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Clinical scenarios for use of transvalvular microaxial pumps in acute heart failure and cardiogenic shock – A European experienced users working group opinion

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ABSTRACT

For patients with myocardial infarct-related cardiogenic shock (CS), urgent percutaneous coronary intervention is the recommended treatment strategy to limit cardiac and systemic ischemia. However, a specific therapeutic intervention is often missing in non-ischemic CS cases. Though drug treatment with inotropes and/or vasopressors may be required to stabilize the patient initially, their ongoing use is associated with excess mortality. Coronary intervention in unstable patients often leads to further hemodynamic compromise either during or shortly after revascularization. Support devices like the intra-aortic balloon pump failed to improve clinical outcomes in infarct-related CS. Currently, more powerful and active hemodynamic support devices unloading the left ventricle such as transvalvular microaxial pumps are available and are being increasingly used. However, as for other devices large randomized trials are not yet available, and device use is based on registry data and expert consensus.

In this article, a multidisciplinary group of experienced users of transvalvular microaxial pumps outlines the pathophysiological background on hemodynamic changes in CS, the available mechanical support devices, and current guideline recommendations. Furthermore, different hemodynamic situations in several case-based scenarios are used to illustrate candidate settings and to provide the theoretic and scientific rationale for left-ventricular unloading in these scenarios. Finally, organization of shock networks, monitoring, weaning, and typical complications and their prevention are discussed.

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1. Preface

Although guidelines offer evidence-based recommendations, they contain gaps in guidance regarding decision-making, when trial data are scarce. Opinion papers provide guidance for clinicians in areas with limited or evolving evidence. The present manuscript illustrates clinical scenarios in which a group of experienced Impella users sees a potential of clinical benefit based on the underlying disease's pathophysiology and individual users have had positive experiences. As the group of authors consists of experienced Impella users, there is obviously a potential conflict of interest regarding lecturing and research funding as disclosed below.

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1.1. Definition of hemodynamic instability

The definition of cardiogenic shock (CS) based on systolic blood pressure (SBP) ≤90 mmHg, cardiac index <2.0 l/min/m^2 with left-ventricular end-diastolic pressure (LVEDP) >18 mmHg and clinical signs of tissue hypoperfusion can rarely be determined in routine when immediate interventional treatment is required. Other definitions are based on hypotension and end-organ hypoperfusion [1–5], which also varies widely. An alternative option is arterial lactate as a surrogate (values >2.0–2.5 mmol/l suggest organ hypoperfusion). However, lactate may be normal in cases of overt shock as it depends on hepatic function and catecholamine administration rather than hypoperfusion alone [6,7].

When selecting patients who might benefit from temporary circulatory support (TCS), it is pivotal to identify both key elements of CS: Decreased cardiac output and organ hypoperfusion. Assessing cardiac output acutely requires invasive monitoring, which often is too time consuming when immediate revascularization is required. Combining clinical judgment, arterial lactate and rapid echocardiography focusing on left-ventricular function, mechanical complications and stroke volume rapidly identifies hemodynamically compromised patients suitable for TCS.

Patients with chronic heart failure (CHF) and acutely decompensated HF (ADHF) often deteriorate because of already impaired hemodynamics and neurohumoral environments independent from acute ischemia [8].

Experienced users opinion: *Clinical assessment, lactate levels, and focused echocardiography are rapidly available and useful tools for identifying hemodynamically compromised patients.*

2. Available TCS devices and associated inherent pathophysiological changes

While often an isolated reversible hemodynamic problem triggers CS and patients might recover on TCS, untreated CS proceeds to a hemo-metabolic problem requiring multi-organ support associated with high mortality [9]. Currently three categories of TCS are available: intra-aortic balloon pump (IABP), axillar-flow pumps (AFP), and extracorporeal pumps combined with membrane oxygenation (ECMO) [10,11].

IABP requires forward blood-flow and a left ventricle (LV) capable of increasing stroke volume upon minor afterload reduction along with increased coronary perfusion, which is observed under high-risk PCI conditions, but not necessarily in CS [12]. Tachycardia and arrhythmia limit IABPs efficacy. IABP is inefficient in circulatory arrest. AFP require enough ventricular filling to avoid suction, and have limitations when LV preload is decreased (due to right ventricular [RV] failure) or LV cavity is limited (due to hypertrophy, septum shift or compression). ECMO requires sufficient venous filling and volume return to avoid suction [13].

AFP and ECMO maintain cardiac output in severe hemodynamically compromised patients. LV-AFP and veno-arterial(va)-ECMO both deliver cardiac output to the aorta improving end-organ perfusion, dependent on pump type/cannula size. Both strategies fundamentally differ in their impact on intrathoracic circulation. LV-AFP unload the LV, reduce ventricular size and wall tension. Three different AFPs are iVAC 2L, Heartmate PHP, and the Impella devices; at the time the manuscript was written only the Impella devices were available on the market. The authors believe that rather the extent of unloading is important than the specific design of the individual AFP. ECMO may increase LV afterload and lead to a “non-ejecting heart”: The LV is unable to eject against retrograde ECMO flow but is filled from the pulmonary circulation, resulting in largely increased LV wall tension and filling pressures, pulmonary edema and impaired LV recovery [11]. Several reviews discuss the use of the differing devices [11,14,15]. Fig. 1 illustrates typical LV pressure volume loops in CS under different support modalities.

3. Evidence-based data

Data on AFPs in CS from randomized controlled trials (RCT) are limited due to the very low number of patients included. One of the first RCTs was the ISAR-SHOCK-trial, randomizing 26 patients. The primary end-point was change in cardiac index within 30 min, a trial not powered for outcome [16]. The next RCT was the (IMPRESS-in-Severe-Shock-trial, which randomized 48 patients to IABP vs ImpellaCP. 83% of devices were placed after revascularization, all patients in the Impella arm and 83% in the IABP arm had cardiac arrest prior to randomization and all patients were ventilated. 6 month-mortality was 50% in both groups [17]. The trial included patients in severe post-cardiac arrest syndrome. These two trials have been repeatedly included in meta-analyses demonstrating a lack of effect by Impella in CS [18,19].

Several single- and multi-center registries indicated a potential benefit for some CS patients when treated with an Impella [20–23]. Other registries provided neutral results [24]. A recent multi-national approach including several of the experienced users tried to perform a matched-pair analysis from real-world CS patients treated with Impella to patients randomized in the IABP-Shock-II-trial. The comparison was limited by lacking data on LV function from the RCT, but in matched patients the effect appeared to be neutral [25]. These results are in contrast to large registries reporting a potential benefit of Impella in CS, particularly if implanted before revascularization [20–22,26–28]. A clearly focused RCT is needed and currently performed by some of the experienced users in the DanGer-Shock study. Until the trial results will be available, individual decision making is required whether to use an AFP or not. While there are no guideline recommendations clearly encouraging this approach, the present manuscript illustrates

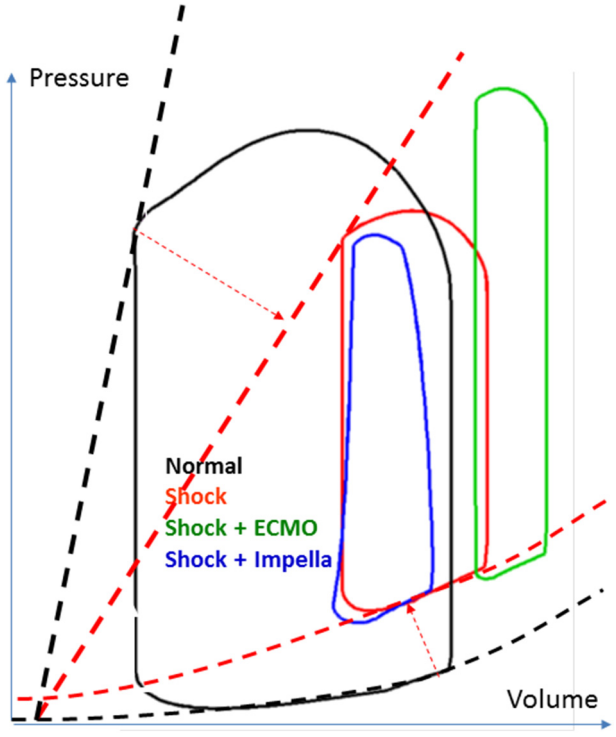


Fig. 1. Differential hemodynamics of axillar-flow pumps (AFP) and extracorporeal membrane oxygenation (ECMO) in cardiogenic shock are shown in left ventricular (LV) pressure-volume loops (black loop indicating physiological patterns). In acute myocardial infarction-related shock, end-systolic and end-diastolic pressure-volume relationship (red dotted lines) and stroke volume are impaired (red loop). Axillar-flow pumps (blue loop) deliver cardiac output to the aorta and decrease LV size, pressure, wall tension, and LV oxygen consumption, while veno-arterial ECMO delivers flow support to the aorta but may increase LV size, pressure, wall tension and oxygen consumption.

clinical scenarios in which the group of experienced users sees a potential of clinical benefit based on the underlying disease's pathophysiology.

4. Indications–guidelines

Aggregated results of several small RCTs comparing TandemHeart and Impella2.5 with IABP suggested that TCS increases cardiac index, mean arterial pressure and bleeding [19]. Though IABP was initially guideline-recommended for CS, the IABP-SHOCK-II-trial highlighted its limitations [29,30]. IABP is no longer recommended for routine use (IIIA) and is only considered when another TCS is unavailable, contraindicated, or cannot be placed. Despite missing evidence, guidelines recommend va-ECMO as preferred option, especially during hypoxemia [8]. TCS is recommended for bridge-to-recovery and for bridge-to-decision with permanent circulatory support or transplantation as definitive options. Device selection should be guided by clinical judgment and experience [31]. Several guidelines endorse establishing CS-centers linked to high-volume hospitals treating all CS cases [8,32]. Since proper trial data are lacking, the users' opinion provided in this article is based on individual experience and does not resemble guideline recommendations. A proper recommendation cannot be given for most of the scenarios; if it can be given it is indicated in the specific section. TCS is recommended for hemodynamically compromised patients in selected cases based on individual decision due to lack of supportive data from large prospective RCTs. In infarct-related CS, early revascularization should be performed [31].

5. Unmet clinical need

Besides strict definition of hemodynamic instability, evidence is lacking for selection and timing of devices. IABP has shown no benefit on mortality [2], increasing numbers and doses of catecholamines in non-randomized studies were associated with higher mortality [27,33]. Although a few case series showed promising results of AFP support [5,20,26], the only randomized outcome study was severely underpowered [17]. An adequately powered study (DanGer-Shock, NCT01633502) is still ongoing [34]. Growing translational evidence associates pre-PCI AFP-placement with myocardial protection and augmented myocardial recovery (Fig. 2) [21,35,36]. Observational data suggest that pre-PCI AFP-placement might be associated with improved survival [5,20,26]. Implantation can usually be achieved within 5–10 min and should not exceedingly delay standard care.

Based on the existence of unmet need beyond the scarce clinical evidence, a group of experienced AFP users from several countries met repetitively during major European conferences and agreed to provide a guidance for clinical scenarios for AFPs based on the disease's pathophysiology and the device's mode of action. The “experienced users” authoring this manuscript do not represent and do not want to claim to represent any national or international society.

6. Clinical scenarios for AFP usage based on pathophysiological considerations

6.1. ST-elevation myocardial infarction (STEMI) patients with initially stable hemodynamics

Patients present with acute anterior STEMI with significant myocardium at risk and without.

overt CS [37].

Despite prompt revascularization, these patients suffer from high mortality and HF at mid-term follow-up. These patients show no benefit from IABP regarding mortality, reinfarction, HF or infarct-size reduction [38]. Experience with AFP in stable patients with STEMI is limited, but translational data suggest that LV unloading could provide acute and sustained LV recovery [39,40]. If patients are just borderline stable (pre-shock), reperfusion might rapidly lead to hemodynamic deterioration. AFP-placement before revascularization is feasible [41], may improve myocardial salvage [35,36], confer myocardial protection and prevent deterioration to overt CS [40].

Experienced users opinion: *In pre-shock patients with large anterior AMI, ongoing studies will determine whether AFP implantation pre-PCI reduces infarct size and stabilizes hemodynamics.*

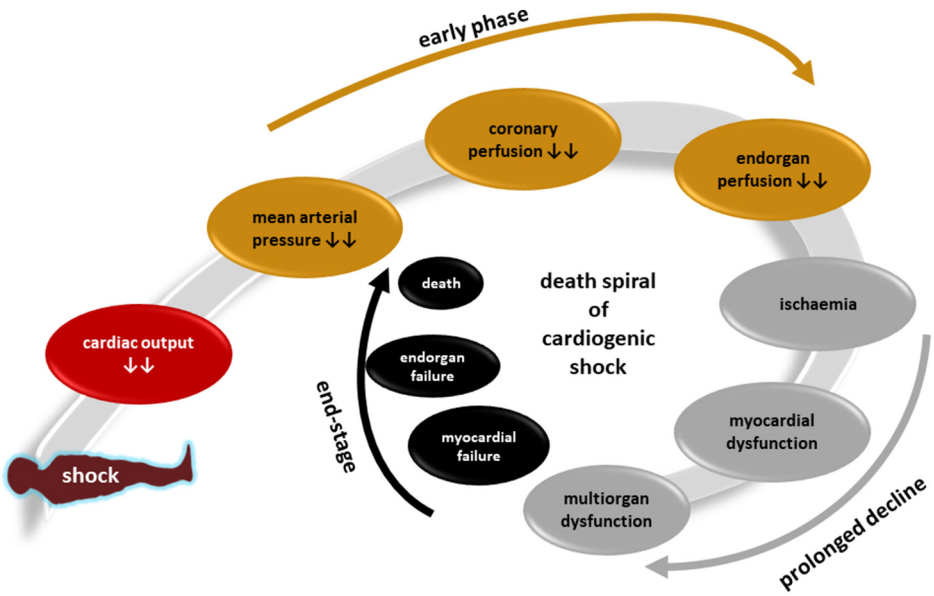


Fig. 2. The death spiral of cardiogenic shock. The death spiral indicates how a dramatic drop in cardiac output results in impaired mean arterial pressure (MAP) and subsequently reduced coronary as well as end-organ perfusion. Primarily vasopressor-based correction of MAP would further decrease coronary and end-organ perfusion. Either no treatment in this phase or vasopressor-based treatments will rapidly lead to ongoing ischemia which results in a transformation of end-organ hypoperfusion via reversible multi-organ dysfunction to progressive multi-organ failure consequently leading to death. If cardiac output is restored early enough either by successful medical treatment, revascularization and/or hemodynamic support, the spiral can be reversed and lead to recovery. To prevent ongoing ischemia, cardiac output should be improved or ideally be normalized within the golden hour of shock (modified according to [96]).

6.2. Hemodynamically unstable AMI patients

Patients are admitted with acute chest pain, ST-segment elevation, hypotension requiring catecholamines, and sometimes with a history of short out-of-hospital cardiac arrest.

Acute LAD occlusion or left-main lesions are often accompanied by acute HF (reduced LV-EF, increased LVEDP) and CS with mortality exceeding 50% [42–44] despite guideline recommended early revascularization and vasopressors/inotropes to maintain organ perfusion [30,45]. In progressive organ-dysfunction due to low cardiac output it seems intuitive to restore cardiac output as fast as possible without stressing the myocardium with catecholamines. AFPs simultaneously unload the LV and augment cardiac output [5,20,26]. Rapid AFP-placement can be performing pre-PCI and continued LV unloading in CS with high wall tension might help to decrease catecholamine levels.

Experienced users opinion: *We recommend early awareness for CS and immediate echocardiography. In unstable CS patients with coronary occlusion, LV unloading using AFP may stabilize the patient when inserted rapidly pre-PCI.*

6.3. Patients with right ventricular infarction

RV failure following right or bi-ventricular ischemia poses several problems: Diagnosis of RV failure is complex and can be facilitated by echocardiographic and/or invasive hemodynamic parameters [46]. When conventional therapy eliminating factors like hypovolemia, hypoventilation, pulmonary vasoconstriction and inotropes for the RV fail, TCS can be considered [47]. Options include va-ECMO or ImpellaRP, a right-ventricular AFP pumping blood from the right atrium to the pulmonary artery. Feasibility of ImpellaRP has been demonstrated in case series and consecutive cohorts with RV failure due to AMI or post-cardiotomy shock [48]. It can be combined with left-sided AFPs in a "BiPella" topology for biventricular support. Monitoring of central and systemic hemodynamics following ImpellaRP placement is crucial for initial settings and subsequent weaning after stabilization.

Experienced users opinion: *It is important to screen for and detect RV failure, which often requires invasive hemodynamic measurements. TCS are used to stabilize hemodynamics, unload RV, preserve end-organ function and systemic perfusion.*

6.4. Patients with biventricular failure

Biventricular failure can present as primary involvement of both ventricles or as RV failure secondary to LV dysfunction or after LV assist device (LVAD) implantation.

Biventricular AFP provide full percutaneous biventricular support and unloading, which may require less intense antithrombotic treatment than ECMO. Choice of AFP type and intensity depends on residual LV function. Biventricular AFP implantation requires advanced technical skills and coordinated flow-management regarding ventricular interdependence and anatomical contraindications, and good oxygenation compared to va-ECMO [49]. While the concept of biventricular unloading is appealing, experience compared to va-ECMO plus LV venting is rather limited.

Experienced users opinion: *Prompt as compared to delayed biventricular support is associated with better outcomes. As transplantation is the only definitive treatment for biventricular failure and as the RV is resilient to recovery, any effort should be directed towards RV functional recovery.*

6.5. Patients after cardiopulmonary resuscitation

CS is common after resuscitation from out-of-hospital cardiac arrest, but severity is extremely variable depending on duration and etiology of arrest [50–53]. Lactate is commonly increased due to systemic hypoperfusion, but is not specific for low-output failure as in non-resuscitated CS patients.

Preventing hypoxemia and end-organ hypoperfusion is the mainstay of treatment. Post-arrest CS may be severe and refractory to conventional treatment and TCS can restore hemodynamic stability. Echocardiography should be performed at first contact; quick TCS implantation using va-ECMO is preferred [23,54,55]. TCS implantation in refractory post-arrest CS can improve patient survival with good neurological outcome when used as part of a dedicated protocol [23,54,55].

Experienced users opinion: *Although neurologic prognosis at presentation is unknown, rapid treatment including TCS may be warranted in patients with post-arrest CS [50]. A standardized treatment protocol ensuring high-quality post-resuscitation care is recommended [53,56,57].*

6.6. Patients with pre-terminal ischemic or dilated cardiomyopathy and low-output syndrome

Definitive therapy for end-stage HF comprises transplantation or implantation of a permanent LVAD [58]. ADHF or CS patients are at high surgical risk often precluding prompt surgery [59]. A bridge-to-decision concept with TCS and deferred permanent LVAD implantation after recovery of end-organ function may be beneficial. In hemometabolic shock, when up to 8 l/min of support and more may be needed, a device with full LV unloading is warranted (TandemHeart, Impella5.0, CentriMag) [60]. In refractory biventricular failure CentriMag BiVAD or va-ECMO should be placed [61]. Recent data suggest combining ECMO with Impella5.0 to provide LV unloading facilitates more rapid ECMO weaning [62]. Device registries are an important source to obtain "real-world clinical data" to document acute and late outcome in non-ischemic ADHF [63].

Experienced users opinion: *TCS can be used in unstable ADHF patients as a bridge-to-surgery strategy to stop or revert the shock spiral until definitive treatment [64]. Optimal timing is crucial to prevent multi-organ or biventricular failure. Early TCS implantation is the key to favorable outcomes.*

6.7. Patients with myocarditis

Patients often present with fatigue, chest pain, ubiquitous ST-elevations, no overt coronary artery disease, severely and globally reduced LV-EF, high LVEDP, tachycardia, and hypotension.

Myocarditis may present with a fulminant course [65]. Hemodynamic presentation often involves LV&RV dysfunction and ventricular arrhythmias. Myocarditis is usually a dynamic process. Support strategy and device selection are patient-specific. First evidence from endomyocardial biopsies indicates that in addition to giving adequate support, LV unloading by AFP exerts disease-modifying effects that could be important for myocardial recovery [66].

Experienced users opinion: *In unstable myocarditis patients, LV unloading supports hemodynamics and reduces LV overload. Thus AFP may be beneficial in select cases.*

6.8. Patients with Takotsubo syndrome (TS)

Patients present with chest pain, ST-segment elevations, severely reduced LV-EF, increased LVEDP and apical ballooning.

TS is characterized by severe myocardial failure [67] often accompanied by LV outflow-tract obstruction (LVOTO), RV failure, CS and cardiac arrest. Catecholamines are considered causal for TS, potentially aggravate LVOTO and should be avoided [68]. TCS may be used for bridge-to-recovery in shock or pre-shock [69,70]. IABP may worsen LVOTO [71], va-ECMO increases afterload and may amplify mitral regurgitation and pulmonary edema. LV unloading appears most favorable in TS, especially in LVOTO [72–74].

Experienced users opinion: *Based on the pathophysiology of TS and the risk of outflow tract obstruction, AFP might be the most promising device for bridge-to-recovery and to avoid the use of catecholamines.*

6.9. Patients with peripartum cardiomyopathy (PPCM)

Previously healthy females present with new severe AHF accompanied by hypotension and tachycardia within several weeks after giving birth.

PPCM with CS is life-threatening. Preventing CS in women with AHF and risk for PPCM requires early diagnosis [75]. In CS complicating PPCM, catecholamine therapy is detrimental. The German PPCM registry associated dobutamine with adverse outcomes in PPCM [76], whereas in PPCM with CS early LV unloading was accompanied with LV recovery. As LV unloading is often associated with inotropic weaning, AFP might be a promising TCS strategy [77,78].

Experienced users opinion: *LV unloading with AFP may be associated with increased survival in PPCM with CS. Referring the patient to a tertiary hospital with experience in TCS could be beneficial for treatment of CS complicating PPCM.*

6.10. Patients with post-cardiotomy CS

The prognosis of post-cardiotomy CS (PCCS) without TCS is poor (survival ~25%) mainly due to multi-organ failure [79]. AFP are increasingly used [80–82] with survival rates >60% [5,83]. Indications are inability to wean from cardiopulmonary bypass and/or poor postoperative hemodynamics [9]. Based on pathophysiological considerations, AFP should be a good choice in PCCS.

Experienced users opinion: *AFP exerts profound venting capacity, minimizes metabolic demand [7,10] and offers hemodynamic support for end-organ perfusion. When ECMO is used, AFP (e.g. Impella5.0) should be added for efficient LV venting when LV is distended, pulsatility lost or lung congested.*

7. Pre-shock and CS algorithms

CS algorithms can be adopted from cardiac arrest standards [53], as arrest often precedes CS hospital admission, e.g. in ischemic CS [20]. Such an approach was recently associated with improved 30-day survival in an IABP-Shock-II-trial eligible cohort [20]. Protocols include rapid CS identification, immediate echocardiography, characterization of systemic perfusion deficit, primary stabilization using vasopressors/inotropes, and early TCS implementation followed by revascularization as appropriate. The focus on a very early treatment of cardiogenic shock is analogous to the concept of treatment during “the golden hour of shock” in traumatology [84].

Once CS is suspected, ischemic etiologies should be distinguished from non-ischemic. In AMI-related CS, revascularization is immediately required (“STEMI-fast-track”) along with early LV-unloading. Even cases of pre-shock may be considered for TCS facilitating a “time to support”-concept [85]. Early LV-unloading enables safe revascularization, limits inotropic use, improves myocardial perfusion, and should limit myocardial necrosis. In medically treated non-ischemic CS with inotropes/vasopressors TCS should be provided if first line therapy fails or either recovery or future destination therapy (transplantation or LVAD) seems amenable.

In AMI-related CS, admission to a center corresponding to level 2 intensive critical care unit (ICCU) [32], with both coronary angiography and first line TCS should be considered (Table 1). If unresponsive, patients should be transferred to an expert CS center (level 3 ICCU).

In non-ischemic CS, medical treatment should be started quickly and the patient be transferred to an expert center in order to optimize chances of recovery by a multidisciplinary approach and further support strategies. In absence of myocardial recovery, an earlier bridge to transplant or permanent LVAD should be considered (Fig. 3 & Table 1).

8. Hemodynamic monitoring

AFP implantation pre-PCI is associated with higher survival and revascularization in AMI-CS [28]. Hemodynamic measurements should not delay TCS initiation and revascularization. Invasive hemodynamic monitoring allows continuous capture of cardiac filling pressures and output for adjustment of catecholamines and AFP parameters. A pulmonary artery catheter is useful when using AFPs for longer periods. Complete hemodynamic assessments should be performed at least twice a day. Routine echocardiography visualizes AFP position, volume status, and RV, LV and valvular function.

9. Weaning & escalations

Hemodynamic monitoring should guide vasopressor/inotropes and volume treatment. After stabilization, volume and vasopressors/inotropes should be reduced. Impella devices should be reduced on intervals of 1–2 support levels. Success is monitored by hemodynamic stability and absence of systemic malperfusion. If patients are stable on low support without requiring higher doses of vasopressors/inotropes, AFP can be explanted.

Table 1
Where, when and how to act in acute myocardial infarction-related cardiogenic shock (AMI-CS).

Where to act	What to do	How to do
Emergency room ambulance	Consider shock in compromised patients	• SBP <90 mmHg • Pathological ECG/focused TTE • Requires inotropes/vasopressors • Clammy skin • Tachycardia • Lactate >2 mmol/L
Catheterization lab	Hemodynamic stabilization	• AFP support pre-PCI • Reduction of inotropes/vasopressors
Catheterization lab	Revascularization	• PCI as preferred revascularization • At least PCI of culprit lesion
Intensive care unit	Extended monitoring	• Extended hemodynamic monitoring o pulmonary arterial catheter o pulse contour cardiac output
Intensive care unit	Assess for recovery	• TTE to assess LV unloading • ↑cardiac output • ↑cardiac power output • ↑urine excretion • ↓lactate • ↓inotropes • ↑LV-EF in TTE
Intensive care unit	Identify cause of ongoing ventricular failure	• Persistent LV failure • Additive RV failure

It is important to consider cardiogenic shock as a possibility of all deteriorated patients with chest pain in the emergency room. If systolic blood pressure (SBP) is low, patients have clammy skin, tachycardia and/or elevated lactate levels, an electrocardiogram (ECG) and rapid-focused trans-thoracic echocardiogram (TTE) should be performed immediately. If shock is suspected, early stabilization using AFP is important, ideally implemented before percutaneous coronary intervention (PCI). After revascularization, treatment in the intensive care unit (ICU) should focus on hemodynamic assessment (pulmonary artery or pulse contour cardiac output catheters to be considered) and catecholamine weaning. Assessment of AFP positioning and myocardial recovery should be performed by TTE at least once per shift on ICU. If left ventricle (LV) recovers, patients can stay on medical therapy; if LV does not recover or additional right-ventricular (RV) failure is unmasked, more advanced temporary or permanent assist devices should be considered.

AMI-CS: acute myocardial infarction-related cardiogenic shock; lab: laboratory; ECG: electrocardiogram; ICU: intensive care unit; PCI: percutaneous coronary intervention; SBP: systolic blood pressure; TTE: transthoracic echocardiography.

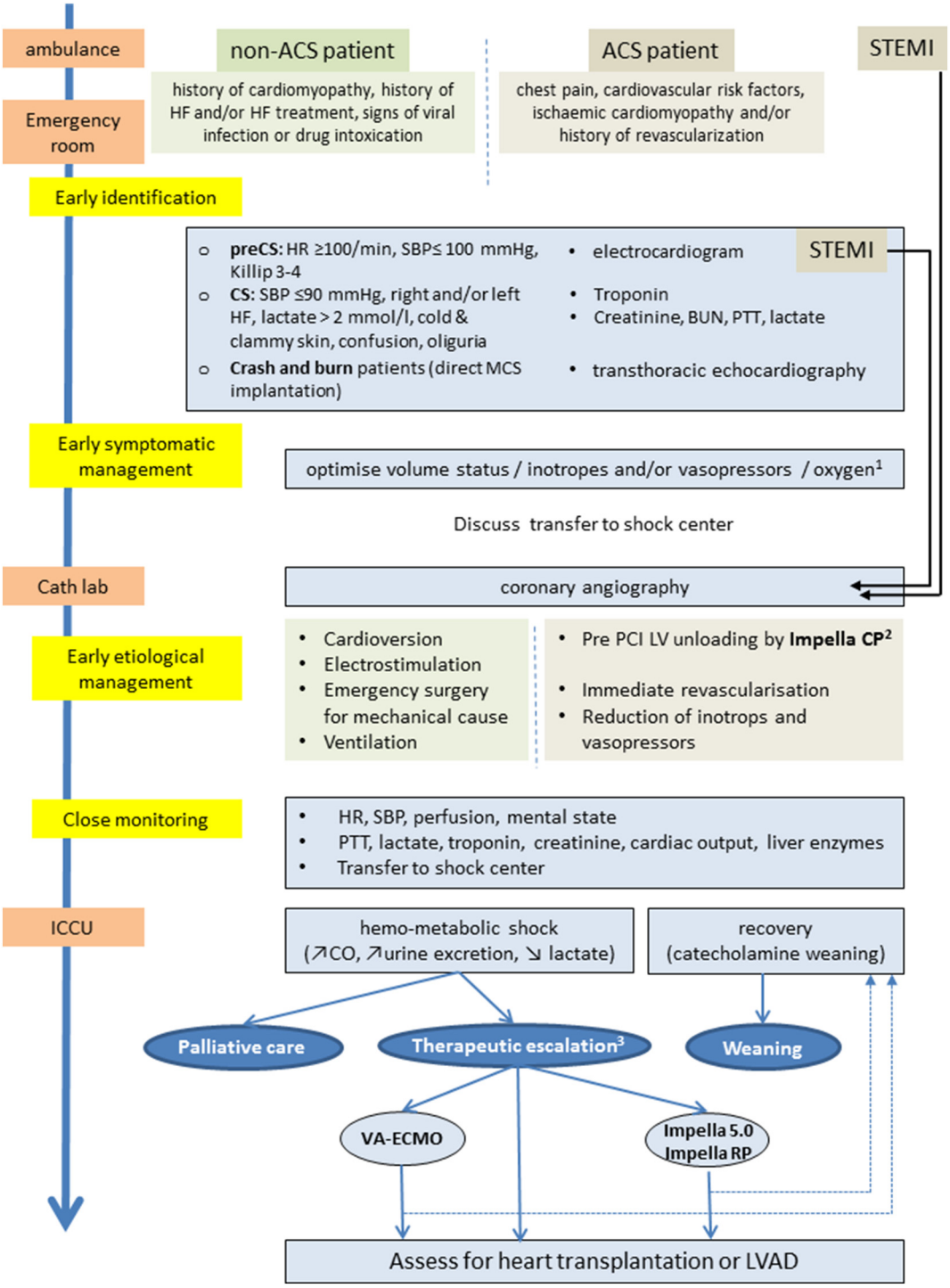


Fig. 3. CS management algorithm. Exemplary algorithm for a local shock network including diagnostic and early interventional approaches for ischemic as well as non-ischemic cardiogenic shock cases with a focus on STEMI fast-track to the catheterization lab if detected preclinically. 1. Oxygen therapy could be realized by nasal cannula, facial mask, non-invasive or mechanical ventilation as appropriate to obtain an oxygen arterial saturation > 90%. 2. The choice of the percutaneous AFP device should be based on local availability and operator experience. Impella CP is favored in CS patients. 3. Based on local conditions and experience but also on first support use, Impella CP or 5.0 could be used alone or in association with VA-ECMO. ACS: acute coronary syndrome; BUN: blood urea nitrogen; CO: cardiac output; CS: cardiogenic shock; ECG: electrocardiogram; eGFR: estimated glomerular filtration rate; HF: heart failure; HR: heart rate; ICCU: intensive cardiac care unit; LV: left ventricle; LVAD: permanent LV assist device; STEMI: ST-segment elevation myocardial infarction; TCS: temporary circulatory support; PCI: percutaneous coronary intervention; p-Impella: percutaneous Impella (CP or 2.5); PTT: prothrombin time; SBP: systolic blood pressure; TTE: transthoracic echocardiography; VA-ECMO: veno-arterial ECMO.

If AFP do not efficiently stabilize circulation, combined AFP plus ECMO (ECPella) is a validated strategy in biventricular or LV failure with severe hypooxygenation [86]. In ECPella setting, expeditious ECMO removal should be attempted. Subsequently, AFP support must be reduced until support is moderate. If LV recovers, AFP is explanted. If LV does not recover within several days, Impella5.0 could allow for full circulatory support, quick ECMO removal, and prolonged evaluation while ambulating the patient. Duration of support is often

unpredictable, and weaning should incorporate evaluation of bridging strategies (myocardial recovery, bridge to permanent LVAD and/or transplantation) [87].

10. Acute kidney injury

Acute kidney injury (AKI) is a common complication in CS potentially predicting mortality [88]. Patho-mechanisms driving AKI in CS beyond contrast-induced nephropathy include hypotension reducing renal perfusion, renal congestion by increased venous pressure, and disturbed renal autoregulation potentially worsened by vasopressors [89]. While IABP and ECMO seems to increase the risk for AKI [90], AFP actually protect high-risk patients from AKI despite preexisting chronic kidney disease [91].

11. Complications & contraindications

11.1. Vascular complications

Vascular complications in CS are usually due to a mismatch between sheath dimension and calcified, tortuous femoral arteries resulting in perforations, dissections and arterio-venous fistula. Careful selection of the puncture site by imaging and angiographic control after sheath removal reduces complications. Micropuncture and ultrasound guidance can improve vascular access. Most bleedings can be resolved by manual compression. In case of significant bleeding, balloon dilatation for 2–3 min using a PTA-balloon usually achieves hemostasis. Covered stents or surgical repair should be considered in case of persistent bleeding or flow limiting dissections.

11.2. Pump displacement

In case of ventricular dislocation, controlled pull-back either with fluoroscopic or echocardiographic control is possible. In case of aortic dislocation, pump re-insertion into the LV should be controlled by imaging. If repositioning cannot be achieved, AFP should be replaced.

11.3. Thrombus formation

If a thrombus is suspected in the AFP impeller, the AFP catheter should immediately be removed. Sufficient anticoagulation when using AFPs is assumed at ACT >160 s.

11.4. Hemolysis

AFP-induced hemolysis due to device malposition in CS is often not clinically relevant and ceases after repositioning the AFP across the aortic valve.

For more practical aspects a collaborative viewpoint is available [92].

11.5. Contraindications

LV thrombus increases the risk of clot suction into the AFP leading to consecutive device failure. Mechanical aortic prosthesis is an absolute contraindication for AFPs. Bioprosthetic valves can be passed with AFPs [93]. Patients with severe aortic regurgitation will be suboptimally supported by AFP, however, va-ECMO or TandemHeart would increase afterload and ventricular distension even more [94]. Using AFP in aortic stenosis -once contraindicated- is nowadays considered feasible [95]. Peripheral vascular disease is not a contraindication, but its presence and severity should be assessed before sheath insertion. Selecting alternative access sites such as axillary or subclavian arteries or pre-implantation peripheral vascular intervention are options before placing AFPs in patients with significant peripheral artery disease [92].

12. Conclusion

Hemodynamic compromise in CS is detrimental for early and effective therapeutic intervention. If patients do not rapidly respond to catecholamines and volume, TCS placement may be useful. LV overload often impairs recovery. Interventional strategies providing active LV unloading seem to be intuitive, but study data are lacking. In many scenarios, LV unloading using AFP may improve patient hemodynamics in parallel with rapid catecholamine weaning and limit vasopressor-facilitated end-organ ischemia, prevent hemo-metabolic shock and reduce morbidity and mortality in CS.

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