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Cardiogenic Shock Complicating Acute Myocardial Infarction: The Use of Coronary Angioplasty and the Integration of the New Support Devices Into Patient Management

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Conventional therapy for cardiogenic shock complicating acute myocardial infarction continues to be associated with a high in-hospital mortality rate. Hemodynamic support with new mechanical devices and emergency coronary revascularization may alter the long-term prognosis for patients with this complication. Between July 1985 and March 1990, 68 patients presented to the University of Michigan with acute myocardial infarction and cardiogenic shock. Interventions performed included thrombolytic therapy (46%), intraaortic balloon pump counterpulsation (70%), cardiac catheterization (86%), coronary angioplasty (73%), emergency coronary artery bypass grafting/ventricular septal defect repair (15%), Hemopump insertion (11%), percutaneous cardiopulmonary support (4%) and ventricular assist device (3%).

The 30-day survival rate was significantly better in patients who had successful angioplasty of the infarct-related artery than in patients with failed angioplasty (61% vs. 7%, p = 0.002) or no attempt at angioplasty (61% vs. 14%, p = 0.003). This difference was maintained over the 1-year follow-up period. The only clinical variable that predicted survival was age <65 years.

The early use of the new support devices in 10 patients was associated with death in 8 (80%), but this poor outcome may reflect a selection bias for an especially high risk population. Collectively, these recent data continue to suggest that emergency revascularization with angioplasty may reduce the mortality rate, but further study is required to define optimal utilization and integration of new support devices.

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Cardiogenic shock complicates acute myocardial infarction in 2.4% to 12% of patients (1–3). Conventional therapy for cardiogenic shock with coronary care unit monitoring and vasopressor agents to support the blood pressure has historically been associated with an 80% to 90% mortality rate in a large series (4,5). Intraaortic balloon pump therapy for shock results in initial favorable clinical and hemodynamic responses, but ultimately in most patients death is merely delayed and the hospital mortality rate remains >80% (6–8). In several recent nonrandomized series coronary revascularization performed early in the course of cardiogenic shock with use of coronary artery bypass grafting (9–12) or coronary angioplasty (13–18) resulted in an apparent reduction in the hospital mortality rate to <50% in selected patients with shock. In addition, over the past decade, new devices to support the systemic circulation, such as a catheter-mounted left ventricular assist device (19–22), percutaneous cardiopulmonary bypass support (23–26) and several surgically implanted ventricular assist devices (27–33), have become available for clinical investigation. It is possible that the new support devices will stabilize these critically ill patients long enough to permit significant functional recovery of the myocardium and to accomplish coronary revascularization such that the in-hospital mortality rate may be improved.

The present study reviews one center's experience with the treatment of cardiogenic shock at a time when the standard care for cardiogenic shock included the aggressive use of coronary angioplasty and when several of the new support devices became available.

Methods

Study patients. Our study group consisted of all patients admitted to the University of Michigan Medical Center between July 1985 and March 1990 who presented with or developed cardiogenic shock during hospitalization for acute myocardial infarction. Cardiogenic shock was defined as 1) sustained systolic blood pressure <80 mm Hg, or <90 mm Hg if the blood pressure was supported by intravenous pressor agents or intraaortic balloon pump therapy;

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2) pulmonary capillary wedge pressure ≥18 mm Hg or, if not determined, left ventricular end-diastolic pressure ≥20 mm Hg; and 3) evidence of decreased tissue perfusion. Acute myocardial infarction was defined as 1) chest pain >20 min in duration and unresponsive to sublingual nitroglycerin; 2) electrocardiographic (ECG) changes consistent with acute myocardial infarction; and 3) elevation of serum creatine kinase MB fraction elevation.

Coronary angioplasty. Nearly all patients with complicated myocardial infarction treated at the University of Michigan during the study period underwent, in addition to fluid resuscitation and administration of intravenous vasopressor agents, emergency cardiac catheterization using a nonionic contrast medium. Left ventriculography generally was not performed. A temporary atrioventricular sequential pacemaker was placed for bradyarrhythmias or heart block. Intraaortic balloon pump therapy was often initiated before angiography. The decisions to proceed to coronary angioplasty and to use or not to use one of the support devices was made by an experienced interventional cardiologist. Angioplasty was generally performed only on the infarct-related artery. However, angioplasty of noninfarct arteries was attempted in some patients with multivessel disease in an effort to improve collateral flow if angioplasty of the infarct-related artery was unsuccessful. Angioplasty was performed through vascular sheaths in the femoral artery with use of the Judkins technique. Patients were pretreated with aspirin (325 mg) and heparin (10,000 to 15,000 U) was administered immediately after sheath insertion. All significant stenoses in the infarct-related artery were dilated with an appropriately sized balloon catheter system. Angioplasty was considered technically successful if flow in the infarct-related artery was Thrombolysis in Myocardial Infarction (TIMI) grade 2 or 3 (34). After angioplasty, the patient was monitored in the coronary care unit and treated with intravenous heparin (adjusted to keep the partial thromboplastin time 1.5 to 2 times control), aspirin (325 mg/day), a calcium channel blocker (if tolerated) and vasopressor agents as needed.

Coronary artery bypass grafting. Cardiopulmonary bypass was established as the saphenous vein was being harvested after a single two-stage venous cannula and an aortic cannula were connected to a silicone membrane oxygenator primed with 2,000 ml of Normosol and 150 ml of 12.5-g albumin. Packed red blood cells (1 to 3 units) were added to the prime solution if the preoperative hematocrit was <30%. The left ventricle was vented routinely by introducing a sump catheter through the left superior pulmonary vein. The aorta was then cross clamped. Cardioplegic arrest was induced in all patients with warm (37°C) substrate-enriched blood cardioplegic solution containing 24 mEq/liter of potassium chloride, marked hypocalcemia and a high glucose concentration. Initial infusion was given at a rate of 350 ml/min to arrest the heart. After arrest, the cardioplegic flow rate was reduced to 150 ml/min and the warm infusion was continued for a total of 5 min. Immediately after induction of warm cardioplegia, systemic cooling to 28°C was started and the patient received an additional 250 ml/min for 3 min of nonsubstrate-enriched cold cardioplegic solution. Topical hypothermia with 4°C Normosol was used.

In all patients, the first graft was placed into the artery supplying the largest area of contracting myocardium. The next grafts were placed into arteries supplying viable myocardial regions with smaller coronary arteries. The last artery grafted supplied the infarct region. After the distal anastomoses, 200 ml of the cold cardioplegic solution was instilled through the vein grafts. Reinfusion of the cold cardioplegic solution was instilled into the aortic root every 20 min at a flow rate of 200 ml/min for 2 min. While the last distal anastomosis was being constructed, the patient's systemic temperature was rewarmed to 37°C. After completion of the last distal anastomosis and before release of the aortic cross clamp, warm glutamate/aspartate-enriched blood was given into the aorta and down the grafts for 3 min at a flow rate of 150 ml/min. The aortic cross clamp was removed and the heart was defibrillated if necessary. A partial occluding clamp was applied and the proximal anastomoses performed. Distal vein grafts were perfused continuously until the proximal anastomoses were completed. Extracorporeal circulation was continued for an additional 15 min after all proximal anastomoses had been completed. The patient was then weaned from cardiopulmonary bypass with the use of inotropic and vasodilating drugs and 1:1 intraaortic balloon counterpulsation.

Hemopump. The Hemopump (Johnson and Johnson Interventional Systems) was inserted in the operating room with the established technique described by Duncan et al. (35). Briefly, a 12-mm Dacron graft was constructed on the femoral artery and the 21F device was advanced under fluoroscopic guidance across the aortic valve and placed into a stable position in the left ventricle. The Hemopump is a motor-driven turbine that rotates at up to 27,000 rpm, ejecting left ventricular blood in a nonpulsatile manner into the ascending aorta at a rate up to approximately 3.5 liters/min. The Hemopump may be used as a support device for up to 7 days.

Percutaneous cardiopulmonary support. Percutaneous cardiopulmonary bypass support was provided with the CPS device (C.R. Bard, Inc.). An 18F cannula was placed in the femoral artery and a 20F cannula was placed in the femoral vein percutaneously by modified Seldinger technique. The arterial cannula was advanced into the descending aorta to approximately the level of the renal arteries and the venous cannula was advanced under fluoroscopic guidance to the mid-right atrium. Then, heparin (30,000 U) was given and an activated clotting time was maintained at >300 s. The venous blood was then cycled through the pump oxygenator and heat exchanger and pumped through the arterial cannula at rates up to 5 liters/min. The oxygenation membrane has a 6-h lifetime, the recommended time limit for use of the device.

Table 1. Clinical Data for the Series of 68 Patients

Age (yr) (mean ± SD)	59 ± 11
% male	61
Medical history (%)	
Hypertension	58
Prior myocardial infarction	41
Angina	38
Coronary artery bypass surgery	3
Baseline medications (%)	
Digoxin	9
Nitrates	31
Beta-blockers	17
Calcium channel blockers	24
Infarct location (%)	
Anterior	50
Inferior	28
Indeterminate	22
Hours from chest pain to shock (range)	25 ± 55 (0.5–336)
Peak creatine kinase (IU ± SD) (range)	3,444 ± 2,858 (270–12,720)

Table 2. Interventions to Achieve Reperfusion or Provide Systemic Support in 68 Patients

Thrombolytic therapy	31 (46%)
Tissue-type plasminogen activator	20 (30%)
Streptokinase	8 (12%)
Urokinase	12 (17%)
Intravenous pressor agents	65 (95%)
Intraaortic balloon pump	48 (70%)
Cardiac catheterization	59 (86%)
Coronary angioplasty	48 (71)%
Coronary artery bypass/VSD repair	10 (15%)
Hemopump	7 (11%)
Percutaneous cardiopulmonary support	3 (4%)
Ventricular assist device	2 (3%)

All values are number and (%). VSD = ventricular septal defect.

Ventricular assist device. The Symbion Total Artificial Heart (Symbion, Inc.) was used as a bridge to cardiac transplantation in two patients. The use of the Symbion device is reviewed elsewhere (32,36).

Statistics. All numeric results are expressed as mean values ± SD. Categoric variables were analyzed with the chi-square test and continuous variables were analyzed with a *t* test. A p value <0.05 was considered statistically significant; however, values from 0.05 to 0.10 were included for completeness. Multivariate logistic regression analyses with an alpha to enter and remove equal to 0.15 were used to test hypotheses regarding the independent effect of variables on the in-hospital mortality rate.

Results

Patient characteristics (Table 1). Of the 68 patients, 50% had anterior myocardial infarction, whereas 28% had inferior infarction and 22% had infarction of indeterminate location (non-Q wave in 7 patients, left bundle branch block in 5, paced rhythm in 2 and death before an ECG was obtained in 1 patient). The majority of patients presented in cardiogenic shock within 24 h of chest pain onset, but there was great variability in time of symptom onset to shock (mean 25 ± 55 h, range 0.5 to 336 h).

The hemodynamic data for the 68 patients are as follows: heart rate 109 ± 23 beats/min, systolic blood pressure 74 ± 9 mm Hg, right atrial pressure 16 ± 6 mm Hg, systolic pulmonary artery pressure 44 ± 12 mm Hg, diastolic pulmonary artery pressure 26 ± 9 mm Hg, pulmonary capillary wedge pressure 26 ± 9 mm Hg and cardiac index 2 ± 0.8 liters/min per m^2. The cardiac index is likely to be artificially elevated because most patients had been treated with several interventions before the determination of cardiac output. Four patients had ventriculographic and oxygen saturation step-up evidence of a ventricular septal defect and one patient had clinically unsuspected free wall rupture found at autopsy as the cause of cardiogenic shock. No patient had evidence of a flail mitral valve leaflet or primary right ventricular infarction as the cause of the shock.

Interventions (Table 2). Thrombolytic agents were administered to 46% of the patients (23 intravenous, 6 intracoronary, 2 both intravenous and intracoronary). Nearly all patients were treated with an intravenous pressor agent (dopamine 91%, dobutamine 45%, l-norepinephrine 26%, amrinone 12%, epinephrine 3%). Eighty-seven percent were taken to the cardiac catheterization laboratory, most within the 1st 12 h of shock, although there was a very wide range (mean 24 ± 61 h from shock to catheterization, range 0.5 to 336). On the basis of the angiographer's assessment, coronary angioplasty of the infarct-related artery was attempted in 48 (81%) of 59 patients who underwent cardiac catheterization. The primary angioplasty success rate was 73% (88% for single-vessel disease and 61% for multivessel disease, p = 0.04). Ten patients were referred for emergency surgery (four for ventricular septal defect, five for coronary disease considered unsuitable for angioplasty and one for failed angioplasty).

Table 3 summarizes the use of the new support devices. Hemopump placement was attempted in seven patients. Placement was unsuccessful because of atherosclerotic disease of the iliac artery in three patients, all of whom died. Of the four patients with successful Hemopump placement, one patient died on day 4 when the device was accidently dislodged from the ventricle during changing of the bed linen, one died on day 3 after suffering a massive embolic cerebral vascular accident and two patients survived to discharge (Hemopump in place 3 and 5 days, respectively). While the Hemopump was in place, it delivered up to 3.5 liters of nonpulsatile flow, which was an adequate supplementation to ventricular output in all patients.

Percutaneous cardiopulmonary bypass support (USCI/Bard) was used in three patients as a bridge to other therapy. One patient was supported until a left ventricular assist device was implanted, one was supported until a Hemopump was implanted and one was supported for 42 h while awaiting

Table 3. New Support Device Use in 10 Patients

Pt No.	Age (yr)/ Gender	Device	IRA	MVD	Adjunctive PTCA	Days Supported	Outcome
1	33/F	HP	LAD	Yes	Yes, successful	3	Discharged day 19, alive at 1 year
2	48/F	HP	ND	ND	No	0	Died during device placement
3	49/M	HP	LAD	No	Yes, successful	5	Discharged day 7, died of refractory CHF
4	39/M	CPS	RCA	Yes	Yes, successful	0.5	Bridge to VAD
		VAD				8	Died awaiting transplantation
5	56/M	CPS	LM	Yes	Yes, successful	0.2	Bridge to HP
		HP				4	Died when device dislodged
6	69/F	HP	LM	Yes	Yes, successful	0	Died when device could not be inserted
7	49/M	HP	LAD	No	Yes, successful	0	Died during device placement
8	57/F	VAD	LAD	Yes	No	2	Died of multiple organ failure
9	48/M	HP	LAD	Yes	Yes, successful	6	Embolic stroke, died
10	43/M	CPS	LAD	No	Yes, successful	2	Died awaiting neurologic recovery from initial cardiac arrest

CHF = congestive heart failure; CPS = cardiopulmonary bypass support; F = female; HP = Hemopump; IRA = infarct-related artery; LAD = left anterior descending coronary artery; LM = left main coronary artery; M = male, MVD = multivessel disease; ND = not defined (patient died before angiography could be performed); Pt = patient; PTCA = percutaneous transluminal coronary angioplasty; RCA = right coronary artery; VAD = ventricular assist device.

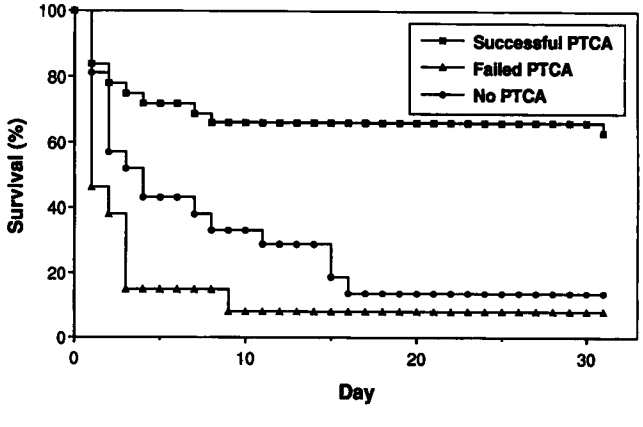
neurologic recovery after cardiac arrest to be considered for placement of the left ventricular assist device. All three patients died. Cardiopulmonary bypass support provided up to 4.5 liters/min of flow and adequate tissue perfusion in all patients.

The Symbion ventricular assist device was placed in two patients, in the first as a bridge to transplantation and in the second because the patient could not be weaned from cardiopulmonary bypass after emergency coronary artery bypass grafting. Both died of multiple organ failure before cardiac transplantation.

Survival at 30 days and 1 year. The 30-day survival rate was significantly better in patients with successful angioplasty of the infarct-related artery than in patients with failed angioplasty (61% vs. 7%, $p = 0.002$) or no attempt at angioplasty (61% vs. 14%, $p = 0.003$) (Fig. 1). This difference was maintained over the 1-year follow-up period (Fig. 2). Patients treated with angioplasty who had single-vessel disease had a greater likelihood than patients with multivessel disease of successful recanalization of the infarct-related artery (89% vs. 59%, $p = 0.03$) and a better 30-day survival rate (56% vs. 38%, $p = 0.04$). The only clinical variable that predicted improved survival was age <65 years ($p = 0.026$).

None of the six patients treated with emergency coronary artery bypass grafting and none of the four patients who underwent emergency repair of a ventricular septal defect survived to hospital discharge. Death before 30 days occurred in five of seven patients treated with the Hemopump and in all patients treated with the percutaneous cardiopulmonary bypass support (n = 3) or ventricular assist device (n = 2). One of the two patients treated with the Hemopump who lived to hospital discharge survived to 1 year; the other died of refractory left ventricular failure at 78 days.

Figure 1. The 30-day survival rate in 68 patients. PTCA = percutaneous transluminal coronary angioplasty.



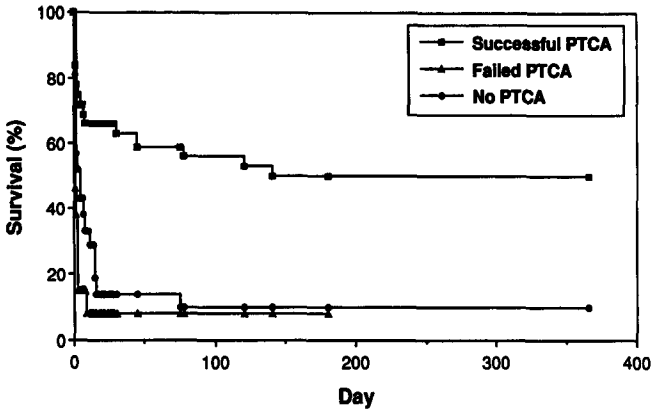


Figure 2. The 1-year survival rate in 68 patients. PTCA = percutaneous transluminal coronary angioplasty.

Discussion

The principal finding of our study is that emergency percutaneous coronary angioplasty for cardiogenic shock is associated with a favorable short- and long-term prognosis, which is concordant with other reports (14–19) including an earlier one from our institution (13). Moreover, the early experience with new support devices, such as percutaneous cardiopulmonary bypass or a catheter-mounted left ventricular assist device, has not yet demonstrated a successful outcome.

Revascularization with coronary angioplasty. Table 4 summarizes the published studies, none randomized, of patients with cardiogenic shock treated with angioplasty (13–19). Because the definition of cardiogenic shock is not uniform among the studies, direct comparison of the results must necessarily be limited. Angioplasty has been successful in establishing recanalization of the infarct-related artery in 54% to 100% of vessels in which it was attempted. All of the series suggest improvement in survival in treated as compared with historical control patients. Furthermore, in all series that separately analyzed patients on the basis of success of the angioplasty procedure, patients with failed angioplasty have a mortality rate similar to that of historical control patients. Our data show that despite more widespread use of angioplasty (the procedure was attempted in 71% of all of our patients presenting with cardiogenic shock), the ability to successfully restore patency to the infarct-related artery remains high (73%). Of patients in whom angioplasty was successful, 63% survived to hospital discharge and 48% were alive at 12 months. In contrast, only 7% of patients who had an unsuccessful attempt at angioplasty of the infarct-related artery survived to hospital discharge and 1 year. Consistently, patients with single-vessel disease have had an improved outcome compared with that of patients with multivessel disease. The latter patients may have a lack of compensatory hyperkinesia (37), which in this setting may be essential to sustain adequate left ventricular function and end-organ perfusion.

DeWood et al. (11) first showed that early emergency coronary artery bypass grafting for cardiogenic shock improved survival. Several further encouraging series have subsequently been reported (9,10,12); however, none of these were randomized controlled series. None of our patients sent for emergency coronary artery bypass surgery in the setting of cardiogenic shock complicating acute myocardial infarction survived to hospital discharge. It is likely that this outcome was the result of selection bias. The only patients sent for an emergency operation at our institution were patients who had undergone unsuccessful angioplasty, had diffuse high grade coronary artery disease or had a ventricular septal defect.

Support devices. Our early experience with the new support devices has been disappointing; however, this outcome may again reflect selection bias toward using the devices only in patients whose condition was the most unstable. Merhige et al. (19) found that in dogs with ischemia, the Hemopump—a catheter-mounted left ventricular assist device that works on the principle of the Archimedes screw—decreased cardiac work, decreased left ventricular end-diastolic pressure, maintained aortic pressure and favorably redistributed blood flow in the heart so that flow to the ischemic areas was increased. Wampler et al. (20) described the use of the device in 28 patients with cardiogenic shock

Table 4. Summary of Studies Using Coronary Angioplasty to Treat Cardiogenic Shock Complicating Acute Myocardial Infarction

First Author	Years of Pt Enrollment	No.	Successful PTCA (%)	Survival (%)						
				Hospital/30 Days			Long-Term			
				S	F	A	Mo	S	F	A
Meyer (14)	1981	1	100	100	—	100	6	100	—	100
Rothbaum (15)	1982–1986	18	—	—	—	61	—	—	—	—
Stack (16)	1984–1986	43	—	—	—	58	12	—	—	53
Lee (13)	1982–1985	24	54	77	18	50	—	—	—	—
Verna (17)	1986–1987	6	100	83	—	83	6	67	—	67
O'Keefe (18)	1980–1988	39	—	—	—	59	—	—	—	—
Kahn (37)	1987–1989	16	—	—	—	50	—	—	—	—
Present study	1985–1990	48	73	61	7	45	12	48	7	36

A = all patients treated with coronary angioplasty (PTCA); F = patients with failed angioplasty; Mo = months; Pt = patient; S = patients successfully treated with angioplasty.

after acute myocardial infarction or after cardiotomy and found a 1-month survival rate of 45%. We used the Hemopump in seven of our patients with shock. Our results demonstrate some of the limitations of the Hemopump, including 1) difficulty advancing the 21F device in a diseased iliac artery, 2) ventricular arrhythmias due to catheter-induced endocardial irritability, 3) potential for accidental dislodgment, and 4) restriction to 7 days of use. The device is also contraindicated in patients with known left ventricular thrombus or severe aortic valve disease. A recent description (39) of a modified technique for placement of the Hemopump may increase the rate of successful placement of the device.

Percutaneous cardiopulmonary bypass support in cardiogenic shock complicating acute myocardial infarction was first described by Pennington et al. (26). Their patient was maintained on an extracorporeal membrane oxygenation system and then weaned to a left ventricular assist device, but subsequently died. Shawl et al. (23–25) reported on the use of the Bard cardiopulmonary bypass support device in 10 patients with cardiogenic shock. They found that 8 of the 10 patients were able to undergo successful supported angioplasty of the infarct-related artery and survived to a mean follow-up of 10 months. In our initial experience, all three patients were stabilized hemodynamically, were well oxygenated with a normal acid/base status and were systemically perfused on the cardiopulmonary bypass support device. The major limitations of this device are that it is recommended to be used only 4 to 6 h and, because it does not directly perfuse the myocardium, continued myocardial necrosis may occur. There is also realistic concern over the potential ethical dilemma of an awake aware patient supported hemodynamically by the device but with no hope of recovering enough cardiac function to survive independently.

We treated two patients in cardiogenic shock with the Symbion left ventricular assist device before the use of the device was severely restricted. There are numerous surgical reports (31,33,40) of patients successfully supported with various ventricular assist devices, but most were postcardiotomy patients who could not be weaned from cardiopulmonary bypass and not patients with acute myocardial infarction. Adamson et al. (27) reported a 41% survival rate in 13 patients with acute myocardial infarction and shock and Joyce et al. (32) reported a 50% survival rate in 26 similar patients. Other reported experiences (29,30) with a left ventricular assist device have been less successful, although the series are small.

Conclusions. Although not confirmed with randomized trials, emergency revascularization of the infarct-related artery by angioplasty appears to enhance survival in patients with cardiogenic shock complicating acute myocardial infarction. The patients with the greatest likelihood of successful angioplasty are those <65 years of age with single-vessel disease. The new support devices may have a role in stabilizing the condition of these critically ill patients long enough to allow more definite therapy and recovery of myocardial function, but to evaluate the devices objectively, their use must not be restricted to patients with the least likelihood for survival. One challenge for the future will be to define the optimal integration of coronary revascularization and the various support devices to further favorably affect the otherwise poor outcome in this patient group.

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