



Management of acute cardiogenic shock

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The management of acute cardiogenic shock has evolved into an art and science that combines the most sophisticated technologies with the experience of investigators who have addressed this problem for the past several decades. Traditional teaching has paved the way for a foundation upon which to systematically treat this disorder, using the advanced forms of cardiac mechanical devices and interventional therapies available today. We are no longer limited by the assortment of inotropic drugs, anti-arrhythmics, and intra-aortic balloon pumps for reversing cardiogenic shock. Instead, we have at our disposal several powerful devices that serve to assist or replace the acutely failing heart. The purpose of this article is to describe the experience of managing acute cardiogenic shock in today's setting. An algorithm is suggested for the treatment of both precardiotomy and postcardiotomy shock states (Fig. 1). Although the literature is rich with publications spanning nearly 4 decades of cardiac assist, the reference section is mostly limited to the more recent publications with notable exceptions. The reader is encouraged to use the Internet for the most recent material because the field is evolving so rapidly.

The desire to have some form of effective therapy for managing acute cardiogenic shock was established in medical and surgical settings by cardiologists and surgeons confronted with a desperate situation in which the patient was unable to successfully maintain adequate cardiac out-

put after an acute myocardial infarction (MI) or after open-heart surgery. In the past, the only management consisted of inotropic drugs, vasoconstrictors, and anti-arrhythmics. Before any pumps became available, patients were managed in the intensive care unit with impending multi-organ system failure and death. Among the most desperate surgical scenarios were patients who were transferred from the operating room while still attached to the heart-lung machine. In general, the results of these maneuvers were poor. The use of these techniques persisted for several decades, with occasional cases still being observed in the current era. It wasn't until the commercialization of the intra-aortic-balloon-pump (IABP) and the development of the ventricular assist devices (VAD) that a more realistic and appropriate method of managing acute cardiogenic shock could be established. Today, the list of cardiac conditions that have been supported by the application of mechanical pumps continues to grow:

Postcardiotomy shock conditions

- Coronary artery bypass grafting (CABG)
- Failed transplant
- Valve replacement
- Ross Procedure
- Implantable left ventricular assist system (need for RVAD implantation)
- Ventricular remodeling procedures
- Post-infarct ventricular septal defect (VSD) or Mitral regurgitation (MR)

Precardiotomy shock conditions

- Acute MI shock
- Acute viral myocarditis
- Postpartum spontaneous Cor. Dissection
- Intractable ventricular arrhythmia

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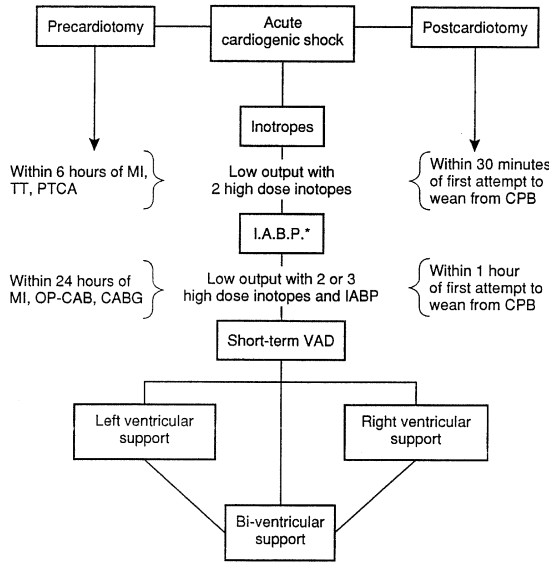


Fig. 1. Acute cardiogenic shock conditions associated with VAD use.

- Decompensated cardiomyopathy
- Failed percutaneous transluminal coronary angioplasty (PTCA)
- Pulmonary embolus

At present, there are no acute cardiogenic shock states that may not benefit from mechanical assist or replacement. Instead, the contraindications to this technology reside in the judgment of the physician, as specific patient profiles (eg, advanced age, multiple comorbidities, active infection, recent stroke) result in poor outcomes.

Postcardiotomy shock

The most common use of mechanical assist is in the postcardiotomy shock setting [1–6]. Whether the case began as an elective, urgent, or emergent procedure, the surgeon is confronted with a situation in which the patient cannot separate from CPB after the operation. Strategies to address this problem have been defined at our center and at others. A formula for VAD insertion has been proposed [7] in which the presence of two high-dose inotropic drugs coupled with poor hemodynamics triggers VAD consideration.

- Hemodynamic Criteria*
 - Systolic BP < 100 mmHg
 - Mean PAP > 25 mmHg

- CVP > 15 mmHg
- CI < 2.0 L/min/m²
- Pharmacological Criteria*
 - Epinephrine ≥ 10 mcg/min
 - Dobutamine ≥ 10 mcg/kg/min
 - Dopamine ≥ 10 mcg/kg/min
 - Milrinone ≥ 0.50 mcg/kg/min
- * Two inotropic drugs with hemodynamic criteria trigger VAD

The philosophy of low cardiac output despite pharmacologic support has allowed the surgical team to identify patients for VAD insertion using a common indication. This strategy has translated into earlier insertion and less need for bi-VAD support, resulting in lower multi-organ system failure (MOSF) postoperatively and higher wean and discharge rates. Given that CABG is the most common cardiac surgical procedure performed in adults, the use of the VAD for postcardiotomy shock found a niche in this setting. However, postcardiotomy shock after any cardiac operation may benefit from VAD application.

In the past, presence of a mechanical heart valve was a contraindication for the use of a VAD. The rationale for this concept was the observation that mechanical heart valves were prone to thrombosis in the setting of a VAD because the blood flow across the prosthesis was greatly diminished with VAD unloading—elimination of

the prosthetic leaflet motion predisposed the valve to thrombosis. Experience on the bench, in the laboratory, and in the clinical setting has changed the approach to this problem. Understanding the importance of prosthetic valve leaflet mobility allowed investigators to arrive at cannulation and management strategies that allow VADs to be placed in cases of postcardiotomy shock after mitral and aortic valve replacement [8,9]. For mitral valve replacement (MVR), the solution was a simple strategy of cannulation. Establishing device inflow from the left ventricular apex (instead of the left atrium) allowed blood to flow from the pulmonary veins into the left atrium, across the mitral valve, and into the left ventricle where it was captured by the inflow cannula. The mitral prosthesis maintains flow across its leaflets, thereby reducing the risk of thrombosis. For aortic valve replacement (AVR), the inflow and outflow positions do not matter. Instead, the important aspect is the ability of the native left ventricle to eject. Thus, incomplete unloading of the left ventricle is important to allow enough blood to be propelled forward through the prosthetic aortic valve. This strategy may require the VAD to be placed in a weaning mode to partially fill the heart for native ejection, which can be seen on the arterial pressure tracing or by echocardiography. In either MVR or AVR, the use of a VAD has been reported with increasing frequency, allowing another subset of postcardiotomy shock patients to benefit from this technology.

In the case of failed transplant, the use of a VAD has been extremely successful in treating right ventricular (RV) failure or acute rejection as the cause [10,11]. More frequently than not, patients coming to cardiac transplantation have pulmonary hypertension. The majority of the pulmonary hypertension is reversible—irreversible pulmonary hypertension is a contraindication to transplantation. On occasion, an initially successful transplant may fail due to RV dysfunction secondary to long ischemic time, poor myocardial preservation, air emboli or debris in the right coronary circulation, donor-recipient size mismatch (ie, small donor, large recipient), or unrecognized irreversible pulmonary hypertension. Regardless of the cause, the situation is grave if RV function cannot be immediately restored or supported. The use of a right VAD (RVAD) has been reported in several cases as salvaging failed transplants due to this problem. Most commonly, RV support is needed for 3 to 5 days, after which the RV recovers enough function to permit VAD removal. The experience

at our center and at others has been favorable in the application of the VAD for this indication. Fortunately, the situation is rare, and the use of nitric oxide has diminished the need for RVAD support in this setting. For acute cardiac allograft rejection, the VAD (usually a biventricular circuit) is the only means of salvaging this catastrophic situation. Both the Thoratec and the BVS 5000 have been successfully used for this rare, but lethal condition.

Many other cardiac surgical procedures have benefited from the use of a VAD for postcardiotomy shock [12–14]. The technically challenging procedures, such as the Ross Operation and left ventricular remodeling procedures, have occasionally resulted in postcardiotomy shock requiring VAD support. Complications from an acute MI, such as ruptured papillary muscle (with acute severe MR) and postinfarction VSD, have traditionally been labeled as high-risk surgeries that may result in postcardiotomy shock states. At our center, we have had experience with these categories and have been particularly interested in the postinfarct VSD entity. Our approach to this problem is based on the status of ventricular function associated with the VSD. If myocardial function is profoundly impaired and the likelihood of a successful repair remote, then the approach is to establish biventricular support at the atrial level, thereby rerouting the blood away from the VSD. The VSD is not corrected at the initial operation. Circulatory support is maintained with good end-organ perfusion established. If myocardial function returns over the course of several weeks, then repair is performed at that time. If myocardial function remains impaired and the patient is a transplant candidate, then listing is initiated. If the patient is not a transplant candidate, then correction of the VSD is attempted, with the possibility that a long-term (and possible destination) LVAD will be placed. We have had the occasion to treat three patients in this manner—one patient required transplantation, the other two were successfully repaired.

Pre-cardiotomy shock

Coronary artery syndromes are nothing new to the cardiology history. Ever since the relationship between coronary occlusion and myocardial infarction was demonstrated, the management of acute coronary syndromes has evolved into a very sophisticated strategy in therapy.

Despite our best efforts, however, the problem of acute MI with cardiogenic shock remains a serious problem. Recent surveys estimate that more than 1.5 million Americans suffer an acute MI every year. Cardiogenic shock resulting from the MI occurs in approximately 7% to 15% of these cases. The 30-day mortality is in the order of 50% to 80%. In The Shock Trial, the hospital mortality from this entity ranged from 47% to 77% depending upon the treatment used (ie, Thrombolytics, IABP, or both). In addition, depending upon whether the shock occurred in less than or more than 24 hours from the MI, the mortality was 63% or 54%, respectively. Interestingly, the median time to the onset of shock following an MI was 6.2 hours [15]. This information has led to a further understanding and appreciation for early aggressive intervention before the onset of multi-organ system failure and death due to low output or arrhythmia. A treatment plan has been adopted at our institution that incorporates the talents, technologies, and expertise of both physician and surgeon (Fig. 2). The application of this collaborative approach has resulted in a 60% discharge rate for patients who were treated with VADs for acute MI shock. Several small series of AMI-Shock patients have reported with variable results [16–18].

The causes of precardiotomy shock include a variety of disorders apart from acute MI. One entity that has had excellent success with VAD support is acute viral myocarditis [19–25]. This disorder has a natural history that spans the spectrum

of full recovery to fulminant heart failure. The majority of the commercial VADs have been used successfully in this setting. Depending upon the type of myocarditis (giant cell versus non-giant cell), the VAD is used as either a bridge to native heart recovery or transplantation. In addition, depending upon the philosophy of the surgeon and the behavior of the heart (ie, associated arrhythmias, univentricular or biventricular failure), the use of LVAD alone or use of bi-VAD routinely may vary. Regardless of the approach, the results have been favorable, mostly because the patients are young. In general, younger patients have better outcomes because they have more physiologic reserve to tolerate morbidities and have more options as end-points (eg, transplantation).

The intractable arrhythmia is a lethal disorder that could be stabilized with VAD support [26–28]. Although mentioned in cardiothoracic surgical texts as an indication for VAD support, the cardiology community needs to be reminded that this entity is well served by mechanical cardiac systems that function independent of the cardiac rhythm. VADs operate on fill-to-empty mode. In the BVS system, the blood fills the VAD bladder by gravity drainage. Once the bladder is full, a sensor triggers the console to shuttle compressed air to squeeze the bladder and propel the blood forward. The flow of blood, therefore, is preload dependent and afterload sensitive—totally asynchronous with the ECG. The Thoratec VAD is filled by an active vacuum that is applied to the space between the

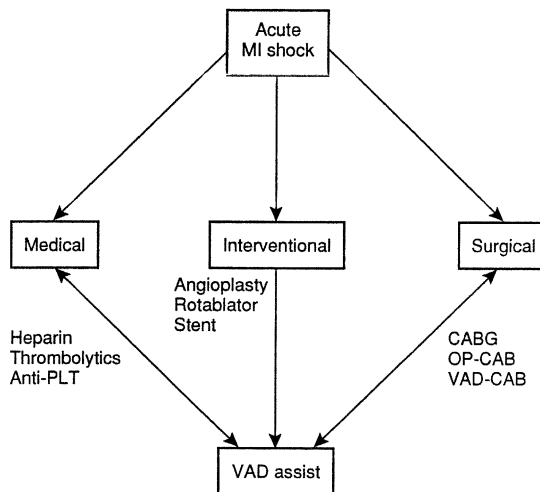


Fig. 2. Options in management for acute MI with cardiogenic shock.

bladder and its outer casing. Once the bladder is filled with blood, an internal sensor triggers the console to shuttle compressed air to the bladder and propel the blood forward. Once again, the fill-to-empty feature is independent of the cardiac rhythm. One aspect to keep in mind, however, is the status of the unsupported ventricle. Univentricular support with arrhythmias can be accomplished. However, the blood flow through the pulmonary bed needs to be unimpeded. Congested lungs, elevated pulmonary vascular resistance, or any process that impairs blood flow through the lungs will make LVAD support suboptimal. In general, intractable arrhythmias are well served with bi-VADs as the presence of biventricular machines eliminates the concern of native RV contribution to overall cardiac output.

Other entities that have been addressed with the use of VADs in the precardiomy shock setting include postpartum coronary artery dissection, failed angioplasty, pulmonary embolus, trauma, and acute decompensation of chronic cardiomyopathies. Each of these entities has been treated successfully with VAD technology [29–34]. Depending upon the condition and the likelihood of native heart recovery, the choice of VAD may be short, intermediate, or long-term. For example, a failed angioplasty may benefit from short-term support as the native heart recovers from the incident. On the other hand, acute decompensation of a cardiomyopathy may be better served with an intermediate or long-term system as a bridge toward transplantation. Other factors that enter into the decision-making include the condition of the patient, the device(s) available at the institution, the possible end-points, and the cost. Patients who are profoundly unstable may be better served with a BVS-type system, which can be placed quickly and without the need for CPB. It is the least expensive of the VADs and can be configured for univentricular or biventricular support. We have used the BVS in this setting as a quick means of establishing circulatory support and hemodynamic stability [35]. If the patient improves, then decisions can be made to transition to another system if continued mechanical support is necessary. Others have adopted a bridge-to-bridge concept, using extra-corporeal membrane oxygenation (ECMO) for rapid resuscitation and converting to a VAD upon further stabilization and longer-term support [36–38]. The group at Columbia-Presbyterian Hospital has suggested an algorithm in which short-term support is established followed by transition to

a longer-term system at 6 days. During the 6-day period, native heart recovery is assessed and the patient is screened for transplant candidacy [39]. This protocol has served their program extremely well with excellent results.

The role of VADs for precardiomy shock has gained in popularity as the application has increased and the outcomes have improved. Like the cardiac surgical experience, the role of VADs in the cardiology setting is unlimited. Similarly, it is important to recognize the shock state early and to establish rapid restoration of hemodynamics before end-organ failure occurs. Our center recommends consultation with the VAD service in all patients with profound precardiomy shock. As a starting point with cardiogenic shock from acute MI, we recommend consultation as soon as possible and implementation of mechanical support in the 6-hour to 24-hour time frame from the event. As the technology and the outcomes continue to improve, then the timing of insertion may be even sooner. Collaboration between the surgeon and cardiologist stands the best chance of salvaging this devastating problem.

Summary

The present state of the art in mechanical cardiac assist technology has permitted application of machines to a variety of conditions that confound the cardiologist and cardiac surgeon alike. Decades of research and development have allowed the present devices to be used as bridges to native heart recovery and bridges to transplantation. We are now entering the era in which devices are being placed for permanent assist or replacement. Although the acute cardiogenic shock patient remains problematic, we now have at our disposal a variety of tools that have enabled us to salvage more patients than ever before. The experience with these systems continues to grow, with leading centers and investigators contributing meaningful information toward the application and development of the latest technologies. It has been said that mechanical therapies precede biological therapies. We are at the crossroads in which a combination of biological therapies with mechanical therapies is underway. Current research is investigating the role of mechanical cardiac support while biological therapies are introduced into the failing heart. In the meantime, the role of mechanical cardiac assist and

replacement has matured into an effective means of treating acute cardiogenic shock of any variety.

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