 30 d ≥14.5	57/95	NA	0.89
MIRACL2 score[34]	Unwitnessed arrest Nonshockable rhythm Nonreactivity of pupils Age (y) Changing intra-arrest rhythms Low pH <7.20 Epinephrine administration	Unfavorable neurologic outcome (CPC 3–5) at 6 mo ≥5	71/91*	93/67*	0.90*
TTM score[36]	Age (y) Arrest at home Initial VT/VF No flow Low flow Treatment with adrenaline Absence of pupillary or corneal reflex pH GCS motor score 1 $PaCO_2$ <4.5 kPa	Unfavorable neurologic outcome (CPC 3–5) at 6 mo >16	40–41*/95–96*	91/55*	0.84*

AUROC indicates area under the receiver operating characteristic curve; CAHP, Cardiac Arrest Hospital Prognosis; CPC, Cerebral Performance Category; CPR, cardiopulmonary resuscitation; GCS, Glasgow Coma Scale; ICU, intensive care unit; NPV, negative predictive value; OHCA, out-of-hospital cardiac arrest; PPV, positive predictive value; rCAST, revised post–Cardiac Arrest Syndrome for Therapeutic Hypothermia; ROSC, return of spontaneous circulation; TTM, targeted temperature management; and VF/VT, ventricular fibrillation/ventricular tachycardia.

*Results reported for the developmental cohort.

rhythm or refractory CS were not included in the trial. A score >16 was associated with an unfavorable neurologic prognosis with a specificity of 95% to 96%, positive predictive value of 91%, and area under the receiver operating characteristic curve of 0.84. More recently, the MIRACLE2 score was derived using information from the King's Out of Hospital Cardiac Arrest Registry of individuals with OHCA presenting to King's Hospital (London,

UK).[34] Patients were enrolled in the registry if they presented with STE on ECG (56.2%) or without STE with absence of a noncardiac pathogenesis.[38] A high score (≥5) predicted an unfavorable neurologic outcome (CPC 3–5) in 92.3% of patients, with an area under the receiver operating characteristic curve of 0.9. With a focus on survival, a systematic review identified 3 tools[31–33] with superior performance characteristics for predicting survival after OHCA.[28] It is important to recognize that these scores are most accurate in predicting risk when used in a population of patients resembling the patient population examined for the derivation cohort.

Although the data supporting the variables that predict adverse outcomes are robust, the prospective application of prognostic tools in the care of individuals with complex cases of OHCA has not been reported, and their validity in this context has been questioned. Despite the absence of prospective data evaluating the use of prognostic tools, observational studies have demonstrated improved adjusted survival with an early invasive strategy for low-risk patients after OHCA; on the other hand, a survival advantage with an invasive strategy was not seen in intermediate- or high-risk cohorts of individuals with OHCA with or without CS.[38,39] Although the use of risk scores can provide an estimate of the likelihood for survival with favorable neurologic outcomes, these scores are most valuable when used in the context of other clinical features. These tools should not be used for early neurologic prognostication to determine withdrawal of care; formal neurologic prognostication to guide the decision to withdraw care should be performed >72 hours after ROSC.

THE ROLE OF EMERGENCY CARDIAC CATHETERIZATION, CORONARY ANGIOGRAPHY, AND INTERVENTION

An Algorithm for Invasive Management

The goal of invasive management in the cardiac catheterization laboratory is to identify and treat a culprit coronary lesion responsible for the clinical presentation, if present, and to provide MCS for hemodynamically or electrically unstable patients when indicated. In addition, the cardiac catheterization laboratory can be used to deliver thrombolysis to an obstructive clot or to extract the clot in patients with massive pulmonary embolism (PE) refractory to or not eligible for medical therapies, and, on occasion, to perform pericardiocentesis in patients with hemodynamically unstable pericardial effusion when a bedside procedure is not feasible. The decision to proceed with invasive coronary angiography and intervention will depend on several key factors (Figure 2), including the patient's electrical and hemodynamic status at the time of presentation as well as the postarrest ECG. STE on ECG, CS, or ongoing electrical instability would strongly favor proceeding with invasive therapies unless there are findings to suggest a high likelihood for a poor neurologic outcome or other unfavorable features (see following).

Current guidelines support emergency or urgent angiography in select patients presenting with cardiac arrest (such as those with STE on ECG).[14,40] This recommendation enables the consistent establishment of a prehospital systems of care approach that by default will lead to catheterization laboratory activation. From a cardiac interventional perspective, however, the identification of the postarrest patient who would be best treated with invasive therapies is nuanced and needs to be individualized. The benefits of immediate revascularization and other invasive therapies should be balanced with the potential irreversible consequences of anoxic encephalopathy. When there is a high likelihood (ie, >90%) for a poor neurologic outcome, the treatment team must assess the clinical situation and the benefits of invasive therapies carefully before proceeding. A number of clinical factors are associated with poor neurologic outcome in people with OHCA. These include advanced age, unwitnessed arrest, absence of bystander CPR, nonshockable rhythm on initial assessment, and prolonged duration of cardiac arrest before ROSC.[31–33,35] Elevated lactic acid level (>7), low pH (<7.2), or diffuse cerebral edema on presentation CT scan generally indicate a longer low-flow or no-flow duration and are associated with worse outcomes.[31–33,35,41] Despite the challenges in estimating the likelihood for a poor outcome accurately in patients presenting with OHCA, multiple unfavorable features (>6 features in the more extreme range of severity) and an extremely elevated clinical risk score (see Table 1 for cutoffs denoting a high risk score for each of the clinical risk scores), should dictate a thoughtful consideration of the appropriateness of invasive therapies in the clinical context. Studies have shown poor survival when >6 unfavorable features are present[35] and, as mentioned previously, a lack of survival benefit with invasive therapies in patients with extremely high postarrest risk scores.[38,39] Furthermore, whereas advanced dementia or life-limiting illness may not directly affect the immediate outcome of a patient with OHCA, in these situations, advanced therapies may not be in keeping with the patient's goals of care, and conservative therapy may be deemed appropriate after a careful discussion with the patient's surrogate medical decision-maker.

One of the earliest steps in the assessment of a patient with OHCA is the consideration of medical futility. Although the estimation of futility of care is challenging, a small group of patients may meet objective criteria for futility in which transfer to the cardiac catheterization laboratory would be unlikely to serve a beneficial long-term purpose. Beyond the futility of care consideration, there remains a continuum of risk for an unfavorable outcome in the individual with OHCA (Figure 3). As such, it is important to individualize care. Instead of focusing on one specific cutoff to designate a high-risk patient, the totality of risk factors should be considered in the context of the patient's presenting clinical features. For example, when criteria for invasive

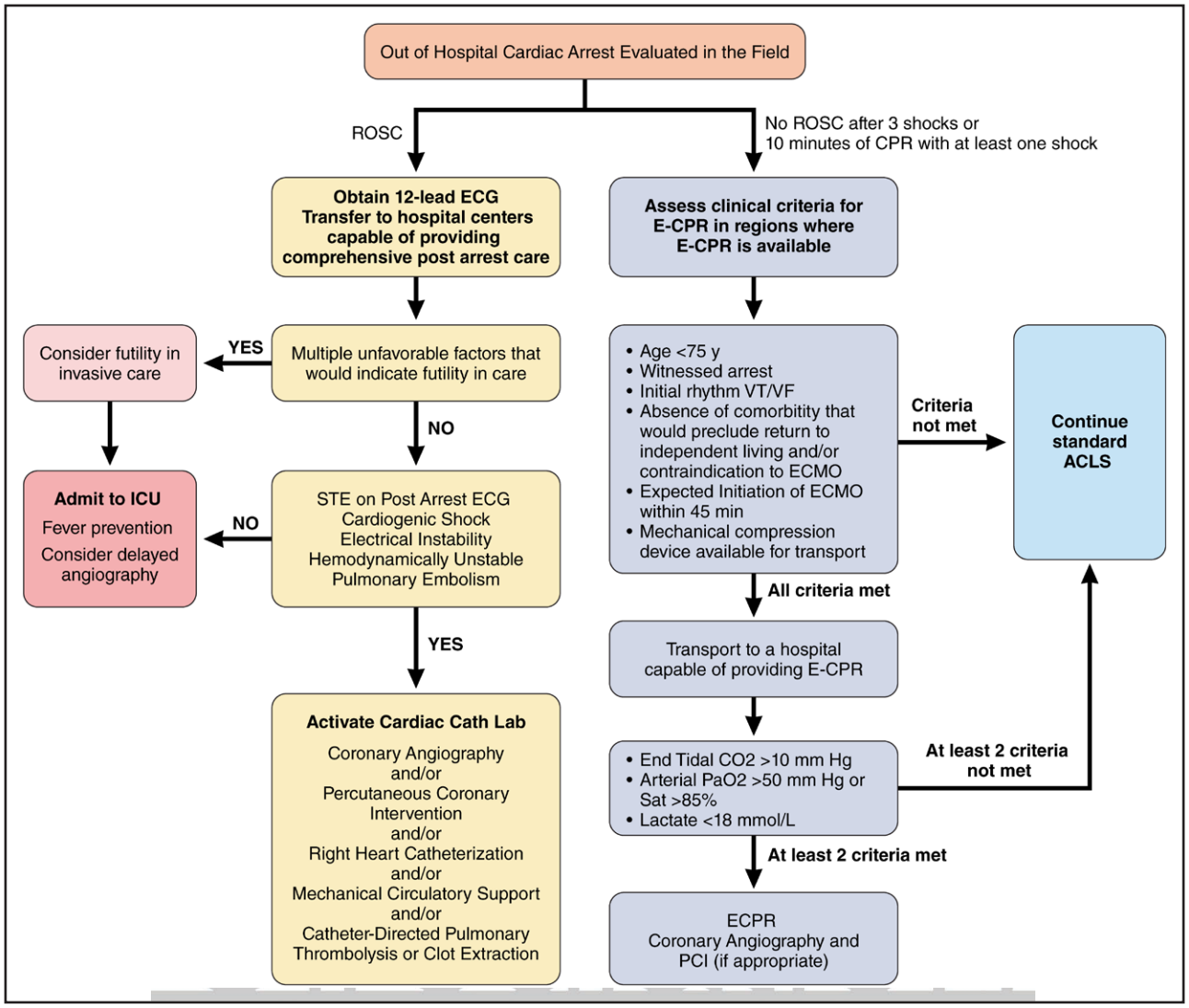

Figure 2. An algorithm for managing the patient with out-of-hospital cardiac arrest.
The approach to managing a patient with out-of-hospital cardiac arrest beginning in the field and continuing to the cardiac intensive care unit. ACLS indicates advanced cardiac life support; CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; ECPR, extracorporeal cardiopulmonary resuscitation; ICU, intensive care unit; PCI, percutaneous coronary intervention; ROSC, return of spontaneous circulation; STE, ST-segment–elevation; and VT/VF, ventricular tachycardia/ventricular fibrillation.

management are present, a greater adoption of emergency invasive therapies may be contemplated in a young patient without comorbidities before the arrest, even in the setting of prolonged no-flow or low-flow times, a high postarrest risk score, or other severely unfavorable features. However, a frail elderly patient or a patient with substantial prearrest medical comorbidities may be best managed conservatively. In all cases, when possible, it is important to have a clear discussion with family members or surrogates regarding expectations of outcomes and goals of treatment, incorporating any previously expressed wishes regarding goals of care, before proceeding with invasive therapies.

Cardiac Arrest Without STE on ECG

Most patients resuscitated from OHCA do not have STE on their postarrest ECG.[4] As previously mentioned, the absence of STE on ECG does not exclude an acute coronary occlusion. Observational studies have shown that nearly 1 of 3 people who experience OHCA without STE have an acute coronary occlusion on coronary angiography[4,15,17,42–45] (Supplemental Figure). In contrast to the observational data, randomized controlled trials (RCTs) have reported a lower rate of acute coronary occlusion in patients without STE on ECG who are referred for early angiography (Supplemental Figure), although a clear culprit coronary lesion was identified in 14% to 47% of enrolled patients referred for angiography in the RCTs.[18,46] Observational studies of patients without STE on postarrest ECG suggested that early coronary angiography with PCI was associated with improved outcomes.[4,6,15,17,42,43,45,47] These studies were likely limited by selection bias, because patients not suitable for invasive management due to unfavorable features were

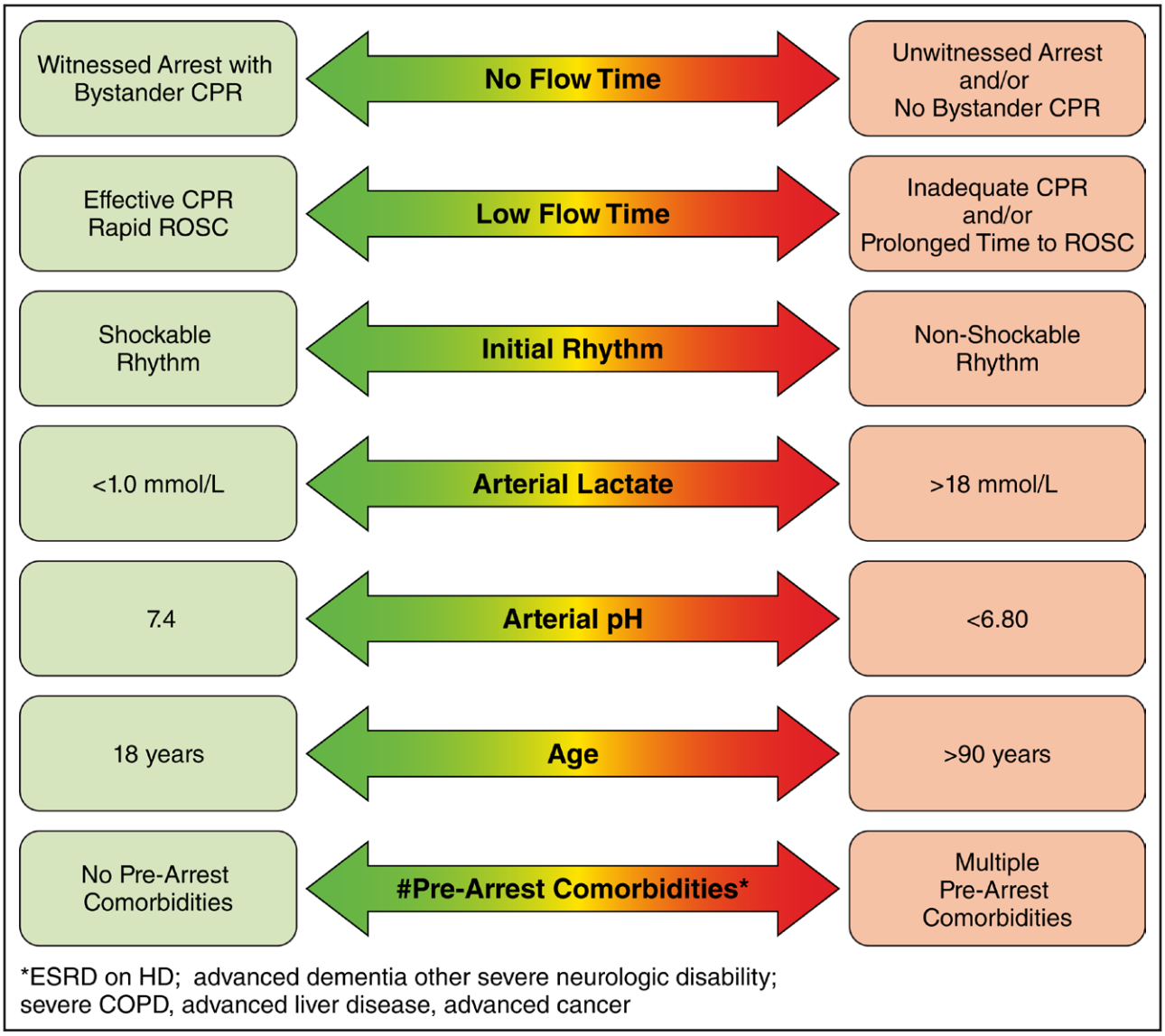

Figure 3. The spectrum of risk factors affecting outcome after out-of-hospital cardiac arrest.
The spectrum of risk for various clinical and laboratory features that might indicate a favorable or unfavorable neurologic and overall outcome. COPD indicates chronic obstructive pulmonary disease; CPR, cardiopulmonary resuscitation; ESRD HD, end-stage renal disease on hemodialysis; and ROSC, return of spontaneous circulation.

treated conservatively. In some studies, a better outcome was reported in patients referred for invasive angiography irrespective of whether revascularization was performed,[42] which lends further support to the potential for selection bias in these reports.

Over the past several years, 6 RCTs enrolling 1591 patients have examined the role of immediate or early coronary angiography in patients resuscitated after OHCA without STE[18,19,46,48–50] (Table 2). In these studies, 75% to 90% of patients had a witnessed arrest, and 50% to 79% received bystander CPR. The mean time from arrest to ROSC ranged from 15 to 29 minutes across the trials. Roughly one-third of patients randomized to immediate angiography received PCI. These studies collectively failed to show a difference in survival outcomes with early coronary angiography at various time points. The consistency of these data is evident, although 4 of the 6 studies were clearly underpowered, which may have been a result of a lower-than-expected event rate in the control group (which had been estimated using data from observational studies). The lower-than-anticipated event rate in the conservatively treated patients reinforces the notion that the magnitude of benefit of routine early angiography after OHCA (even if accompanied by PCI) is smaller than previously assumed. This may, in part, be related to the reported decrease in the proportion of patients with acute ischemia as the cause of the arrest over the past 3 decades,[9] which led to a diminution in the benefits of coronary angiography previously reported in the observational studies. Each study

Table 2. Baseline Characteristics and Clinical Outcomes in Randomized Trials of Coronary Angiography in Patients Without STE on ECG

Variables	COACT[18]	DISCO[49]	PEARL[46]	TOMAHAWK[19]	EMERGE[48]	COUPE[50]
Year published	2019	2019	2020	2021	2022	2022
No. of patients	538	79	99	530	279	66
Percent with shockable rhythm	100	NA	76	55	32	82
Coronary angiography performed						
Early	265/273 (97)	38/39 (97)	49/49 (100)	253/265 (96)	126/141 (89)	32/32 (100)
Delayed	172/265 (65)	NA	24/50 (48)	165/265 (62)	74/138 (54)	20/34 (59)
No obstructive coronary artery disease						
Early	94/265 (36)	NA	14/49 (29)	99/252 (39)	57/126 (45)	16/32 (50)
Delayed	59/172 (34)	NA	8/24 (33)	46/165 (28)	41/74 (55)	12/20 (60)
Multivessel coronary artery disease						
Early	99/265 (37)	NA	12/49 (24)	116/252 (46)	47/126 (37)	6/32 (19)
Delayed	64/172 (37)	NA	11/24 (46)	98/165 (59)	22/74 (30)	6/20 (30)
Culprit coronary artery identified						
Early	36/265 (14)	14/38 (37)	23/49 (47)	94/247 (38)	38/126 (30)	12/32 (38)
Delayed	29/172 (17)	NA	10/24 (42)	67/156 (43)	17/74 (23)	5/20 (25)
Culprit artery acutely occluded						
Early	9/265 (3)	NA	7/49 (14)	NA	NA	NA
Delayed	13/172 (8)	NA	1/24 (4)	NA	NA	NA
Rearrest						
Early	21/273 (8)	NA	3/49 (6)	NA	10/141 (7)	3/32 (9)
Delayed	16/265 (6)	NA	3/50 (6)	NA	5/138 (4)	9/34 (27)
Bleeding event						
Early	7/273 (3)	NA	2/49 (4)	12/260 (5)	NA	3/32 (9)
Delayed	13/265 (5)	NA	0/50 (0)	8/232 (3)	NA	3/34 (9)
Acute renal dysfunction or renal failure*						
Early	14/244 (6)	NA	1/49 (1)	49/259 (19)	NA	5/32 (16)
Delayed	21/243 (9)	NA	2/50 (2)	38/241 (16)	NA	0/34 (0)
CPC 3 or 4 in survivors						
Early	4/272 (1)	NA	2/49 (2)	NA	4/141 (3)	1/32 (3)
Delayed	NA	NA	1/50 (1)	NA	4/138 (3)	3/34 (9)
Overall survival						
	90 d	24 h	Discharge	30 d	180 d	Discharge
Early	176/273 (65)	36/39 (92)	27/49 (55)	122/265 (46)	51/141 (36)	20/32 (63)
Delayed	178/265 (67)	34/40 (85)	24/50 (48)	143/265 (54)	46/138 (33)	20/34 (59)

Values are n (%) unless indicated otherwise. COACT indicates Coronary Angiography after Cardiac Arrest; CPC, Cerebral Performance Category; DISCO, Direct or Subacute Coronary Angiography in Out-of-Hospital Cardiac Arrest; EMERGE, Emergency Versus Delayed Coronary Angiogram in Survivors of Out-of-Hospital Cardiac Arrest; NA, not available or not reported; PEARL, Early Coronary Angiography Versus Delayed Coronary Angiography; STE, ST-segment–elevation; and TOMAHAWK, Immediate Unselected Coronary Angiography Versus Delayed Triage in Survivors of Out-of-Hospital Cardiac Arrest Without ST-Segment Elevation.

*The COUPE trial (Coronary Angiography in Out-of-Hospital Cardiac Arrest) reported the incidence of renal failure.

concluded that early or emergency coronary angiography in patients resuscitated after OHCA without STE did not result in improved outcomes compared with delayed or no coronary angiography. The majority of the clinical trials found no increase in adverse events with early angiography compared with delayed angiography. The exception was the COUPE trial (Coronary Angiography in Out-of-Hospital Cardiac Arrest),[50] which reported an increased rate of acute renal failure in the early angiography group. A meta-analysis of these trials (which did not include the COUPE trial) showed similar early and midterm survival and no difference between the groups in recovery of neurologic function, need for renal replacement therapy, or bleeding events.[51] Patients with refractory CS or electrical instability were excluded from most of these trials.[18,19]

Whereas the findings do not suggest a benefit for routine early angiography in comatose patients after OHCA without STE on postarrest ECG, some subsets of patients—particularly those with favorable postarrest features and a high degree of suspicion for an acutely occluded coronary[52,53] (ie, chest pain preceding arrest, or marked ST-segment depressions suggesting diffuse ischemia or a true posterior infarction), or who are in CS or have ongoing electrical instability—might derive a benefit from coronary angiography, hemodynamic support, or other resuscitative measures. In the latter situations, current guidelines provide a Class of Recommendation 2a (indicating that the intervention is reasonable) for proceeding with emergency angiography.[14] In survivors of OHCA with no or little neurologic sequela, a nonemergency coronary angiogram can provide important information; in cases where there is a high clinical suspicion for acute ischemia leading to the arrest but no obstructive coronary artery disease, nonurgent provocative spasm testing may help uncover the cause of the arrest.

Cardiac Arrest With STE on ECG

In patients who have not experienced an OHCA, primary PCI is associated with improved mortality rates compared with fibrinolytic therapy or conservative care.[54] For similar reasons, and with a mindset that "time is muscle," the rationale for proceeding with emergency angiography and PCI in the comatose patient with OHCA and STE on ECG is to restore vessel patency (assuming there is a coronary occlusion), decrease the extent of myocardial damage, and reduce the risk for recurrent ventricular arrhythmias with the hopes of improving survival. Studies have shown that >80% of individuals with OHCA and STE on ECG have an acutely occluded vessel.[55]

There are no RCTs that directly inform the role of emergency cardiac catheterization, coronary angiography, or PCI in individuals with OHCA and STE on postarrest ECG. Current guidelines provide a Class of Recommendation 1 for emergency coronary angiography and reperfusion in patients resuscitated from OHCA with evidence of STE on their initial ECG.[14,40,56] These recommendations are on the basis of numerous observational studies demonstrating favorable outcomes in patients resuscitated from OHCA with STEMI undergoing PCI.[57–59] These studies included patients with a wide neurologic status range after arrest. Outcomes in awake patients with OHCA and STEMI undergoing PCI were comparable with outcomes in patients with STEMI without arrest; however, outcomes for comatose patients with OHCA and STEMI were much less favorable.[58] Whereas there is little question about the benefit of emergency coronary reperfusion in noncomatose patients with STEMI after OHCA, there are reasons to question whether this same strategy is uniformly beneficial in comatose patients with OHCA. More than two-thirds of patients hospitalized after OHCA die after withdrawal of life-sustaining therapy because of known or presumed anoxic brain injury, with the remaining deaths a result of shock and multiorgan failure.[60,61] In this context, it should not be surprising that coronary reperfusion has limited effect on survival among individuals with OHCA who present with features strongly associated with adverse neurologic outcomes. Observational studies have supported this concept, demonstrating a lack of benefit of invasive therapies for STEMI in a subset of patients who have findings to suggest a poor neurologic outcome.[38] Coronary reperfusion should retain its critical role in the subset of patients with OHCA and STE on ECG, but further information is needed to help identify patients in whom time-dependent coronary reperfusion is not beneficial and perhaps even harmful.

Cardiac Arrest With CS

CS is a complex hemodynamic condition of low cardiac output with high morbidity and mortality rates. Mortality rates with CS remain high despite the use of temporary mechanical support and emergency revascularization.[62] The occurrence of OHCA is associated with heightened in-hospital mortality in patients admitted to the cardiac intensive care unit (ICU), regardless of hemodynamic status,[63] and arrest in patients with CS is noted as a detrimental effect modifier in the updated SCAI (Society for Cardiovascular Angiography and Interventions) CS classification.[64] Rates of antecedent cardiac arrest in landmark clinical trials of CS have ranged from 28% to 78%[65–71] (Supplemental Table), although all of these trials excluded patients with OHCA and poor neurologic function or prolonged time to ROSC. Subset data in this group of patients with OHCA are lacking; therefore, it seems reasonable to manage patients with OHCA manifesting CS similarly to patients with CS who have not experienced OHCA, with 1 caveat: given the high rates of anoxic encephalopathy and irreversible end-organ injury in this population, it is not unreasonable to consider withholding advanced interventions in patients with extreme likelihood of futility arising from recognized comorbidities and post-ROSC findings that portend a high likelihood for a poor neurologic outcome. These findings are further supported by retrospective data demonstrating an advantage to invasive therapies in patients with OHCA and SCAI shock stages B through E who have a low postarrest risk score but no survival advantage with invasive therapies among patients with OHCA and CS who have a high postarrest risk score.[38]

For patients with CS and OHCA manifesting more favorable prognostic features, the cardiac catheterization laboratory may serve several purposes, including aiding in the diagnosis of CS, stabilizing hemodynamic compromise with hemodynamic support devices when indicated, and reversing the inciting cause for the arrest if an acute

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coronary occlusion is suspected and revascularization is feasible and reasonable. Revascularization should be performed in patients who present with an acute coronary syndrome as the cause of their cardiac arrest and CS; PCI of the culprit vessel only is recommended.[72]

It seems reasonable to consider initiation of MCS to facilitate revascularization and support the circulation using a multidisciplinary shock team in patients thought to have a reasonable neurologic prognosis. The use of an intra-aortic balloon pump (IABP) for CS has declined significantly after the IABP-SHOCK II trial (Intra-Aortic Balloon Pump in Cardiogenic Shock) found no difference in 30-day mortality rate[68] with IABP insertion to manage CS. Over the past decade, the Impella (Abiomed) and TandemHeart (Cardiac Assist) devices have played an increasing role in the management of CS; observational data have reported mixed results. Some studies have demonstrated improved outcomes with the Impella device when used in the context of a multidisciplinary approach to care.[73,74] Roughly 20% of participants in these studies had experienced an OHCA. Other studies have not reported improved outcomes with Impella when compared with a matched cohort of patients with CS treated with IABP or medical therapies,[75] of whom roughly one-third had experienced cardiac arrest. The IMPRESS in Severe Shock trial (Impella Versus IABP Reduces Mortality in STEMI Patients Treated With Primary PCI in Severe Cardiogenic Shock)[76] randomized 48 patients with severe CS (among whom the large majority had cardiac arrest) to Impella support or IABP. The trial was largely underpowered for clinical events but did not demonstrate a benefit with the use of Impella compared with IABP. The ongoing DanGer Shock study (Danish German Cardiogenic Shock)[77] evaluating the benefits of Impella support in patients with acute STEMI complicated by CS permits enrollment of patients with OHCA but will exclude those with severe neurologic injury assessed by the Glasgow Coma Scale. The trial aims to enroll 360 patients and results are expected to be reported in 2024.

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) is another option to provide support in the catheterization laboratory, especially in patients with refractory hypoxia, biventricular failure, or severe CS who demonstrate favorable postarrest features. Although the small ECMO-CS trial (Extracorporeal Membrane Oxygenation in the Therapy of Cardiogenic Shock) failed to show a definitive clinical benefit, the crossover rate to ECMO in the no-early-ECMO arm was 39%, which may have influenced these results.[70] Furthermore, this trial did not enroll comatose patients after OHCA. The ECLS-SHOCK trial (Extracorporeal Life Support in Cardiogenic Shock)[71] enrolled 420 patients with SCAI stage C, D, or E CS complicating an acute myocardial infarction. In this trial, >75% of the patients had undergone resuscitation before randomization. At 30 days, there was no difference in the primary outcome of all-cause mortality between the groups, but the ECMO group had a high rate of major bleeding and vascular complications. There are several more ongoing or completed European trials assessing the role of ECMO in CS. The EURO SHOCK trial[78] (which was terminated early because of slow enrollment) and the ANCHOR trial (Assessment of ECMO in Cardiogenic Shock) (NCT04184635) will assess outcomes using early ECMO in patients with CS. Both trials will permit enrollment of a select group of patients with OHCA.

Cardiac Arrest With Massive PE

Approximately 5% of cardiac arrests are a result of PE, and 95% of these cases present with pulseless electrical activity or asystole.[79] Initial steps in the management of hemodynamically unstable PE includes early optimization of hemodynamic status with vasopressors or inotrope coupled with maintenance of adequate preload with fluid resuscitation. In addition, in all cases of PE, prompt decision-making by a multidisciplinary PE response team with consideration for intravenous fibrinolytics versus thrombectomy (either surgical or percutaneous) is of critical importance. Most data supporting an aggressive approach to treating the unstable patient with massive PE are derived from patients without cardiac arrest. As in all patients with OHCA, the decision to proceed with aggressive invasive therapies for the management of massive PE should be considered in the context of the patient's presenting clinical features and baseline comorbidities. Current guidelines provide a Class of Recommendation 2a for proceeding with treatment of confirmed PE in patients with cardiac arrest as a reasonable option.[14] For select patients with OHCA, the cardiac catheterization laboratory can serve an important role in the emergency management of massive PE. Whereas the standard of care for the treatment of massive PE with or without cardiac arrest is tissue-type plasminogen activator, in patients with contraindications to fibrinolytics or treatment failure (eg, persistent shock, hypoxia), catheter-directed lysis or mechanical thrombectomy with or without VA-ECMO may be considered. Catheter-directed lysis can be performed with a multiple side hole catheter that will allow fibrinolytic agents to be delivered directly into the pulmonary arteries. This also can be done using ultrasound-assisted catheter-directed thrombolysis or with mechanical thrombectomy using a number of devices. No RCTs have shown a clinical benefit to mechanical thrombectomy in massive PE when compared with other devices; however, observational data have demonstrated that mechanical thrombectomy could be safe and effective for the treatment of PE.[80–82] In cases of refractory shock or hypoxia, VA-ECMO should be considered if there are no contraindications and the patient lacks features to suggest an unfavorable neurologic outcome. A single-center experience using VA-ECMO for

massive PE (60% with cardiac arrest) reported promising results, particularly when used as first-line therapy.[83] A detailed discussion surrounding surgical embolectomy and VA-ECMO for massive PE is summarized in a recent AHA scientific statement.[84] At many centers, percutaneous therapies for pulmonary emboli are performed by the interventional radiology team. In these settings, when a patient is critically ill, critical care intensivists or anesthesiologists should be available to assist in clinical management during the procedure; as an alternative, transfer to another center can be considered.

Cardiac Arrest With Ongoing CPR

Ongoing CPR historically was considered a barrier to safe transport to the catheterization suite and to the ability to perform angiography and coronary intervention, which would expose those performing chest compressions to radiation and potential injury with movement of the C-arm, and was technically challenging because of obscure radiographic visualization of the coronaries. Automated mechanical compression devices now enable operators to avoid these issues and have become an integral tool in the management of cardiac arrest in the catheterization laboratory. Despite the theoretical benefits, the evidence base for the use of these devices remains poor. A meta-analysis of 12 studies including observational studies and RCTs found higher rates of ROSC with the use of automated compression devices[85]; however, subsequent to this, 3 RCTs failed to show benefit.[86–88] In addition, pooled data of clinical trials have demonstrated a higher risk of compression-induced injuries with mechanical compression devices when compared with manual compression, with a higher risk of rib fractures, heart and liver injuries, injuries to major vessels, and pneumothorax.[89] These trials were performed outside of the catheterization laboratory and may underestimate the specific benefit of mechanical compression devices in this setting. AHA guidelines for CPR and emergency cardiovascular care assign a Class of Recommendation 3 to the routine use of mechanical compression devices but endorse a Class of Recommendation 2b for their use in situations where it may be difficult or dangerous to provide high-quality compressions, such as the catheterization laboratory.[14]

ECMO provides another method to circulate blood artificially in the setting of cardiac arrest, thereby enabling a supported circulatory milieu to allow for PCI. The deployment of VA-ECMO emergently after failure of conventional CPR is termed ECPR. Successful use of ECPR was first published in 1966,[90] and its use has grown substantially since that time. The Extracorporeal Life Support Organization recorded <500 ECPR cases in 2009, which increased to >11 000 in 2021.[91] Use continues to grow, as studies suggest a survival benefit compared with conventional CPR.[6,92,93] The AHA assigns a Class of Recommendation 2a (ie, may be considered) for ECPR for select patients with cardiac arrest, if the suspected cause of the cardiac arrest is potentially reversible during a limited period of mechanical cardiorespiratory support.[14]

Since the publication of the 2020 AHA guidelines for CPR and emergency cardiovascular care,[14] 3 major RCTs examining the use of ECPR for OHCA have been completed. Two were single-center trials with established EMS and in-hospital protocols.[94,95] The third was a multicenter trial including 10 hospitals across the Netherlands with variable ECPR proficiency.[96] In the ARREST trial (Advanced Reperfusion Strategies for Patients With Out-of-Hospital Cardiac Arrest and Refractory Ventricular Fibrillation),[94] patients with OHCA and refractory ventricular fibrillation or tachycardia (defined as unresponsive to 3 attempts at direct current shocks and 300 mg of amiodarone) and an estimated transfer time from the field to the hospital of <30 minutes were transferred to the University of Minnesota Medical Center, where they were randomized to direct transport to the cardiac catheterization laboratory for ECMO placement followed by immediate coronary angiography and PCI when appropriate or standard advanced cardiac life support (ACLS) resuscitative methods upon hospital arrival. The primary outcome was 6-month survival. The trial was terminated early when the first preplanned interim analysis demonstrated superiority in survival in the ECPR group that exceeded the prespecified monitoring boundary (43% versus 7%; P=0.006).[94] The data were corroborated by contemporaneous publication of a parallel community implementation project on the basis of a hub-and-spokes model that showed that a community-wide implementation using the same protocol led to a 43% neurologically intact survival rate of 57 patients cannulated over a 4-month period.[97]

The Prague OHCA trial used a slightly different protocol for care.[95] In this trial, an invasive approach to treatment of OHCA, including rapid intra-arrest transport from the field to the catheterization laboratory for immediate ECMO (if ROSC was not achieved) followed by coronary angiography and intervention, was compared with standard prehospital ACLS care. Randomization was performed in the field and patients with shockable or nonshockable rhythms were eligible for inclusion. At 180 days, the primary outcome of neurologically favorable survival (CPC 1 or 2) was not significantly different between the 2 groups (31.5% versus 22.0%; P=0.09), although the secondary outcome of survival with minimal or no neurologic impairment (CPC 1 or 2) at 30 days was significantly greater with the invasive protocol (30.6% versus 18.2%; P=0.02).[95] A recent secondary analysis of the data further highlights the benefit of ECPR in specific subgroups, including those with an initial rhythm of ventricular fibrillation and those who are unable to achieve ROSC in the field despite prolonged CPR.[98] In the latter group, 6-month survival was 5-fold higher with

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the invasive approach (adjusted hazard ratio for mortality rate, 0.21 [95% CI, 0.14–0.31]; *P*=0.001).

In the INCEPTION trial (Early Initiation of Extracorporeal Life Support in Refractory OHCA),[96] 133 patients with refractory ventricular fibrillation or ventricular tachycardia (defined as persistent arrest after 15 minutes of ACLS) meeting all inclusion and no exclusion criteria were immediately transferred to a participating hospital and randomized (in the field or on arrival to the hospital) to a strategy of ECPR or standard ACLS. A total of 52 of the 70 patients randomized to ECPR underwent ECMO cannulation, and 46 of these patients (88%) had successful cannulation. The primary end point of neurologically favorable survival (CPC 1 or 2) at 30 days was achieved in 14 of 70 (20%) patients in the ECPR group versus 10 of 63 (16%) patients in the standard ACLS group (odds ratio, 1.4 [95% CI, 0.5–3.5]; *P*=0.52).

Several reasons have been proposed to explain the differences in the primary end point results among the 3 studies[94–96] (Table 3). The Prague OHCA trial[95] included patients with any initial rhythm, and 40% of enrolled patients presented with a nonshockable rhythm. In addition, the Prague OHCA trial enrolled patients in the field, a time when there may still be a chance for ROSC, and the investigators permitted crossover to the ECPR group at the discretion of the treating physician. Although this crossover occurred in only 8% of the enrolled patients, 45% of those crossing over survived with a favorable neurologic outcome, further supporting the role of ECPR in appropriate patients. In the INCEPTION trial,[96] none of the participating hospitals had an established ECPR program before the study started, and without previous system experience, the hospitals performed an average of 1 or 2 cannulations per center per year during the

Table 3. Clinical Characteristics, Management, and Outcomes of Patients Enrolled in ECPR Trials

	ARREST[94]			Prague OHCA[95]			INCEPTION[96]		
Variables	ECPR	Standard	RD,* % (95% CI)	Invasive	Standard	RD,* % (95% CI)	Invasive	Standard	OR,† % (95% CI)
Number	15	15		124	132		70	64	
Age, y	59 (10)	58 (11)		59 (48–66)	57 (47–65)		54 (12)	57 (10)	
Witnessed OHCA	11 (73)	13 (87)		124 (100)	132 (100)		68 (97)	63 (98)	
Bystander CPR	13 (87)	12 (80)		123 (99)	129 (98)		69 (99)	61 (95)	
Initial shockable rhythm	15 (100)	15 (100)		72 (58)	84 (64)		70 (100)	64 (100)	
Intermittent ROSC	5 (33)	4 (27)		41 (33)	45 (34)		27 (39)	22 (34)	
Preadmission declaration of death	0	0		1 (1)	19 (14)		26 (37)	54 (85)	
Sustained ROSC at ED arrival	0	0		34 (27)	58 (44)		17 (27)	19 (30)	
Arrest to arrival to hospital, min	48 (21)	51 (13)		44 (13)	48 (16)		36±12	38±11	
Hospital arrival to ECPR, min	7 (4)			12 (9–15)	16 (11–17)		40 (36–90)	NA	
Time to ECPR interval,‡ min	59 (28)	–		61 (55–70)	62 (51–73)		74 (63–87)		
ICU stay, d	12 (4–23)	14		11 (3–21)	13 (4–18)		1 (1–4)	4 (1–9)	
Hospital stay, d	15 (4–35)	23		NR	NR		2 (2–14)	18 (2–30)	
Survival to discharge or 30 d§	6 (43)¶	1 (6.7)¶	36 (7.4, 65)	52 (42)	43 (33)	9.4 (–2.4, 21)	14 (20)	13 (19)	
CPC 1 or 2 at discharge or 30 d§	3 (21)	0	24 (–0.066, 43)	38 (31)¶	24 (18)¶	12 (2.0, 23)	14 (20)	10 (16)	1.4 (0.5, 3.5)
Survival at 6 mo‖	6 (43)¶	0	43 (17, 69)	41 (33)¶	32 (23)¶	10 (2.2, 20)	14/68 (20)	10 (16)	1.4 (0.5, 3.6)
CPC 1 or 2 at 6 mo	6 (43)¶	0	43 (17, 69)	39 (32)	29 (22)	9.5 (–1.3, 20)	14/68 (20)	10 (16)	1.4 (0.5, 3.7)

Values are mean (SD), n (%), or median (interquartile range) unless indicated otherwise. CPC indicates Cerebral Performance Category; CPR, cardiopulmonary resuscitation; ECPR, extracorporeal cardiopulmonary resuscitation; ED, emergency department; ICU, intensive care unit; INCEPTION, Early Initiation of Extracorporeal Life Support in Refractory OHCA; NA, not available; NR, not reported; OHCA, out-of-hospital cardiac arrest; and ROSC, return of spontaneous circulation.

*Risk difference (RD; 95% CI) calculated with the Wald method.

†OR provided by the study primary article and supplement.

‡Measured from collapse in the Prague OHCA trial and the 9-1-1 call in the ARREST trial (Advanced Reperfusion Strategies for Patients With Out-of-Hospital Cardiac Arrest and Refractory Ventricular Fibrillation).

§Measured at hospital discharge in the ARREST trial and at 30 days in the Prague OHCA trial.

‖Six-month Kaplan-Meier survival analysis showed statistically significant differences between groups in both the ARREST (log-rank test *P*<0.0001) and Prague OHCA (log-rank test *P*=0.014) trials.

¶Significant differences in primary and secondary end points.

study period. As such, ECMO success rates were not as high as those reported in the earlier 2 trials, and time to cannulation was considerably longer. In addition, median time to decannulation in the ECPR group was 26 hours, and median hospital stay was 2 days, suggesting the possibility of early termination of care.

Despite their differences, the studies highlight the feasibility of an invasive ECPR-based approach and the potential for ECPR to improve outcomes when implemented in a select group of patients in high-performing, practiced systems with standard protocols for care, supplemented by individualized decision-making. Efforts must be undertaken to organize EMS to coordinate rapid triage and transfer without compromising ACLS care. Considering the encouraging results from observational data and the preliminary trial results, several regions across the world have worked to develop ECPR programs.[97,99,100] Key features to success include selection of patients ideally suited for ECPR (eg, <70 years old, short no-flow and low-flow times, likely reversible cardiac cause for arrest); early consideration of ECPR in the field in such patients (eg, after 3 unsuccessful attempts at defibrillation or after a brief period of CPR [<15 minutes]); rapid coordination with and transport to specialized hospital centers capable of providing ECPR; use of an automated mechanical compression device to provide for adequate CPR and ease of transfer; and rapid mobility of an ECMO team on site at the hospital to provide immediate assessment and, when appropriate, immediate cannulation. ECPR teams should be available all day, every day, and teams should be capable of initiating ECPR within 10 to 15 minutes of the patient's arrival. Postprocedure care by specifically trained teams of specialists with extensive experience in managing patients on ECMO is as critical as patient selection and procedural processes to achieve the best possible outcomes.

Success of ECPR programs requires experienced, collaborative care. When implementing an ECPR program, protocols for prehospital care, emergency ECMO cannulation, and ICU care are essential components of planning. EMS professionals should be educated on the identification of eligible patients and methods to coordinate the transfer of these patients in a timely manner to hospitals capable of providing ECPR. Hospital ECMO teams should have solid experience with ECMO cannulation and ICU care of the patient on ECMO who has not experienced cardiac arrest before contemplating ECPR. Programs should conduct periodic simulations for every stage of care and provide regular quality meetings with case reviews aimed at identifying specific needs and creating best practices. Whether this approach will result in improved survival in real-world patients with refractory arrest remains to be seen, but ongoing data from regional systems have provided encouraging results.[93,97,99,101]

BEST PRACTICES FOR CATHETERIZATION LABORATORY MANAGEMENT

The approach to the treatment of patients with OHCA and STE on ECG or refractory CS or massive PE in the catheterization laboratory mimics the treatment for patients without OHCA who have similar conditions. Although a detailed discussion surrounding the catheterization laboratory management of such conditions is beyond the scope of this scientific statement, there are key differences in the individual with OHCA that warrant a particularly thoughtful approach to care. The patient with OHCA is critically ill, requiring mechanical ventilation and multiple intravenous drips, with heightened risk for bleeding, acute kidney injury, and acute stent thrombosis. Best practices focused on minimizing the potential for procedure-related complications are particularly important in these complex patients, in whom such events will contribute substantially to morbidity and mortality (Figure 4).

In hemodynamically stable patients, radial artery access is recommended, in keeping with American College of Cardiology/AHA guidelines.[72] In hemodynamically unstable patients, when hemodynamic support is being considered with the Impella device, femoral access, ideally with ultrasound guidance, will offer the added ability to use a single arterial puncture for coronary angiography and PCI as well as MCS. In acute STEMI, PCI should be performed as per American College of Cardiology/AHA guidelines,[40] and if multivessel disease is present with CS, culprit vessel–only revascularization is recommended.[72] In patients with chronic kidney disease or acute kidney injury, measures should be taken in the catheterization laboratory to minimize contrast use and the risk of further kidney injury.[72]

After revascularization, close surveillance for access site integrity and bleeding, occult or manifest, is warranted. The incidence of acute stent thrombosis is heightened in patients with acute myocardial infarction presenting with OHCA.[102] Although observational reports implicate targeted temperature management as a risk factor, this is unsupported in larger data sets and should not dissuade the institution of temperature control when appropriate.[103] Because prasugrel and clopidogrel are prodrugs, ticagrelor absorption, especially crushed, may be more reliable in this setting. When drug absorption is uncertain, the use of an intravenous P2Y12 inhibitor, such as cangrelor, can ensure adequate platelet inhibition. In the individual with OHCA demonstrating favorable neurologic function who did not undergo urgent angiography, delayed coronary angiography (with consideration for provocative spasm testing if nonobstructive coronary artery disease is noted and there is no clear cause of the arrest otherwise) will likely provide important information to guide therapies.

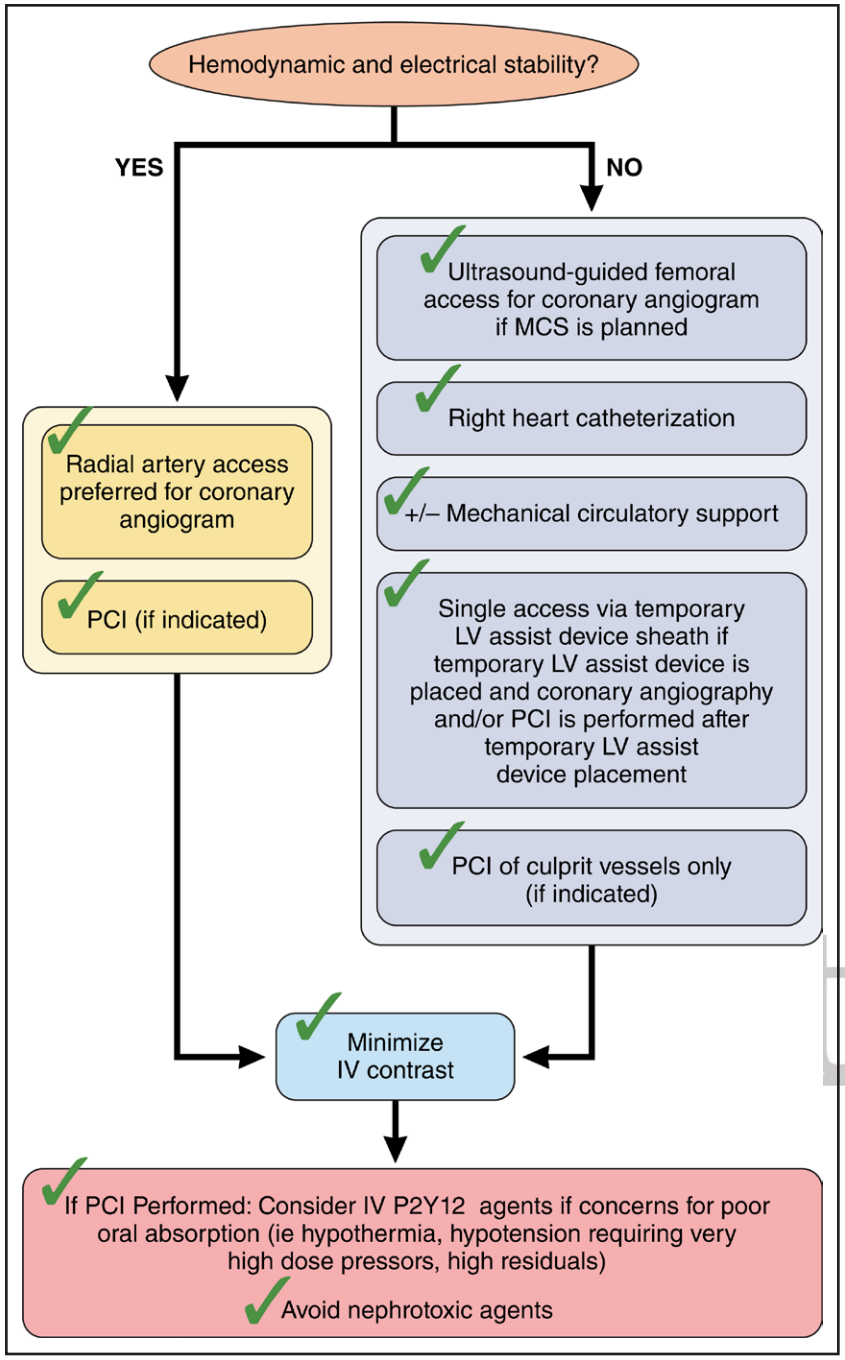

Figure 4. Best practices for catheterization laboratory management of the patient with out-of-hospital cardiac arrest referred for angiography, percutaneous coronary intervention, or mechanical circulatory support.
Key points to ensure optimal care in the critically ill patient with out-of-hospital cardiac arrest undergoing invasive management. IV indicates intravenous; LV, left ventricular; MCS, mechanical circulatory support; and PCI, percutaneous coronary intervention.

ICU MANAGEMENT

Integrated care after cardiac arrest is key to optimizing clinical outcome.[14] Patients should be admitted to an ICU with expertise in the recognition and management of components of the postcardiac arrest syndrome. A multidisciplinary team approach is critical to success. Details and the evidence base guiding individual interventions in this setting are beyond the scope of this scientific statement. A summary of pertinent AHA guideline recommendations are summarized in Table 4.[14,104,105]

SYSTEMS OF CARE FOR OHCA

The Chain of Survival, introduced by the AHA in 1991, emphasizes the coordinated efforts of community leaders and health care agencies to work together to optimize care for the patient with OHCA.[106] The Chain of Survival consists of 6 elements: activation of emergency response, effective CPR, defibrillation, advanced resuscitation by health care professionals, postcardiac arrest care, and recovery.[5] Whereas prehospital care remains the critical focus for the individual with OHCA, communication and coordination with hospitals equipped to

Table 4. Summary of Important Recommendations* for Postresuscitation ICU Management After OHCA

Subject and recommendation	COR; LOE
Delivery of postresuscitation care	
A comprehensive, structured, multidisciplinary system of care should be implemented in a consistent manner for the treatment of post–cardiac arrest patients.	1; B-NR
Blood pressure targets	
It is preferable to avoid hypotension by maintaining a systolic blood pressure of at least 90 mm Hg and a mean arterial pressure of at least 65 mm Hg in the postresuscitation period.	2a; B-NR
Oxygenation and ventilation	
We recommend avoiding hypoxemia in all patients who remain comatose after ROSC.	1; B-NR
Once reliable measurement of peripheral blood oxygen saturation is available, avoiding hyperoxemia by titrating the fraction of inspired oxygen to target an oxygen saturation of 92% to 98% may be reasonable in patients who remain comatose after ROSC.	2b; B-R
Maintaining the arterial partial pressure of carbon dioxide within a normal physiological range (generally 35–45 mm Hg) may be reasonable in patients who remain comatose after ROSC.	2b; B-R
Seizure prevention and treatment	
We recommend treatment of clinically apparent seizures in adult post–cardiac arrest survivors.	1; C-LD
We recommend promptly performing and interpreting an electroencephalogram (EEG) for the diagnosis of seizures in all comatose patients after ROSC.	1; C-LD
The treatment of nonconvulsive seizures (diagnosed by EEG only) may be considered.	2b; C-LD
The same anticonvulsant regimens used for the treatment of seizures caused by other etiologies may be considered for seizures detected after cardiac arrest.	2b; C-LD
Seizure prophylaxis in adult post–cardiac arrest survivors is not recommended.	3 (No benefit); B-R
General ICU care	
The benefit of any specific target range of glucose management is uncertain in adults with ROSC after cardiac arrest.	2b; B-R
The routine use of prophylactic antibiotics in post-arrest patients is of uncertain benefit.	2b; B-R
The effectiveness of agents to mitigate neurological injury in patients who remain comatose after ROSC is uncertain.	2b; B-R
The routine use of steroids for patients with shock after ROSC is of uncertain value.	2b; B-R
Indications and targets for TTM†	
We recommend TTM for adults who do not follow commands after ROSC from OHCA with any initial rhythm.	1; B-R
We recommend TTM for adults who do not follow commands after ROSC from IHCA with initial nonshockable rhythm.	1; B-R
We recommend TTM for adults who do not follow commands after ROSC from IHCA with initial shockable rhythm.	1; B-NR
We recommend selecting and maintaining a constant temperature between 32°C and 36°C during TTM.	1; B-NR
It is reasonable that TTM be maintained for at least 24 h after achieving target temperature.	2a; B-NR
It may be reasonable to actively prevent fever in comatose patients after TTM.	2b; C-LD
We do not recommend the routine use of rapid infusion of cold IV fluids for prehospital cooling of patients after ROSC.	3 (No benefit); A
Neuroprognostication	
In patients who remain comatose after cardiac arrest, we recommend that neuroprognostication involve a multimodal approach and not be on the basis of any single finding.	1; B-NR
In patients who remain comatose after cardiac arrest, we recommend that neuroprognostication be delayed until adequate time has passed to ensure avoidance of confounding by medication effect or a transiently poor examination in the early postinjury period.	1; B-NR
We recommend that teams caring for comatose cardiac arrest survivors have regular and transparent multidisciplinary discussions with surrogates about the anticipated time course for and uncertainties around neuroprognostication.	1; C-EO
In patients who remain comatose after cardiac arrest, it is reasonable to perform multimodal neuroprognostication at a minimum of 72 h after normothermia, although individual prognostic tests may be obtained earlier than this.	2a; B-NR

COR indicates Class of Recommendation; EEG, electroencephalogram; EO, expert opinion; ICU, intensive care unit; IHCA, in-hospital cardiac arrest; IV, intravenous; LD, limited data; LOE, Level of Evidence; OHCA, out-of-hospital cardiac arrest; NR, nonrandomized; R, randomized; ROSC, return of spontaneous circulation; and TTM, targeted temperature management.

*Recommendations from the 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care.[14,104]

†For current position on temperature management please refer to the American Heart Association science advisory "Temperature Management for Comatose Adult Survivors of Cardiac Arrest."[105]

care for such patients is essential for the transfer of care and immediate postresuscitation management. The AHA guidelines for CPR and emergency cardiovascular care assign Class of Recommendation 2a to transferring patients with OHCA directly to specialized cardiac arrest centers as a reasonable approach to management.[5] On the basis of these recommendations, certifying companies, such as The Joint Commission, in collaboration with

the AHA, launched a program for Comprehensive Heart Attack Center certification. These certified hospitals are committed to providing invasive angiography and intervention, hemodynamic support, temperature management, and postarrest expertise in neuroprognostication, as well as providing ECMO when indicated. Regions with designated systems of care directing EMS agencies to transport the individual with OHCA directly to a specialized center have reported favorable outcomes.[107,108] The postresuscitation care link in the Chain of Survival is of particular importance in situations of refractory ventricular fibrillation or ventricular tachycardia when ECPR is being considered, or for those patients with STE on ECG or findings to suggest CS who might benefit from immediate invasive therapies. As part of these systems of care, certified hospitals commit to a process for collecting data relating to each aspect of care. Establishing this formal process of data collection allows for future research and understanding to improve future interventions and outcomes of OHCA.

PUBLIC REPORTING OF OUTCOMES AFTER OHCA

OHCA has historically been associated with high mortality rates.[1] Public reporting of outcomes of PCI can lead to the unintentional avoidance of intervention for this population of patients because of a conscious or subconscious fear that a negative outcome might contribute to a higher individual operator or hospital center risk-adjusted mortality rate.[109] Several attempts have been made to mitigate this unintended consequence of public reporting in some states, by excluding mandatory reporting of patients with refractory CS, anoxic brain injury, or OHCA. However, this has not led to increased rates of PCI in this high-risk population of patients.[110] As the role of the catheterization laboratory in treating patients with refractory and resuscitated OHCA expands, additional strategies may be needed to ensure this vulnerable population has access to lifesaving technology across all regions and centers in the United States.

FUTURE DIRECTIONS AND CONSIDERATIONS FOR RESEARCH

This document summarizes the available data regarding the cardiac catheterization laboratory management of patients with OHCA. Despite our attempts to provide useful suggestions for care, it is imperative to recognize the lack of outcomes data for many areas of management. This includes the prospective use of cardiac risk scores to guide management decisions, the value of emergency angiography in patients with OHCA and STE on ECG manifesting multiple unfavorable features or high postarrest risk scores, and the real-world value of ECPR in a select group of patients with ongoing arrest with a coordinated, highly experienced response team.

CONCLUSIONS

OHCA is a devastating condition requiring emergency coordinated systems of care and a multidisciplinary team–based approach. The interventional cardiologist and the cardiac catheterization laboratory have important roles in the Chain of Survival for many patients with OHCA. Rapid assessment and triage to identify selected patients who might best benefit from invasive therapies is critical to ensure optimal outcomes. Because of uncertainty regarding neurologic outcomes, there remains a role for individualized care using the best evidence available.

ARTICLE INFORMATION

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the writing group are required to complete and submit a Disclosure Questionnaire showing all such relationships that might be perceived as real or potential conflicts of interest.

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Disclosures

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Writing group member	Employment	Research grant	Other research support	Speakers' bureau/ honoraria	Expert witness	Ownership interest	Consultant/ advisory board	Other
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This table represents the relationships of writing group members that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all members of the writing group are required to complete and submit. A relationship is considered to be "significant" if (a) the person receives $5000 or more during any 12-month period, or 5% or more of the person's gross income; or (b) the person owns 5% or more of the voting stock or share of the entity, or owns $5000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

*Modest.

†Significant.

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*Modest.

†Significant.

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