Extracorporeal Life Support in Myocardial Infarction-Induced Cardiogenic Shock: Weaning Success

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Background. **Outcome data of patients with acute myocardial infarction (AMI)–induced cardiogenic shock (CS) receiving extracorporeal life support (ECLS) are sparse.**

Methods. **A consecutive series of 106 patients with AMI-induced CS receiving ECLS was evaluated regarding ECLS weaning success, hospital mortality, and long-term outcome. The Intraaortic Balloon Pump in Cardiogenic Shock II (IABP-SHOCK II) risk score was applied, and multivariable Cox regression analysis was performed.**

Results. **Mean patient age was 58.2 ± 11.2 years, and 78.3% were men. In 34 patients (32.1%), ECLS was implemented during ongoing cardiopulmonary resuscitation. De novo AMI was present in 58 patients (54.7%), and percutaneous coronary intervention complications were causative among 48 patients (45.3%). Multivessel coronary artery disease was diagnosed among 73.6% with mean Synergy between PCI with Taxus and Cardiac Surgery (SYNTAX) scores of 30.8 ± 4.8. Actuarial survival was 54.4% at 30 days, 42.2% at 1 year, and 38.0% at 5 years and was significantly higher among patients with low and intermediate IABP-SHOCK II risk scores at ECLS onset (log-rank *P* = .017). ECLS weaning with curative intention after a mean perfusion time of 6.6 ± 5.1 days was feasible in 51 patients (48.1%) and more likely among patients with complete revascularization (*P* = .026). Multivariable Cox regression analysis identified complete revascularization (hazard ratio, 2.38; 95% confidence interval, 1.1 to 5.1; *P* = .028) and absence of relevant mitral regurgitation at ECLS discontinuation (hazard ratio, 2.71; 95% confidence interval, 1.2 to 6.0; *P* = .014) to be associated with beneficial long-term survival after ECLS discontinuation.**

Conclusions. **Emergency ECLS is a valuable option among patients with AMI-induced CS with low and intermediate IABP-SHOCK II risk scores. ECLS weaning is manageable, but additional revascularization of all nonculprit lesions is mandatory after ECLS implementation.**

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Cardiogenic shock (CS) develops in approximately 5% to 10% of patients with acute myocardial infarction (AMI), and out-of-hospital cardiac arrest occurs in 2% of these patients.[1] Recent epidemiologic investigations have found a decline in AMI deaths but not in incidence rates of AMI-related CS.[2]

The increasing use of venoarterial extracorporeal membrane oxygenation (va-ECMO) for extracorporeal life support (ECLS) in patients with profound CS offers several advantages. Rapid deployment can be performed percutaneously even during mechanical cardiopulmonary resuscitation (CPR) in the emergency department, and it provides sufficient hemodynamic support to further interventions.[3,4]

Emergency ECLS for many clinical indications is becoming increasingly frequent, but current studies with sufficient sample size to develop a staged interdisciplinary "heart-team" strategy to enhance both ECLS weaning and outcome in patients with AMI-induced CS are sparse.[5] Although ventricular assist device implantation has become an alternative in selected patients, current data from the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) registry demonstrate a deleterious prognosis for AMI patients with previous ECMO.[6]

Bridge-to-recovery by means of weaning from ECLS should therefore be the primary goal among patients with AMI-induced CS. Moreover, because most patients with ST-elevation AMI demonstrate coronary multivessel disease, multidisciplinary decision making seems to be warranted. Current data to guide intervention in patients with AMI are sparse and based on class III recommendations, meaning that the risk of treating nonculprit coronary lesions outweighs the benefit.[7] In contrast, less attention has been paid regarding surgical

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Abbreviations and Acronyms

AMI	=	acute myocardial infarction
CABG	=	coronary artery bypass grafting
CAD	=	coronary artery disease
CI	=	confidence interval
CPR	=	cardiopulmonary resuscitation
CS	=	cardiogenic shock
ECLS	=	extracorporeal life support
ECMO	=	extracorporeal membrane oxygenation
HR	=	hazard ratio
IABP	=	intraaortic balloon counterpulsation
IABP-SHOCK II	=	Intraaortic Balloon Pump in Cardiogenic Shock II
MELD	=	Model for End-Stage Liver Disease
NT-proBNP	=	N-terminal prohormone brain natriuretic peptide
PCI	=	percutaneous coronary intervention
SYNTAX	=	Synergy between PCI with Taxus and Cardiac Surgery
va-ECMO	=	venoarterial extracorporeal membrane oxygenation

revascularization. The Should We Emergently Revascularize Occluded Coronaries for Cardiogenic Shock (SHOCK) trial demonstrated improvement in 6-month survival in CS patients receiving complete revascularization; however, the study did not include timing of revascularization.[8]

No clear guidelines currently exist for the treatment of AMI CS patients undergoing ECLS as first-line treatment to improve ECLS weaning success. Therefore, the aim of this study was to investigate the prognostic outcome of patients with AMI and profound CS receiving emergency ECLS to identify independent predictors for successful ECLS weaning and reasonable long-term survival.

Material and Methods

A consecutive series of 106 patients with AMI and CS receiving va-ECMO in a "crash-and-burn" manner, according to INTERMACS 1 patient profile criteria, from 2000 to 2017 admitted at the Innsbruck Medical University was enrolled. During this period, 610 patients received ECMO, and 115 patients (18.9%) received vv-ECMO support for isolated respiratory failure. Exclusion criteria for this study were postcardiotomy failure and previous cardiac surgery within the past month.[9] AMI was defined according to current guidelines.[7] Permission to perform this study was obtained from the Innsbruck Medical University Institutional Review Board.

Study Definitions

Cardiogenic shock was defined according to the SHOCK trial[8] as a systolic blood pressure of less than 90 mm Hg or the need for vasopressor/inotropic agents, or both, to maintain a systolic blood pressure above 90 mm Hg, and signs of critical organ hypoperfusion with signs of centralization and reduced urine output or an arterial lactate level above 18 mg/dL.

Outcome evaluation regarding bridge-to-recovery, hospital mortality, and long-term outcome in patients was performed. Successful weaning was defined as successful weaning from any assist device, including va-ECMO, intraaortic balloon counterpulsation (IABP), and ventricular assist device.

Complete revascularization was defined as successful revascularization of all diseased segments with a diameter of 2.5 mm or larger at angiography.

The Synergy between PCI with Taxus and Cardiac Surgery (SYNTAX) score was calculated based on angiographic findings on admission using the calculator available online at http://www.syntaxscore.com/calculator/start.htm.

In addition, the very recently developed Intraaortic Balloon Pump in Cardiogenic Shock II (IABP-SHOCK II) score was applied for all patients from comorbid conditions, baseline laboratory findings, and interventional angiography/surgical revascularization.[10]

Hemodynamic and laboratory variables, together with vasopressor use and dosage at ECLS implantation, were recorded.

The aim was initial full flow (5-5.5 L/min) within the first 12 to 24 hours, and then we stimulated the heart to stroke and stepwise reduced flow within 3 to 5 days according to the recovery of biventricular function. In this phase, inotropic medication was administered. Flow reduction was accompanied by frequent transesophageal echocardiography guidance to validate the recovery potential of the heart. Anticoagulation strategy was monitored by activated clotting time of 180 to 200 seconds.

Cannula size was chosen according to the required body surface areas. Distal leg perfusion was implemented among all patients with open surgical insertion of ECMO and in most with percutaneous too. Only 3 patients did not receive a distal leg perfusion cannula due to failure of insertion. Since 2011, we have used near-infrared spectroscopy monitoring for all patients with femoral ECMO.

Statistical Analysis

Univariable analysis was used to assess clinical, hemodynamic, and laboratory indicators at the time of ECLS onset together with previous AMI history. Data are reported as mean ± SD or median (range) for continuous variables and as absolute numbers with percentages for categorical variables, as appropriate. Comparisons between groups were performed using the Student *t* test and the χ^2 test when appropriate.

Kaplan-Meier survival analysis and log-rank testing were performed to identify relevant prognostic variables associated with ECLS weaning and patient survival after successful ECLS weaning. Multivariable Cox regression analysis was performed among patients successfully weaned from ECLS devices to identify prognostic indicators for long-term survival. The corresponding hazards ratios (HRs) together with 95% confidence intervals (95% CIs) were calculated. P values lower than 0.05 were considered statistically significant.

Results

Figure 1 shows detailed patient presentation and therapeutic treatment among the 106 patients. Relevant clinical variables are presented in Table 1. The study included 83 men (78.3%) and 23 women (21.7%). Mean age was 58.2 ± 11.2 years. Underlying coronary multivessel disease was present in 73.5% of patients (73.5%). The anterior descending artery was the most common culprit lesion (43.4%), followed by AMI caused by occlusion of the right coronary artery (28.3%). The mean SYNTAX score at admission was 30.8 ± 4.8.

CPR was necessary in 44 patients (41.5%), and va-ECMO was implanted in 32.1% during ongoing CPR. Hospital mortality was 42.6% in patients with previous CPR and 41.2% in patients without CPR (P = .9). Long-term survival did not differ significantly between these groups (log-rank P = .70).

IABP before va-ECMO implantation was initiated in 33 patients (31.1%), and hospital mortality was significantly higher among patients receiving initial IABP instead of ECMO first (72.7% vs 47.9%, P = .026). There was no difference in patient groups regarding complete revascularization, so IABP placement was more likely to cause a delay of ECMO implementation rather than more incomplete revascularization (30.9% vs 30.8%, P = .98).

Coronary angiography was without possibility of intervention in 30 patients (28.3%). Emergent or urgent coronary artery bypass grafting (CABG) was performed in 29 patients (27.4%) during ECMO support. In 51 patients (48.1%), complete revascularization could be achieved by percutaneous coronary intervention (PCI) or CABG during ECLS support. Revascularization was completed within 1 PCI session in 19 patients, and a second PCI session during ECMO support was successfully performed in 3 patients to treat the nonculprit lesions too.

Mean duration of va-ECMO support was 6.1 ± 5.4 days in all patients. In 51 patients (48.1%), bridge-to-recovery was successful, 34 patients died on ECLS devices mainly due to severe multiorgan failure. Finally, 11 patients (10.4%) supported with ECLS devices survived to later heart transplantation. Most patients (75.3%) received dual vasopressor medication, and 65 patients (61.3%) were under inotropic support. All patients with Swan-Ganz catheter monitoring showed significant signs of congestion. In addition, severe acidosis was present in all patients, indicated by elevated lactate levels (62.9 ± 37.8 mg/dL).

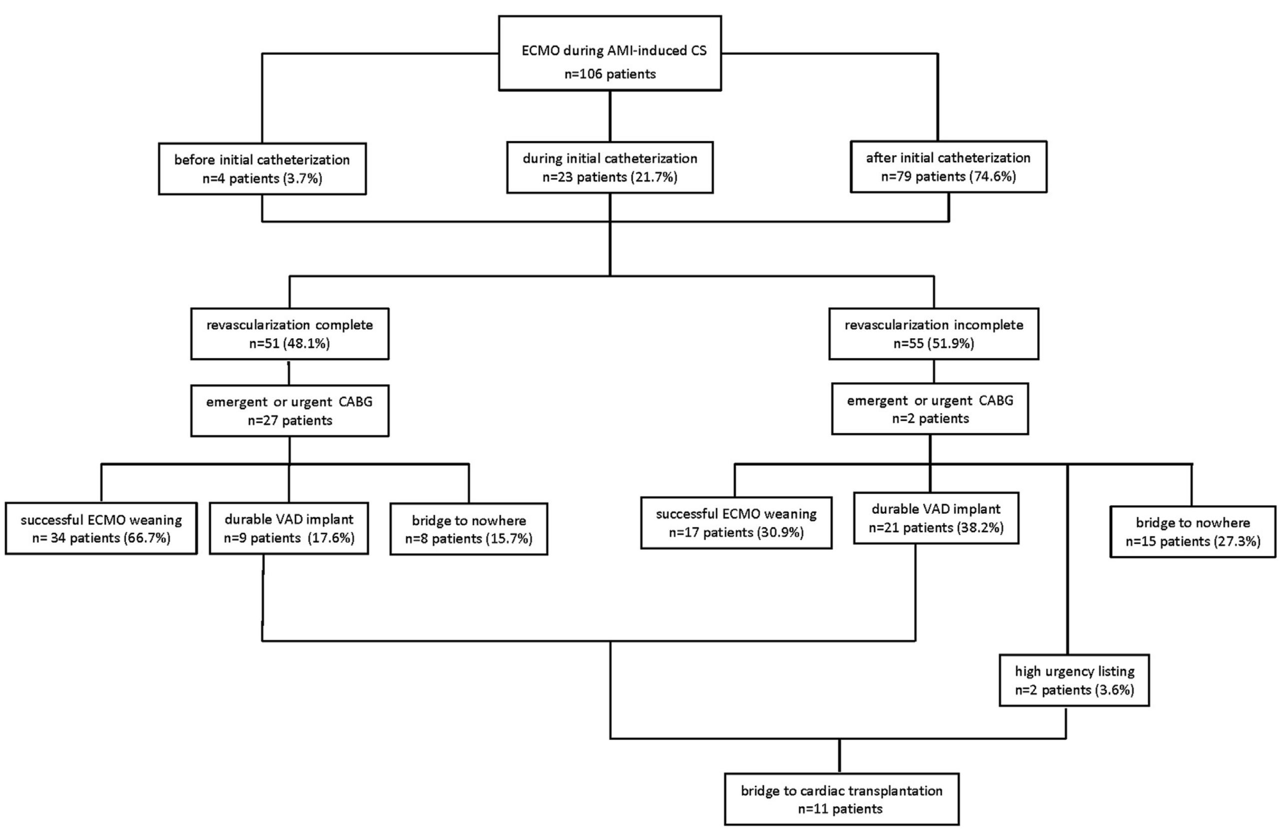

Figure 1. Flowchart displays patient presentation and therapeutic treatment. (AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; CS, cardiogenic shock; ECMO, extracorporeal membrane oxygenation; VAD, ventricular assist device.)

Table 1. Demographic Characteristics of Patients Receiving Mechanical Circulatory Support by Venoarterial Extracorporeal Membrane Oxygenation

Characteristics	Patients (n = 106)
Age, y	58.2 ± 11.2 (22-79)
Male sex	83 (78.3)
Body mass index, kg/m^2/body surface area	26.4 ± 3.9
Severity of coronary artery disease	
1-vessel disease	28 (26.4)
2-vessel disease	40 (37.7)
3-vessel disease	38 (35.8)
SYNTAX score	30.8 ± 4.8
CPR before va-ECMO	
Out of hospital	10 (9.4)
Catheterization laboratory	34 (32.1)
ECMO insertion during ongoing CPR	34 (32.1)
Culprit lesion	
Left main	24 (22.6)
Left anterior descending	46 (43.4)
Circumflex	6 (5.7)
Right coronary artery	30 (28.3)
IABP-SHOCK II score at ECLS onset	
Low (0-2)	28 (26.4)
Intermediate (3-4)	44 (41.5)
High (5-9)	34 (32.1)
Delay time from AMI onset to reperfusion, h	4.16 (0.42-749)
Door-to-balloon time, h	1.0 (0-52)
Intraaortic balloon support before ECMO	33 (31.1)
Cause of AMI	
De novo AMI	58 (54.7)
Acute stent thrombosis/iatrogenic dissection	17 (16.0)
Complications from previous PCI	31 (29.3)
Prior anticoagulant treatment	
None	10 (9.4)
Single-antiplatelet treatment	9 (8.5)
Dual-antiplatelet treatment	68 (64.1)
Lysis	19 (17.9)
Number of vasopressors at va-ECMO implant	
1	12 (11.3)
2	78 (73.6)
3	16 (15.1)
Inotropic medication before ECMO	65 (61.3)
Site of va-ECMO implantation	
Surgical operating room	73 (68.9)
Catheterization laboratory	23 (21.7)
Emergency department	4 (3.8)
Intensive care unit	6 (5.7)
Angiographic intervention performed	
Diagnostic only	30 (28.3)
Successful PCI	53 (50.0)
Failed PCI	23 (21.7)

(*Continued*)

Table 1. Continued

Characteristics	Patients (n = 106)
Surgical technique of va-ECMO insertion	
Percutaneous	53 (50.0)
Open	53 (50.0)
Complications resulting from femoral cannulation	13 (12.3)
Ischemia	6 (5.7)
Bleeding	6 (5.7)
Infection	1 (0.9)
Acute CABG during ECMO	29 (27.4)
Full cardiopulmonary bypass	19 (17.9)
Cardiopulmonary bypass time, min	91 ± 17
Cross-clamp time, min	58 ± 9
Beating-heart ECMO	10 (9.4)
Implantation of ventricular assist device	30 (28.3)
Completeness of revascularization	
Complete	51 (48.1)
Incomplete	55 (51.9)
Duration of ECMO support	6.1 ± 5.8 days
Successful weaning from ECMO	51 (48.1)
Central venous pressure, mm Hg	19.5 ± 5.5[a]
Cardiac index, L/min/m^2 body surface area	1.7 ± 0.44[a]
Systolic pulmonary artery pressure, mm Hg	43.9 ± 13.5[a]
Mean pulmonary artery pressure, mm Hg	30.1 ± 8.7[a]
Mean arterial blood pressure, mm Hg	61.5 ± 12.5
Pulmonary capillary wedge pressure, mm Hg	22.8 ± 6.0[a]
Creatinine kinase, U/L	2095.6 ± 3590.3
Troponin T, ng/L	9466.0 ± 2458.3
Lactate dehydrogenase, U/L	1729.7 ± 406.9
NT-proBNP, ng/L	8267.2 ± 763.1
Lactate, mg/dL	62.9 ± 37.8
Base excess, mmol/L	−7.3 ± −4.6
Creatinine, mg/dL	1.7 ± 0.8
Alanine aminotransferase, U/L	456.1 ± 843.4
Aspartate aminotransferase, U/L	929.3 ± 2099.8
Gamma-glutamyl transferase, U/L	86.7 ± 92.4
MELD score	13.9 ± 6.0

[a]Data are presented for 82 patients with Swan-Ganz catheter monitoring at ECLS implementation.

Data are presented as n (%) or mean ± SD (range).

AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; CPR, cardiopulmonary resuscitation; ECLS, extracorporeal life support; ECMO, extracorporeal membrane oxygenation; IABP-SHOCK II, Intra-aortic Balloon Pump in Cardiogenic Shock II; MELD, Model for End-Stage Liver Disease; NT-proBNP, N-terminal prohormone brain natriuretic peptide; PCI, percutaneous coronary intervention; SYNTAX, Synergy between PCI with Taxus and Cardiac Surgery; va-ECMO, venoarterial extracorporeal membrane oxygenation.

Figure 2 displays the actuarial overall survival of the entire study population: 30-day survival was 54.4%, survival after 1 year was 42.2%, and 38.0% of patients were alive at 5 years. Figure 3 shows the survival of patients who could successfully be weaned from ECLS according to the completeness of revascularization (log-

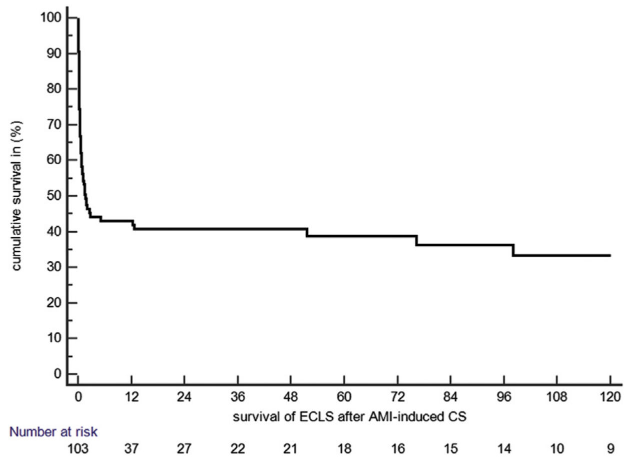

Figure 2. Kaplan-Meier survival analysis shows overall survival in months of all patients receiving venoarterial extracorporeal membrane oxygenation in acute myocardial infarction (AMI)–induced cardiogenic shock (CS) regardless of extracorporeal life support (ECLS) weaning. Overall survival at 30 days, 1 year, and 5 years was 54.4%, 42.2%, and 38.0%, respectively

rank $P = .001$). The survival rates of patients stratified according to the IABP-SHOCK II score are displayed in Figure 4 and showed significant survival benefit in patients with low- and intermediate- vs high-risk at ECLS implementation (log-rank $P = .017$).

Complete revascularization could be achieved in 51 patients (48.1%) and was significantly higher among patients receiving CABG (93.1% vs 31.2%, $P < .001$).

The severity of coronary artery disease (CAD) had no significant effect on ECLS weaning success ($P = .28$) or long-term survival ($P = .74$). Furthermore, the territory of the culprit lesion was not associated with successful ECLS weaning ($P = .78$) or hospital mortality ($P = .73$).

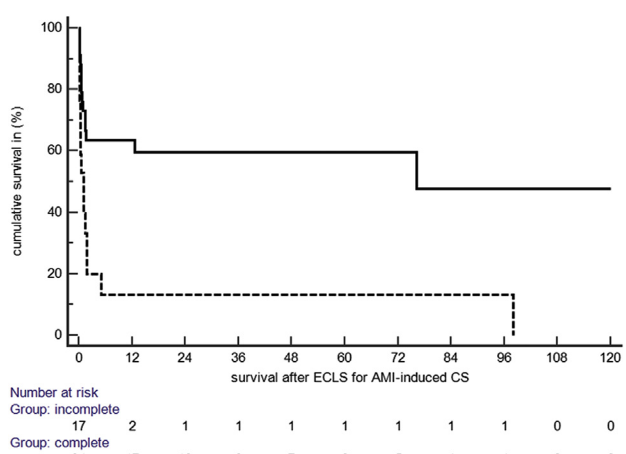

Figure 3. Kaplan-Meier survival analysis shows overall survival in months of the 51 patients who were successfully weaned from extracorporeal life support (ECLS). Complete (solid line) vs incomplete revascularization (dashed line). Log rank P < .001. (AMI, acute myocardial infarction; CS, cardiogenic shock.)

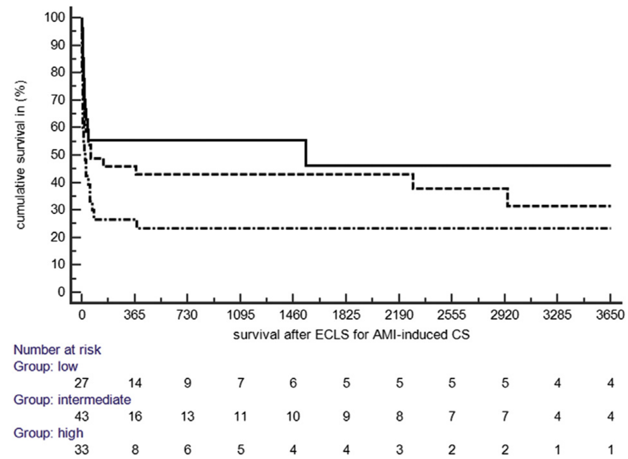

Figure 4. Kaplan-Meier survival analysis shows overall survival in months of patients receiving extracorporeal life support (ECLS) in acute myocardial infarction (AMI)–induced cardiogenic shock (CS): Comparison of outcome according to the Intraaortic Balloon Pump in Cardiogenic Shock II (IABP-SHOCK II) score: low risk (solid line), intermediate risk (dashed line), high risk (intermittent line). Log rank P = .017 for low and intermediate risk vs high risk.

Analysis of Variables Associated With Long-term Survival After ECLS Weaning

Multivariable age-adjusted Cox regression analysis was performed among 51 patients successfully weaned from ECLS to identify independent predictors for long-term survival. Univariate analysis showed IABP insertion before ECMO implantation (log-rank $P = .20$), previous PCI (log-rank $P = .34$), first AMI vs reinfarction (log-rank $P = .24$), and severity of CAD (log-rank $P = .71$) or ECLS insertion during CPR (log-rank $P = .75$) did not influence post-ECLS survival.

Completeness of revascularization (log-rank $P = .001$) and relevant mitral regurgitation (grade 2+; log-rank $P = .002$) were identified at univariate analysis to influence long-term survival after ECLS discontinuation.

After adjustment for age (HR, 0.99; 95% CI, 0.96 to 1.03; $P = .78$), multivariable Cox regression analysis identified previous complete revascularization (HR, 2.38; 95% CI, 1.1 to 5.1; $P = .028$) and absence of relevant mitral regurgitation at ECLS discontinuation (HR, 2.71; 95% CI, 1.2 to 6.0; $P = .014$) were associated with beneficial long-term survival.

Comment

ECLS by emergency ECMO has become a standard treatment in profound CS for a wide heterogeneity of causes; however, AMI-induced CS as an indication is still associated with high morbidity and mortality.[11] Weaning from ECLS was possible among almost half of our patients, but secondary mortality after weaning was high. However, the results of our study clearly showed that patients in AMI-induced CS who received complete revascularization were significantly more likely to be weaned from ECLS and survive with a reasonable long-term prognosis. However, among patients weaned from ECLS, relevant mitral regurgitation at ECLS discontinuation was an independent predictor for further dismal outcome.

Contrarily to our initial belief, neither the severity of CAD nor the territory of the culprit lesion had an effect on later ECLS weaning success. "No-reflow" phenomenon was not associated with any weaning success from ECMO even in underlying single-vessel disease.

This large outcome evaluation investigating the merit of ECLS is based on a homogenous patient population, and our study does not include other acute and chronic etiologies of CS.[12-14]

Current studies of ECLS show insufficient sample size to develop a real treatment algorithm for patients with AMI-induced profound CS. The increasing emergency need for ECLS within the catheterization laboratory during recent years bonding limited health care resources to patients with questionable hope of any survival encouraged us to perform a study like this.[15]

More recently, the IABP-SHOCK II risk score was derived from the data of the IABP-SHOCK II trial including 6 variables as independent predictors for 30-day mortality among patients with CS.[10] This risk stratification score included a Thrombolysis In Myocardial Infarction grade flow of less than 3 after PCI. This is in high concordance with our findings that incomplete revascularization and remaining "no-reflow phenomenon" was negatively associated with both ECLS weaning and survival. Furthermore, outcome was similar among our patients according to the IABP-SHOCK II risk score groups irrespective of the severity of underlying CAD and shows that patients with a low- or intermediate-risk score may profit from ECLS.

Current guidelines by the European Society of Cardiology/European Association for Cardio-thoracic Surgery recommend CABG in patients with CS with coronary anatomy not amenable to PCI.[16] CABG in AMI-induced CS on ECLS devices, however, is infrequently performed because the risks associated with surgery are increased in this setting.[17] Our data, however, clearly demonstrate that in the absence of sufficient reperfusion or lesions unsuitable for PCI, CABG should be performed under the assistance of ECMO support to enhance both ECLS weaning success and long-term prognosis.

Prolonged end-organ ischemia aggravating to irreversibility even after left ventricular decompression is the major cause of death during ECLS among all causes of CS. Therefore, the use of IABP in the forefront of va-ECMO in profound CS may only prolong the exposure of end organs, such as the liver and kidney, to irreversibility.[9,18]

Demondion and colleagues[19] investigated the outcome of CS patients with AMI necessitating ECLS in a similar cohort consisting of 77 patients. ECLS weaning success was only 24% compared with 48.1% in our study. Emergency PCI was performed in 75.3%; however, there was no information about the complexity of lesions or completeness of revascularization. Another study from Germany identified high lactate, impaired kidney function, and previous CPR as independent predictors for hospital mortality, and the authors concluded end-organ ischemia was the most limiting factor in the treatment of these patients.[20]

Most patients in CS show signs of ongoing renal and hepatic failure. Moreover, in a recent study, we identified antithrombin III to be a potent marker for hepatic reserve in patients with CS undergoing ECMO support.[9] Antithrombin III depletion below a cutoff value of 60% was associated with dismal prognosis regarding irreversible hepatic failure. In a registry study, a special score was developed to predict survival probability after ECMO implantation.[21] The initial survival rate was 42% and was similar to our study cohort, which consisted of AMI patients only. Moreover, AMI was identified for a worse outcome after ECMO implantation beside impaired renal and hepatic function.

CPR was not associated with hospital mortality or long-term survival in our study. Because most of our CPR patients experienced "witnessed death" in the catheterization laboratory, the immediate application of professional bystander CPR may be taken into account.[22] This suggests that when CS develops from de novo AMI, patients can have a good result even after CPR. Moreover, systemic hypothermia was routinely performed within 24 hours after a witnessed cardiac arrest.[15,23] Another propensity score–matched study among 162 patients investigated extracorporeal-assisted and conventional CPR.[24] They concluded a more than 3-fold higher neurologically intact survival rate among patients undergoing extracorporeal-assisted CPR (29.2% vs 8.3%, $P = .018$).

In our study, 29 patients received emergent or urgent CABG after va-ECMO implantation as a salvage procedure aiming complete revascularization. Hospital survival was 68.2%, and 1-year survival was 59.1%. Acharya and colleagues[25] reported a 53.3% perioperative mortality rate and a high rate of postoperative complications. However, patients receiving emergent or urgent CABG showed significantly better survival than patients with incomplete PCI, and this further underlines the concept of complete revascularization in AMI patients with CS.

Very recently, Thiele and colleagues[26] published the results from the Culprit Lesion Only PCI versus Multivessel PCI in Cardiogenic Shock (CULPRIT-SHOCK) investigators. They concluded that among patients with multivessel disease and AMI with CS, the 30-day risk of a composite of death or severe renal failure was lower in patients who initially received PCI of the culprit lesion only compared with multivessel PCI.[26] These results are in opposition to our findings; however, we are confident that patients being randomized to a trial like this may not suffer from a profound stage of CS. Moreover, ECLS implementation was the first treatment of choice to enable sufficient coronary interventions at all. More than 70% of patients in the CUPRIT-SHOCK trial received mechanical circulatory support devices with no information about whether the support was implemented before PCI treatment or as a result of hemodynamic instability after PCI interventions.

Emergency ECLS enables us to gain time for a decision on further treatment, and the results of our investigation has significant effect on our future therapeutic strategy in AMI-induced CS based on following concepts: First, never waste valuable time in CS by IABP to minimize the risk for irreversible end-organ ischemia.[9,14] Second, after implementation of ECLS, revascularization has to be completed by treating all nonculprit lesions, too, irrespective of CAD severity or type of revascularization. Third, if we want to create real survivors instead of producing victims, we should consider early prevention of left ventricular distension during ECLS.[27]

This study has several limitations. First, the retrospective character of this investigation cannot completely rule out possible confounding bias. Second, the long observation period and the achievements in interventional cardiology and cardiac surgery as well as the upcoming routine of emergency ECMO implantation have to be taken into account. In conclusion, emergent or urgent CABG on va-ECMO should still be considered in CS patients to obtain complete revascularization. We further cannot control the fact that complete revascularization was not attempted in many patients, especially in the earlier phase of our experience.

Complete revascularization is recommended, enhancing both ECLS weaning success and long-term survival irrespective of severity of underlying CAD. No-reflow phenomenon is not associated with any ECLS weaning success even in underlying single-vessel disease among AMI patients with profound CS. It underscores the concept that revascularization by PCI or CABG is a must, and if not technically feasible or failed, rapid escalation to advanced surgical therapies is required. The results of our study have encouraged us to aim for complete revascularization by PCI or CABG within the same setting in patients with AMI-induced CS.

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INVITED COMMENTARY

In this issue of *The Annals of Thoracic Surgery*, Wagner and colleagues[1] report single-institution results of veno-arterial (V-A) extracorporeal membrane oxygenation (ECMO) in the treatment of cardiogenic shock (CS) resulting from acute myocardial infarction (AMI). The patient population was a series of 106 patients with AMI and resultant CS (AMI with CS), all of whom were supported using V-A ECMO. A majority of patients presented with multisystem coronary artery disease and with a mean SYNTAX score of 31, and 42% of patients underwent cannulation for V-A ECMO in the setting of cardiopulmonary resuscitation.

Overall 30-day survival was 54%, consistent with published outcomes for the AMI with CS subset of patients undergoing V-A ECMO; cardiopulmonary resuscitation status was not associated with differential survival, in contrast to other published data. Complete revascularization, defined as revascularization of all coronary arteries with luminal diameters of 2.5 mm or greater, was achieved in approximately 50% of patients. Moreover, coronary artery bypass grafting (CABG) achieved outcomes far superior to those observed with percutaneous coronary intervention. Of the 106 patients, 29 underwent CABG; revascularization was complete in 93% of these 29 patients. In contrast, of the 76 patients who underwent initial percutaneous coronary intervention (some of whom crossed over to CABG), only 31% had complete revascularization. Completeness of revascularization and the absence of significant mitral valve regurgitation were associated with improved outcomes. Finally, eventual left ventricular (LV) assist device (LVAD) implantation was performed in 30 patients (28% of the group), and heart transplantation was performed in 11 patients (10% of the group).

It is strikingly clear that because the heart is an organ with minimal intrinsic regenerative capacity, the consequences of large-territory AMI are dire. There are essentially 2 broad approaches to treatment of AMI with CS: (1) preservation of viable myocardium, such that native LV function is sufficient to allow weaning of the patient from mechanical circulatory support (MCS) and inotropes; and (2) durable artificial (MCS) or biologic (heart transplantation) replacement of LV function. In this context, rapid, thorough, and effective revascularization is essential to preserve native LV function. Failure to do so places the patient along the second therapeutic path of a durable LV replacement strategy.

This study prompts additional questions. Which, if any, short-term MCS strategy is best in patients with AMI with CS? The physiologic features of V-A ECMO and left-sided MCS, using either left atrial or LV inflow, are substantially different. However, this may or may not translate to differential clinical outcomes. Wagner and colleagues[1] did not conduct a comparative study. Second, is the AMI with CS subset of patients meaningfully different with respect to the philosophy of revascularization, in comparison with patients with AMI who do not have CS? In the latter group, several studies demonstrated improved (or at least noninferior) outcomes with a selective revascularization strategy of culprit lesions alone. However, in this study by Wagner and colleagues,[1] the majority of patients had important multisystem disease, and thus, a selective strategy very well may have been inappropriate. Third, this study is one of many showing that CABG in particular displays the greatest benefits in the sickest patients, particularly relative to the natural history. Should we embrace salvage CABG at greater rates? Fourth, even in patients whom we intend to treat with revascularization, may there be a benefit to concomitant durable LVAD implantation to enhance LV recovery, after which delayed LVAD explantation may be performed? Further studies await us.

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