Catheterization and Cardiovascular Interventions 78:540–548 (2011)

The Ability to Achieve Complete Revascularization Is Associated with Improved In-hospital Survival in Cardiogenic Shock due to Myocardial Infarction: Manitoba Cardiogenic Shock Registry Investigators

Farrukh Hussain,[1*] MD, Roger K. Philipp,[1] MD, Robin A. Ducas,[2] MD, Jason Elliott,[2] MD, Vladimír Džavík,[3] MD, Davinder S. Jassal,[1] MD, James W. Tam,[1] MD, Daniel Roberts,[4] MD, Philip J. Garber,[1] MD, and John Ducas,[1] MD

Objectives: To identify predictors of survival in a retrospective multicentre cohort of patients with cardiogenic shock undergoing coronary angiography and to address whether complete revascularization is associated with improved survival in this cohort. **Background:** Early revascularization is the standard of care for cardiogenic shock. Coronary bypass grafting and percutaneous intervention have complimentary roles in achieving this revascularization. **Methods:** A total of 210 consecutive patients (mean age 66 ± 12 years) at two tertiary centres from 2002 to 2006 inclusive with a diagnosis of cardiogenic shock were evaluated. Univariate and multivariate predictors of in-hospital survival were identified utilizing logistic regression. **Results:** ST elevation infarction occurred in 67% of patients. Thrombolysis was administered in 34%, PCI was attempted in 62% (88% stented, 76% TIMI 3 flow), CABG was performed in 22% (2.7 grafts, 14 valve procedures), and medical therapy alone was administered to the remainder. The overall survival to discharge was 59% (CABG 68%, PCI 57%, medical 48%). Independent predictors of mortality included complete revascularization ($P = 0.013$, OR = 0.26 (95% CI: 0.09–0.76), hyperlactatemia ($P = 0.046$, OR = 1.14 (95% CI: 1.002–1.3) per mmol increase), baseline renal insufficiency ($P = 0.043$, OR = 3.45, (95% CI: 1.04–11.4), and the presence of anoxic brain injury ($P = 0.008$, OR = 8.22 (95% CI: 1.73–39.1). Within the STEMI with concomitant multivessel coronary disease subgroup of this population ($N = 101$), independent predictors of survival to discharge included complete revascularization ($P = 0.03$, OR = 2.5 (95% CI: 1.1–6.2)) and peak lactate ($P = 0.02$). **Conclusions:** The ability to achieve complete revascularization may be strongly associated with improved in-hospital survival in patients with cardiogenic shock.

Key words: cardiogenic shock; revascularization; renal insufficiency; lactate

INTRODUCTION

Cardiogenic shock complicates 7–10% of myocardial infarctions (MI) with mortality rates historically being between 70 and 80% [1]. The landmark SHOCK trial demonstrated in a randomized fashion, the benefits of emergent revascularization versus initial medical stabilization in cardiogenic shock patients with a significant reduction in mortality at 6 months, and up to 10 years [1–4]. On the basis of the SHOCK Trial result, early revascularization became a class I indication for cardiogenic shock patients under the age of 75 as per the

[1]Section of Cardiology Dept. of Cardiac Sciences, University of Manitoba, Winnipeg, Manitoba, Canada
[2]Section of Internal Medicine, Dept. of Medicine, University of Manitoba, Winnipeg, Manitoba, Canada
[3]Division of Cardiology, Peter Munk Cardiac Centre, University Health Network, Toronto, Ontario, Canada
[4]Section of Critical Care, Dept. of Medicine, University of Manitoba, Winnipeg, Manitoba, Canada

Conflict of interest: None of the authors/spouses/families have any conflict of interest, product of financial with regards to this study.

*Correspondence to: Farrukh Hussain, MD, FRCP, Department of Cardiology, St. Boniface General Hospital, 409 Tache Avenue, Winnipeg, Manitoba, Canada R2H-2A6. E-mail: fhussain@sbgh.mb.ca

Received 17 January 2011; Revision accepted 20 January 2011

DOI 10.1002/ccd.23006
Published online 5 May 2011 in Wiley Online Library (wileyonlinelibrary.com)

ACC/AHA guidelines [5]. Although this benefit was not observed in a prespecified subgroup of patients aged ≥75 years, a subsequent analysis of the SHOCK registry demonstrated that this benefit may persist for patients over 75 years of age, despite a worse outcome in elderly patients in the SHOCK trial itself [6,7]. This led to a change in recommendation for revascularization in the elderly in cardiogenic shock in the ACC/AHA 2004 guidelines [7].

The degree of revascularization that should be performed at the time of the initial procedure in the setting of cardiogenic shock is unclear. While routine complete revascularization in the setting of AMI remains controversial, in the setting of AMI complicated by cardiogenic shock data is limited [8–10]. The purpose of this study was to examine whether the ability to achieve complete revascularization in patients with cardiogenic shock complicating AMI is associated with a higher survival rate. In addition, we aimed to study the association of novel markers with outcomes in this setting, in addition to those previously described [11–18].

METHODS

Study Population

A retrospective analysis was performed of all consecutive patients with cardiogenic shock due to myocardial infarction (MI) undergoing cardiac catheterization during the same admission from September 2002 to September 2006 at two tertiary care centers in Winnipeg, Manitoba, Canada. All patients with the diagnosis of cardiogenic shock were identified from our tertiary intensive care unit (ICU) database. The total population included 210 patients who met prespecified criteria for cardiogenic shock.

Cardiogenic shock was defined as clinical evidence of tissue hypoxia in the presence of adequate intravascular volume and sustained major hypotension (systolic blood pressure <90 mm Hg for at least 30 min, or the need for supportive measures to maintain a systolic blood pressure of ≥90 mm Hg) in the absence of significant bradyarrhythmia or tachyarrhythmia.

Data Collection

The study was approved by the university and hospital research ethics boards. Information collected included the following: demographics, risk factors, previous revascularization procedures, hemodynamic data, echocardiographic data, ECG parameters, coronary anatomy, multiple PCI parameters (primary, rescue, salvage, stent number, length, type, pre- and post-TIMI flow, slow flow, culprit lesion location, PCI success, sheath size, and anticoagulation), intra-aortic balloon pump use, CABG parameters (pump time, number of grafts, cardioplegia, and concomitant valvular surgery details), pre- and post-revascularization bloodwork (CK, troponin, CBC, renal function, lactate, blood gas, electrolytes, and coagulation parameters), drug administration, complications and outcomes.

Definitions

Complete revascularization was defined as successful revascularization of all major vessels (LAD, RCA, and CX) and any branch vessels ≥2.5 mm with ≥70% stenoses. Multivessel coronary disease was defined as ≥2 main (LAD or RCA or CX) vessels with ≥70% stenoses. Oliguria was defined as urine output ≤30 cc/hr postprocedure. Anoxic brain injury (ABI) was noted if documented in the chart as such by the intensivist and/or CT brain evidence of ABI with a clinical agreement note. Rescue PCI was defined as PCI performed post thrombolysis within 12 hr of symptom onset. A successful PCI was defined as residual stenosis ≤20% with TIMI 3 flow in all intervened lesions/vessels. Successful stenting was defined as successful delivery and deployment of a stent with ≤20% residual stenosis without accounting for TIMI flow. Slow flow was defined as TIMI ≤ 2 flow in the intervened vessel. Baseline renal insufficiency was defined as CrCl < 60 ml/min. Creatinine clearance was calculated using the standard Cockgroft-Gault equation (CrCl = (140 − Age) × wt (kg) × F}/(Plasma Creatinine × 0.8136), where F = 1 if male and 0.85 if female). ST segment deviation (elevation or depression) was manually measured to the nearest 0.5 mm from the J-point relative to the TP segment in each lead 80 msec after the J point. Resolution of ST segment deviation was determined by comparing the sum of ST segment deviation in all leads except aVR within 24 hr post-angiography and the sum of ST segment deviation (worst ECG) prior to therapy. Ejection fraction (EF) was quantified using standard two-dimensional echocardiography or left ventriculography, whichever was available closer to index catheterization. A set timing for echocardiography was not present since this was a retrospective analysis, and this could include pre- or post-revascularization studies. Angiographic, TIMI flow and procedural success analysis was performed by local angiographic operators according to aforementioned set criteria; there was no core lab available for analysis. The decision for PCI or CABG was at the operator's discretion, given this was a retrospective analysis. SHOCK trial recommendations for revascularization modality were available and known to all operators. When multivessel PCI was performed, it was largely (21/22 patients) performed in the same setting, not as a staged procedure.

TABLE I. Demographics/Baseline Characteristics

Parameter	Number (total $N = 210$), (%)
Mean age (years ± SD)	66 ± 12
Gender (male)	142 (68)
Mean body mass index (± SD)	28.4 ± 5.3
Prior MI	63 (31)
Prior CABG	9 (4)
Prior PCI	17 (8)
Shock on admission	48 (23)
STEMI	140 (67)
NSTEMI	70 (33)
Diabetes	81 (39)
Hypertension	125 (60)
Dyslipidemia	94 (45)
Current smoker	57 (27)
Smoker ever	110 (52)
Transfer patients	143 (68)
Renal insufficiency (CrCl < 60 ml/min)	64 (30)
Prior clinical CHF	41 (20)

Statistical Analysis

Descriptive statistical methods were used to summarize data. Logistic regression models were used to identify univariate and multivariate predictors of survival to hospital discharge. Independent groups T-test was used to compare population means. The Z-score test was used to perform proportion comparisons. All two-sided P values <0.05 were considered significant. All univariate predictors of mortality with P value <0.05 were included into a stringent multivariable model to prevent model instability given our moderate sample size. SAS® version 9.1.2 software was utilized to perform all analyses. The medical therapy group was included in the incomplete revascularization group since these patients comprised an intent to revascularize cohort, therefore intention to treat methodology was utilized.

For further rigour, a subgroup analysis of the STEMI with concomitant multivessel CAD cohort ($N = 101$) was performed to identify univariate and multivariate predictors of survival to hospital discharge and to investigate whether complete revascularization remained associated with survival in this subgroup. Logistic regression was utilized here with stringent P-value <0.05 considered to be significant.

RESULTS

Study Population

A total of 210 patients were registered (mean age 66 ± 12 years) with 142 (68%) being male and risk factors as detailed in Table I. Sixty patients (29%) were aged ≥75 years. Baseline renal insufficiency was present in 64 patients (30%). A minority of patients had a history of prior CABG (4%), prior PCI (8%), and CHF (20%). The majority (68%) of patients were transferred from other centers. ST elevation infarction was present in the majority (67%) of patients (Table I). Thrombolysis was administered in approximately one-half of all ST elevation myocardial infarctions (71/140, 51%). Overall survival was 59% (123/210 patients) with a 76% (74/98 patients) survival in the completely revascularized cohort versus a 44% (49/112 patients) survival in the incompletely revascularized cohort.

Hemodynamics/Echo

Pulmonary artery (PA) catheterization was performed in 166 patients (79%). Average highest recorded pulmonary capillary wedge pressure was 28 ± 7 mm Hg and lowest cardiac index averaged 1.6 ± 0.4 L/min/m^2. Average highest recorded mean PA pressure was 42 ± 10 mm Hg. Echocardiography was performed in 150 patients (71%) (timing of echocardiogram not standardized, all performed after initial catheterization however), an additional 22 patients had left ventriculogram available (10%) for a total of 172 patients with available LV function (82%). LV function was not available for 38 patients (18%) because of inadequate echo images, unquantifiable EF, patient death prior to echocardiography and lack of left ventriculography due to patient instability. Results included the following: LV end diastolic diameter of 5.27 ± 0.8 cm (53 ± 1 mm), LV end systolic diameter of 4.02 ± 1.03 cm, LV ejection fraction of 36% ± 15%, and left atrial diameter of 4.2 ± 0.69 cm (42 ± 1 mm).

Anatomy/Therapy/Course

The majority (51%) of patients had three-vessel disease, while left main stenosis ≥50% was present in a significant minority (17%) (Table II). Of the 210 patients, PCI was performed in 131 (62%) and CABG in 47 (22%), both CABG and PCI in 8 (4%) and medical therapy alone was utilized in 40 (19%). Intra-aortic balloon pump support was utilized in most (71%) patients (Table II). Mean time from symptom onset to PCI was 24 ± 49 h and mean time to CABG was 88 ± 113 hr (Table II). Overall survival to hospital discharge was 59% (123 patients). Mean length of total hospital stay was 16 days with one-half of the stay in the intensive care unit.

PCI Cohort (131 Patients)

Mean age for the cohort was 65 ± 12 years. Primary or rescue PCI was performed in the majority (110/131, 84%) of patients with delayed PCI (>12 hr from symptom onset) in a minority (16%). Successful stenting was performed in 88% and successful PCI (successful stent + TIMI 3 Flow) in 76%. Multivessel PCI was performed in 22 patients (17%). Glycoprotein IIb/IIIa

TABLE II. Therapy/Course/Anatomy

Parameter ($N = 210$ unless otherwise stated)	Number (%)
PCI	131 (62)
CABG	47 (22)
PCI+CABG (included in above)	8 (4)
Medical	40 (19)
PA catheter	166 (79)
IABP	150 (71)
Vasopressors/inotropes	207 (99)
Mean number of inotropes/vasopressors	2.8 ± 1.3
Time to catheterization	33.8 ± 59.6 h
Time to POBA	23.8 ± 48.5 h
Time to CABG	87.6 ± 112.5 h
One vessel disease	44 (21)
Two vessel disease	58 (28)
Three vessel disease	107 (51)
Left main ≥50% stenosis	35 (17)
Primary PCI ($N = 131$)	58 (44)
Successful stenting ($N = 131$)	115 (88)
Successful PCI ($N = 131$)	99 (76)
Multivessel PCI ($N = 131$)	22 (17)
Mean stent length	29 ± 17 mm
Mean no. of stents/patient	1.37 ± 0.99
Slow Flow (TIMI ≤ 2)	23 (18%)
GPIIbIIIa use	101 (77)
Mean no. of grafts ($N = 47$)	2.7 ± 1
Concomitant valve surgery ($N = 47$)	14 (30)
LITA graft ($N = 47$)	21 (45)

TABLE III. Complications and Outcomes

Parameter ($N = 210$ unless otherwise specified)	Number (%)
Overall in-hospital survival	123 (59)
PCI group survival ($N = 131$)	75 (57)
CABG group survival ($N = 47$)	32 (68)
Medical group survival ($N = 40$)	19 (48)
Complete revascularization	98 (47)
Stroke	5 (2)
Anoxic brain injury	21 (10)
Ischemic limb	5 (2)
New dialysis	14 (7)
Transfusion	120 (57)
Sepsis	41 (20)
Ventricular septal rupture	4 (2)
Free wall rupture	1 (0.5)
Severe mitral regurgitation	12 (6)
Mechanical ventilation prior to lab	110 (52)
Coronary dissection ($N = 131$)	6 (5)
Stent thrombosis ($N = 130$)	3 (2)
Ventricular assist device/transplant referral	3 (1)
Length of stay hospital (days)	16.1 ± 21.8
Length of stay ICU (days)	8.2 ± 3.8
ST segment deviation resolution ≥50%	124 (59)
Peak CK level (U)	3736 ± 3703
Peak lactate ($N = 130$)	5.7 ± 5.4
Oliguria	159 (76)

inhibitor use was high (77%). Acetylsalicylic acid was used in 93%, and clopidogrel was used in 89% of patients undergoing PCI. Mean total stent length was 29 ± 17 mm. Bifurcation angioplasty was performed in 20%. Slow flow occurred in 18% of patients with PCI. Coronary dissection occurred in a small minority (5%) of patients with stent thrombosis occurring during index admission in 3 patients (Table III). Complete revascularization was achieved in 45% of the PCI cohort. Survival in the attempted PCI cohort was 57%. Eight patients in this cohort required additional same admission CABG (these were treated as patients with CABG).

CABG/Surgical Cohort (47 Patients)

The average number of vessels bypassed was 2.7 ± 1 with 45% of patients receiving a left internal mammary graft and 14/47 patients (30%) undergoing concomitant valve surgery (Table II). Mean age for this cohort was 65 ± 9.4 years. Mean perfusion time was 136 ± 65 min, and mean cross-clamp time was 79 ± 49 min. Complete revascularization was achieved in 94% of patients. In hospital survival in the overall CABG cohort was 68%. Upon further analysis of the CABG cohort, there was 76% versus 50% survival for the CABG alone ($N = 33$) versus CABG + valve ($N = 14$) groups ($Z = 1.39$, NS), trending to but not achieving significance. The concomitant valve surgical procedures consisted of nine mitral valve replacements, two mitral valve annuloplasty rings, and three aortic valve replacements. Of these, all aortic valve surgery patients died, four of nine mitral valve replacement patients died and both mitral ring annuloplasty patients survived. Of the four ventricular septal rupture patients, two underwent repair with one survivor, and both of the unrepaired ventricular septal rupture patients died.

Medical Therapy Cohort (40 Patients)

Within the medical therapy cohort, 23/40 patients (58%) were over 75 years of age with a mean age of 70 ± 12.4 years and the majority had non-ST elevation infarctions (32/40, 80%). Thrombolysis was administered in 7/40 patients (18%) and an intra-aortic balloon pump was utilized in 16/40 patients (40%). Reasons for not receiving revascularization included: diffuse/distal coronary disease not amenable to revascularization (14 patients), patient refusal (2 patients), noncardiac comorbidity in 11 patients (including sepsis, established multiorgan failure, severe bleeding, renal failure, dementia, stroke, and metastatic carcinoma), cardiac comorbidity in 5 patients (including ventricular septal rupture, ruptured papillary muscle, and severe aortic stenosis), prohibitive surgical risk by surgical assessment (6 patients) and noncritical disease (2 patients). Survival in the medically managed cohort was 49%.

TABLE IV. Univariate Parameters Tested for Predictors of In-hospital Mortality

Parameter	*P*-value	Odds ratios for significant parameters (95% CI for OR)
Age	0.09	1.02 (0.997–1.05) per year
Age ≥75 years	0.06	1.79 (0.98–3.29)
Gender (M)	0.08	1.67 (0.94–3.01)
LV ejection fraction ($N = 150$)	0.35	0.53 (0.14–1.98)
Attempted PCI ($N = 130$)	0.62	1.16 (0.65–2.04)
CABG	0.14	0.59 (0.3–1.18)
LAD culprit	0.59	1.17 (0.66–2.05)
IABP use	0.56	1.2 (0.65–2.21)
STEMI	1.0	N/A
Thrombolysis	0.31	0.74 (0.41–1.33)
Diabetes	0.95	1.02 (0.58–1.8)
Time to catheterization	0.83	1.001 (0.996–1.005) per hour increase
Transfusion	0.63	0.87 (0.5–1.52)
Presence of new severe mitral regurgitation	0.72	1.23 (0.4–3.79)
Three vessel disease	0.016	1.99 (1.14–3.48)
Anoxic brain injury	0.0006	7.23 (2.34–22.33)
Oliguria post procedure	0.0012	3.53 (1.65–7.55)
Baseline renal insufficiency	<0.0001	3.51(1.9–6.5)
Hyperlactatemia	<0.0001	1.21 (1.1–1.33) per mmol increase
Lowest cardiac index	<0.0001	0.12 (0.05–0.3)
Presence of ST deviation resolution ≥50%	0.0042	0.39(0.2–0.74)
Complete revascularization	<0.0001	0.25(0.14–0.46)

Univariate Predictors of Mortality

Univariate predictors of mortality included the follwoing: presence of three-vessel disease ($P = 0.016$, OR: 1.99, 95% CI: 1.14–3.48), anoxic brain injury ($P = 0.0006$, OR: 7.23, 95% CI: 2.34–22.33), oliguria postprocedure ($P = 0.0012$, OR: 3.53, 95% CI: 1.65–7.55), baseline renal insufficiency ($P < 0.0001$, OR: 3.51, 95% CI: 1.9–6.5), hyperlactatemia ($P < 0.0001$, OR: 1.21, 95% CI: 1.1–1.33 per mmol increase), lowest cardiac index ($P < 0.0001$, OR: 0.12, 95% CI: 0.05–0.3 per 1 L/min/m^2 increase), presence of ≥50% ST deviation resolution ($P = 0.0042$, OR: 0.39, 95% CI: 0.2–0.74), and achievement of complete revascularization ($P < 0.0001$, OR: 0.25, 95% CI: 0.14–0.46) (Table IV).

Multivariate Predictors of Mortality

All significant ($P < 0.05$) univariate predictors mentioned earlier were entered into a multivariate model. Independent predictors of mortality included complete revascularization ($P = 0.013$, OR for mortality: 0.26, 95% CI: 0.09–0.76), hyperlactatemia ($P = 0.046$, OR for mortality: 1.14, 95% CI: 1.002–1.3 per mmol increase), baseline renal insufficiency ($P = 0.043$, OR for mortality =3.45, 95% CI: 1.04–11.4), and anoxic brain injury ($P = 0.008$, OR for mortality = 8.22, 95% CI: 1.73–39.1) (Table V).

TABLE V. Independent Predictors of In-hospital Mortality

Parameters	*P*-value	OR (95% CI) where available
Complete revascularization	0.013	0.26 (0.09–0.76)
Hyperlactatemia	0.046	1.14 (1.002–1.3) per mmol increase
Baseline renal insufficiency	0.043	3.45 (1.04–11.4)
Anoxic brain injury	0.008	8.22 (1.73–39.1)

Complete Versus Incomplete Revascularization

The cohort was divided into patients receiving complete versus incomplete revascularization, and multiple relevant comparisons were analyzed (Table VI). The incompletely revascularized cohort were older, had significantly more diabetes, more baseline renal insufficiency, received less thrombolysis, has significantly more three vessel disease, received far less CABG, had significantly more oliguria and survival was significantly lower in this cohort (Table VI). After adjusting for all the aforementioned differences including CABG, age, diabetes, thrombolysis, three-vessel disease, baseline renal insufficiency, oliguria, anoxic brain injury, and lactate level, complete revascularization remained independently predictive of improved in-hospital survival in a very complete multivariate model ($P = 0.005$, OR for survival: 6.2 (95% CI: 1.85–24.6)).

STEMI and Multivessel Coronary Disease Subgroup

Given that this was a diverse population with STEMI, NSTEMI, single vessel and multivessel CAD combined, the ability to achieve complete revascularization may inherently be different in these subgroups. Therefore, to further test the association of the ability to achieve complete revascularization with survival, we isolated the STEMI with concomitant multivessel CAD subgroup in our population and performed similar univariate and multivariate analyses. One hundred and one patients were isolated to this subgroup. All patients in this cohort received revascularization, 76 patients with attempted PCI and 25 underwent CABG (Table VII).

Univariate predictors of in-hospital survival included: complete revascularization ($P = 0.0008$, OR for survival: 2.15 (95% CI: 1.39–3.45)), slow flow ($P = 0.03$, OR for survival: 0.53 (95% CI: 0.29–0.93)), peak lactate ($P = 0.004$), oliguria ($P = 0.01$, OR for survival: 0.52 (95% CI: 0.3–0.84)), anoxic brain injury ($P = 0.006$, OR for survival: 0.33 (95% CI: 0.13–0.66)), and lowest cardiac index ($P = 0.006$) (Table VII).

TABLE VI. Complete versus Incomplete Revascularization Population Comparison

Characteristic	Complete revascularization ($N = 98$)	Incomplete revascularization ($N = 112$)	P-value
Age	64.2 ± 12	67.5 ± 12	0.05
Sex (F)	29 (30%)	39 (35%)	0.42
Diabetes	30 (32%)	51 (46%)	0.03
LV ejection fraction (%)	37.8 ± 15	35 ± 15	0.23
Baseline renal insufficiency (CrCl < 60 ml/min)	22 (23%)	42 (38%)	0.02
Thrombolysis	43 (44%)	28 (25%)	0.004
ST elevation MI	70 (71%)	70 (63%)	0.17
Attempted PCI	58 (59%)	73 (65%)	0.37
CABG	44 (45%)	3 (3%)	<0.0001
Three-vessel disease	39 (40%)	68 (61%)	0.003
IABP	76 (78%)	74 (66%)	0.07
Lactate	5 ± 5	6.3 ± 5.7	0.17
Oliguria (u/o < 30 cc/min)	67 (68%)	93 (84%)	0.01
Anoxic brain injury	7 (7%)	14 (13)	0.2
SYNTAX score	22.9 ± 13	26.2 ± 13	0.13
Survival to discharge	74 (76%)	49 (44%)	<0.0001

Multivariate predictors of in-hospital survival included the follwoing: complete revascularization ($P = 0.03$, OR for survival: 2.47 (95% CI: 1.14–6.21)) and peak lactate ($P = 0.02$).

TABLE VII. STEMI and Multivessel Coronary Disease Cohort Characteristics/Therapy/Outcomes with Univariate Significance for In-hospital Survival

Parameter	Number (%) ($N = 101$)	P-value
Age	65.7 ± 11.2	0.74
Gender (male)	71 (70)	0.52
Diabetes	39 (39)	0.52
Transfer patient	65 (64)	0.33
Prior MI	24 (24)	0.23
Prior CHF	9 (9)	0.48
Shock on admission	27 (27)	0.15
Baseline renal insufficiency	27 (27)	0.34
Thrombolysis	44 (44)	0.09
Time to lab (h)	20.7 ± 44.1	0.95
Lowest cardiac index (l/min/m^2)	1.6 ± 0.5	0.006
LVEF (%)	37 ± 15	0.4
ST resolution > 50%	70 (69)	0.11
PCI	76 (75)	0.08
Multivessel PCI	14 (14)	0.27
Slow flow	17 (17)	0.03
Transfusion	60 (59)	0.95
IABP	81 (80)	0.18
IIbIIIa use	57 (56)	0.48
CABG	25 (25)	0.38
Oliguria	73 (72)	0.01
Anoxic brain injury	13 (13)	0.006
Peak lactate (mmol)	5.8 ± 5.3	0.004
Complete revascularization	40 (40)	0.0008
In-hospital survival	57 (56)	N/A

DISCUSSION

Complete Revascularization

The key finding of this study is that the ability to achieve complete revascularization is strongly associated with improved in-hospital survival in patients with AMI complicated by cardiogenic shock.

The incidence of cardiogenic shock secondary to myocardial infarction has remained relatively unchanged until this decade and despite advances in percutaneous revascularization and surgical techniques the mortality for this condition remains high [19]. Recently, two population-based analyses have indicated a decreased incidence of the in-hospital development of shock in acute coronary syndromes, possibly due to the more liberal use of early revascularization [20,21]. In acute ST elevation myocardial infarction without cardiogenic shock undergoing primary percutaneous intervention, the ACC/AHA guidelines do not recommend intervention on nonculprit vessels during the index procedure (class III recommendation) [5]. Cardiogenic shock, however, is a different entity with myocardial dysfunction leading to worsening cardiac output and systemic pressures and possible worsening of ischemia in nonculprit territories leading to potential worsening global ischemia. Systemic inflammatory response and inappropriate vasodilatation may further worsen perfusion and ischemia to myocardium and other organs [22].

Complete revascularization has not been previously formally addressed as a predictor of survival in cardiogenic shock. Worse TIMI flow post PCI and multivessel PCI have previously been linked to worse survival in a SHOCK trial post-hoc analysis [13]. A SHOCK trial substudy provided the first indication that complete revascularization may carry an advantage [23]. Despite a higher burden of three vessel disease, left main disease and diabetes, patients with CABG had a similar survival to PCI patients in the SHOCK trial, possibly indicating the benefit of more complete revascularization achieved with CABG (87.2% CABG vs. 23.1% PCI) [23]. In our study, we aimed to investigate whether the ability to achieve complete revascularization impacts in-hospital survival. CABG as expected in our population achieved a much higher degree of complete revascularization (94% CABG vs. 45% for PCI). Multivessel PCI in our group performed well with an 88% survival, although conclusions from small subgroup analyses such as this may be called into question. Operators may feel the urge to revascularize the culprit vessel and then follow a wait and watch approach with these patients since it is often logistically easier to perform culprit vessel PCI rapidly. The majority of patients with cardiogenic shock, however

have multivessel disease, and those whose coronary anatomy is unsuitable for complete revascularization by PCI at the index procedure, should be considered for CABG, a viable option with good outcomes [12]. The patients who underwent CABG in our cohort received it relatively late after coronary angiography, therefore a significant survivor bias may contribute to the advantage in surgical patients. With incomplete revascularization, nonrevascularized myocardial territories may not contribute as much to cardiac output, leading to a vicious spiral of worsening cardiac output and ischemia in these segments especially with increased energy requirements due to inotrope use.

One of the pitfalls of our retrospective cohort may be the diversity of patients included. Given that single-vessel disease patients with STEMI may potentially have a better outcome and are more likely to receive complete revascularization thereby creating a potential bias in association, we performed an isolated analysis of STEMI with only mutlivessel coronary disease. In this subgroup as well, the ability to achieve complete revascularization remained independently associated with improved in-hospital survival (Table VII). Specifically in the STEMI with concomitant multivessel disease cohort, all patients received revascularization, therefore the argument that the non-revascularized subgroup of the entire cohort may have biased the results for the entire cohort, does not hold in this subgroup, further strengthening the argument that in a cohort which universally received revascularization, the ability to achieve complete revascularization may potentially add further benefit.

We also attempted to correct for all clinically relevant confounding factors (Table VI) which may differentiate the patients in which complete revascularization was achieved versus incomplete revascularization. Despite this third analysis, complete revascularization remained independently associated with improved in-hospital survival once again.

Given the retrospective nature of our study, it is difficult to make strong statements regarding the direct causal influence of complete revascularization on survival; however, three separate analyses in our population appear to uphold this relationship. At the least, we would conclude this is hypothesis generating deserving further study.

Renal Dysfunction

Baseline renal dysfunction has previously been described as an independent predictor of mortality in cardiogenic shock [11,24]. The ACC-NCDR registry identified that baseline renal dysfunction with creatinine >2 mg/dl had an OR of 4.69 for mortality, whereas the ICONS database from Nova Scotia, Canada identified an OR of 2.1 for mortality with a creatinine >2 mg/dl [11,24]. Our definition for renal dysfunction was a CrCl < 60 ml/min, a more contemporary and relevant definition of moderate renal dysfunction. Although this is a retrospective cohort, this is the first demonstration of moderate renal dysfunction predicting reduced in hospital survival in cardiogenic shock.

Hyperlactatemia

Hyperlactatemia may be an accurate reflection of tissue perfusion and glucose metabolism during cardiogenic shock. There is limited literature demonstrating the predictive power of hyperlactatemia (lactate >6.5 mmol) for in-hospital mortality specifically in ST elevation infarction patients [25,26]. Although the continuous relationship of reduced survival with increasing peak lactate in this cohort is robust, the variable timing of collection of the lactate sample and variable repeat sampling renders this predictor less reliable (Fig. 1). It is possible that patients closer to death may have worsening hemodynamic status with associated higher lactate levels, suggesting an association of lactate with decreasing cardiac output. Previous studies have also utilized peak lactate rather than presentation or first lactate [25,26]. The peak lactate was used in this study rather than presentation or first available lactate since the first available lactate was quite variable in timing of sampling. Lactate remained an independent predictor of death in this study after multivariate testing including lowest cardiac index (Tables IV and V).

Anoxic Brain Injury

Anoxic brain injury has only recently been reported to be a predictor of outcome in cardiogenic shock [27]. Patients with evidence of ABI survived less often, likely due to a combination of poor cardiac outlook, either from previous cardiac arrests or severe/prolonged hypotensive episodes reflecting poor cardiac function or due to possible withdrawal of care earlier than usual. Only 3 of 22 patients with anoxic brain injury did not receive revascularization, therefore ABI was not a surrogate for lack of revascularization therapy. The presence of ABI may however have influenced aggressiveness or duration of post-revascularization care or support offered, thereby resulting in reduced survival. Anoxic brain injury may be a novel, albeit expected predictor of poor outcome in this population.

Study Limitations

There are multiple limitations to our study which include the retrospective nature of the cohort with its

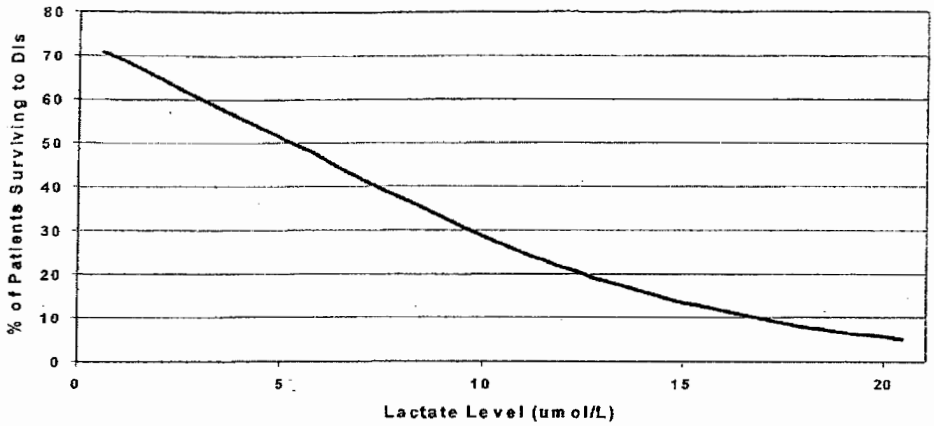

Fig. 1. In-hospital survival correlation with peak serum lactate levels. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

inherent biases. Given the retrospective nature of data collection, not all measurements were available for all patients and not all measurement were made at exactly the same time intervals or course in hospital. Not all patients underwent all testing such as echocardiography, pulmonary artery catheterization, or lactate measurements. This cohort comprises patients admitted with cardiogenic shock that underwent cardiac catheterization and may have excluded patients with extreme instability or excessive comorbidity who did not undergo angiography. We only included those patients undergoing coronary arteriography as this would be the only cohort where completeness of revascularization could be studied given the necessity for anatomical definition. Although there is possible selection bias in this study, this cohort is representative of previous cardiogenic shock cohorts [1]. The time to revascularization was somewhat delayed overall, this is due to the fact that we have a centralized cardiac catheterization facility for the entire large province and the majority of our patients are transferred referrals with the majority being land transfers. This cohort also comprises both ST elevation and non-ST elevation infarction and both single and multivessel coronary disease, this does create variation within the cohort, however multivariate analyses have been undertaken to account for confounding factors in the best possible way. Two further analyses were performed to interrogate the ability to achieve complete revascularization with survival; a multivariate model to adjust for all clinically relevant confounding factors between the completely and incompletely revascularized cohorts was performed. Subsequently, in a universally revascularized cohort of STEMI with only multivessel disease subgroup, a similar univariate and multivariate analysis demonstrated similar association.

CONCLUSION

In cardiogenic shock, the ability to achieve complete revascularization is independently associated with improved in-hospital survival. Furthermore, predictors of poor in-hospital survival in cardiogenic shock include baseline renal insufficiency, hyperlactatemia, and anoxic brain injury. Further prospective randomized study of complete revascularization achieved by PCI/CABG or both in cardiogenic shock may be warranted but likely difficult to carry out.

ACKNOWLEDGEMENTS

Many thanks to Dr. Steven Hodge, Dr. Tarek Kashour, Dr. Alan Menkis, Dr. Michael Raabe, Dr. Nasir Shaikh, Angie Munoz, and Siobhan Loeza-Aceves for their input and guidance with data gathering.

REFERENCES

1. Hochman J, Sleeper LA, Webb JG, Sanborn TA, White HD, Talley JD, Buller CE, Jacobs AK, Slater JN, Col J, McKinlay SM, LeJemtel TH. Early revascularization in acute myocardial infarction complicated by cardiogenic shock. SHOCK Investigators. Should we emergently revascularize occluded coronaries for cardiogenic shock. N Engl J Med 1999;341:625–634.
2. Hochman JS, Boland J, Sleeper LA, Porway M, Brinker J, Col J, Jacobs A, Slater J, Miller D, Wasserman H. Current spectrum of cardiogenic shock and effect of early revascularization on mortality: Results of an international registry. SHOCK registry investigators. Circulation 1995;91:873–881.
3. Hochman JS, Buller CE, Sleeper LA, Boland J, Dzavik V, Sanborn TA, Godfrey E, White HD, Lim J, LeJemtel T. Cardiogenic shock complicating acute myocardial infarction—Etiologies, management and outcome: A report from the SHOCK Trial registry. Should we emergently revascularize occluded coronaries for cardiogenic shock? J Am Coll Card 2000;36:1063–1070.
4. Hochman JS, Sleeper LA, Webb JG, Dzavik V, Buller CE, Aylward P, Col J, White HD. Early revascularization and long-term

survival in cardiogenic shock complicating acute myocardial infarction. J Am Med Assoc 2006;295:2511–2515.
5. Smith Sc Jr, Feldman TE, Hirshfield JW Jr, Jacobs AK, Kern MJ, King SB III, Morrison DA, O'Neill WW, Schaff HV, Whitlow PL, Williams DO. ACC/AHA/SCAI 2005 Guideline Update for percutaneous coronary intervention: A report of the ACC/AHA Task Force on practice guidelines (ACC/AHA/SCAI writing committee to update the 2001 guidelines for percutaneous coronary intervention). J Am Coll Cardiol 2006;47; e1–e121.
6. Dzavik V, Sleeper LA, Picard MH, Sanborn TA, Lowe AM, Gin K. Saucedo outcome of patients aged > 75 in the should we emergently revascularize occluded coronaries in cardiogenic shock trial: Do elderly patients with acute myocardial infarction complicated by cardiogenic shock respond differently to emergent revascularization? Am Heart J 2005;149:1128–1134.
7. Dzavik V, Sleeper LA, Cocke TP, et al. Early revascularization is associated with improved survival in elderly patients with acute myocardial infarction complicated by cardiogenic shock: A report from the SHOCK trial registry. Eur Heart J 2003;24:828–837.
8. Corpus RA, House JA, Marso SP, et al. Multivessel percutaneous coronary intervention in patients with multivessel disease and acute myocardial infarction. Am Heart J 2004;148:493–500.
9. Celik T, Lyisoy A, Jata B, Kardesoglu E, Isik E. Culprit only versus multivessel coronary revascularization in patients presenting with acute ST elevation myocardial infarction: Unending debate. Int J Cardiol 2009;137:65–66.
10. Hannan E, Samadashvili Z, Walford G, et al. Culprit vessel percutaneous coronary intervention versus multivessel and staged percutaneous coronary intervention for ST elevation MI. J Am Coll Cardiol Cardiovasc Interv 2010;3:22–31.
11. Klein LW, Shaw RE, Krone RJ, et al. Mortality after emergent percutaneous coronary intervention on cardiogenic shock secondary to acute myocardial infarction and usefulness of a mortality prediction model. Am J Cardiol 2005;96:35–41.
12. Sanborn TA, Sleeper LA, Webb JG, et al. Correlates of one-year survival in patients with cardiogenic shock complicating acute myocardial infarction. J Am Coll Cardiol 2003;42:1373–1379.
13. Webb JG, Lowe AM, Sanborn TA, et al. Percutaneous coronary intervention for cardiogenic shock in the shock trial. J Am Coll Cardiol 2003;42:1380–1386.
14. Menon V, Webb JG, Hillis D, et al. Outcome and profile of ventricular septal rupture with cardiogenic shock after myocardial infarction. J Am Coll Cardiol 2000;36:1110–1116.
15. Chan AW, Chew DP, Bhatt DL, et al. Long-term mortality benefit with the combination of stents and abciximab for cardiogenic shock complicating acute myocardial infarction. Am J Cardiol 2002;89:132–136.
16. Sutton AG, Finn P, Hall JA, et al. Predictors of outcome after percutaneous treatment for cardiogenic shock. Heart J 2005;91:339–344
17. Dauerman HL, Ryan TJ, Piper WD, et al. Outcomes of percutaneous coronary intervention among elderly patients in cardiogenic shock: A multicenter, decade-long experience. J Invas Cardiol 2003;15:380–384.
18. Hasdai D, Holmes DR, Califf RM, et al. Cardiogenic shock complicating acute myocardial infarction: Predictors of death. Am Heart J 1999;138:21–31.
19. Fang J, Alderman MH, Keenan NL, Ayala C. Acute myocardial infarction hospitalization in the United States, 1979 to 2005. Am J Med 2010;123:259–266.
20. Jeger RV, Radovanovic D, Hunziker PR, et al. Ten-year trends in the incidence and treatment of cardiogenic shock. Ann Intern Med 2008;149:618–626.
21. Goldberg RJ, Spencer FA, Gore JM, Lessard D, Yarzebski J. Thirty-year trends (1975–2005) in the magnitude of, management of, and hospital death rates associated with cardiogenic shock in patients with acute myocardial: A population based perspective. Circulation 2009;119:1211–1219.
22. Reynolds HR, Hochman JS. Cardiogenic shock: Current concepts and improving outcomes. Circulation 2008;117:686–697.
23. White HD, Assmann SF, Sanborn TA, et al. Comparison of percutaneous coronary intervention and coronary artery bypass grafting after acute myocardial infarction complicated by cardiogenic shock. Circulation 2005;112:1992–2001.
24. Mayich J, Cox JL, Buth KJ, et al. Unequal access to interventional cardiac care in Nova Scotia in patients with acute myocardial infarction complicated by cardiogenic shock. Can J Cardiol 2006;22:331–335.
25. Valente S, Lazzeri C, Vecchio S, et al. Predictors of in-hospital mortality after percutaneous coronary intervention for cardiogenic shock. Int J Cardiol 2007;114:176–182.
26. Koreny M, Delle Karth G, Geppert A, et al. Prognosis of patients who develop acute renal failure during the first 24 hours of cardiogenic shock after myocardial infarction. Am J Med 2002;112:115–119.
27. Sleeper LA, Reynolds HR, White HD, Webb JG, Dzavik V, Hochman JS. A severity scoring system for risk assessment of patients with cardiogenic shock: A report from the SHOCK Trial and Registry. Am Heart J 2010;160:443–450.