Acute circulatory failure resulting in cardiogenic shock is a common problem encountered in the intensive care unit. Cardiogenic shock is defined by the presence of the following haemodynamic parameters: sustained hypotension (systolic blood pressure <90mmHg or mean arterial pressure of 30mmHg below basal level), adequate or elevated left ventricular (LV) filling pressure (e.g. left ventricular end-diastolic pressure >18mmHg or right ventricular end-diastolic pressure or pulmonary artery wedge pressure > 15mmHg) and reduced cardiac output (cardiac index <1.8L/min/m² without support or <2.0-2.2 L/min/m² with support). Clinical manifestations of cardiogenic shock include signs of poor tissue perfusion such as cold extremities, oliguria and/or clouded sensorium, in the setting of myocardial dysfunction. Causes of cardiogenic shock include acute myocardial infarction with or without mechanical complications (e.g. ventricular septal rupture, papillary muscle rupture with acute mitral regurgitation, contained free wall rupture), acute myocarditis, tako-tsubo (or stress-induced) cardiomyopathy, acute valvular regurgitation, or any other cause of acute severe left ventricular (LV) or right ventricular (RV) dysfunction.

The mainstay of treatment for cardiogenic shock is pharmacological support using inotropic agents, such as dobutamine, dopamine and norepinephrine, and phosphodiesterase inhibitors, such as milrinone. These agents improve short-term haemodynamics at the expense of increased oxygen demand by increasing myocardial ATP consumption, which may be deleterious over long-term. Calcium-sensitising agents with inodilatory properties such as levosimendan, which does not increase oxygen demand and is less proarrhythmogenic, have been shown to have a statistically non-significant but consistently lower mortality than dobutamine at six months in the treatment of acute decompensated heart failure. Another agent which may be used to treat acute decompensated heart failure is a recombinant B-type natriuretic peptide called nesiritide. However, pooled analysis of randomised controlled trials showed increased risk of death at 1 month and worsening renal function with nesiritide compared to usual therapy.

Mechanical Circulatory Support in the Intensive Care Unit

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In circumstances where a potentially reversible cause of acute heart failure has been identified or where cardiac surgery or transplantation is considered an option for refractory heart failure, mechanical circulatory support systems are available which can maintain the patient until definitive treatment is instituted. Mechanical circulatory support can be life-saving in acute cardiogenic shock and particularly useful as a bridge to recovery in cases of fulminant myocarditis. There is evidence that patients with fulminant myocarditis, i.e. those with severe haemodynamic compromise, rapid onset of symptoms and fever, have a better long-term prognosis than those with acute nonfulminant myocarditis if they survive the initial period of cardiogenic shock. Therefore, in these patients, an aggressive approach including mechanical circulatory support is warranted. Time from onset of illness to recovery of ventricular function in fulminant myocarditis usually takes 2 to 3 weeks. Mechanical circulatory support includes placement of intra-aortic counterpulsation balloon pumps (IABP), extracorporeal membrane oxygenation systems (ECMO), and ventricular assist devices (VAD).

Intra-aortic Balloon Pump (IABP) or Counterpulsation

Intra-aortic balloon pump (IABP) is the most commonly used mechanical support for cardiogenic shock. The IABP is commonly inserted percutaneously through the femoral artery (Figure 1) but, in patients with peripheral vascular disease, it may be inserted through the brachial artery. By synchronising inflation and deflation to the patient’s cardiac cycle, the IABP improves coronary and peripheral perfusion during diastolic balloon inflation and augments left ventricular performance during systolic balloon deflation by reducing the afterload (Figure 2).
Apart from left ventricular failure and cardiogenic shock, indications for IABP include support of high risk patients for percutaneous coronary intervention, cardiac surgery for post-myocardial infarction ventricular septal defect or acute mitral regurgitation, stabilisation of heart failure patients undergoing general anaesthesia and bridge to heart transplant. Its use is contraindicated in severe aortic valvular insufficiency which may worsen during diastolic regurgitation, aortic dissection, peripheral vascular disease and tachyarrhythmias.

Vascular complications associated with the use of IABP include limb ischaemia, aortic or arterial injury such as perforation and dissection, femoral artery thrombosis, peripheral embolisation, and visceral ischaemia. Other complications may be balloon related (such as incorrect positioning, gas embolisation) or related to infection or entrapment. In patients with peripheral vascular disease and diabetes, sheathless method rather than sheathed technique should be used.

**Extra-corporeal Membrane Oxygenation (ECMO)**

ECMO is a form of extracorporeal life support whereby an external pump system carries the venous blood from the large central veins of the patient to an oxygenator (a gas exchange device) where the blood becomes enriched with oxygen and has carbon dioxide removed. The oxygenated blood then re-enters the patient’s circulation, either through the aorta or arterial system (so-called veno-arterial ECMO) (Figure 3) or through the venous system (veno-venous ECMO). Veno-arterial ECMO provides support for severe cardiac failure with or without respiratory failure and can be set up by using peripheral cannulation of the femoral artery and vein (Figure 4), so-called percutaneous cardiopulmonary support system (PCPS). Veno-arterial ECMO may be applied for the short-term management of cardio-respiratory failure or cardiac failure refractory to inotropic and IABP support. Common indications include acute fulminant myocarditis, severe acute respiratory distress syndrome (ARDS), acute decompensated dilated cardiomyopathy, ischaemic cardiogenic shock, drug overdose or sepsis with profound cardiac depression and as a bridge to longer-term ventricular assist device. Veno-venous ECMO involves return of oxygenated blood to the venous system of the patient, usually the right atrium via the internal jugular vein, and is the preferred mode of support for isolated respiratory failure, such as ARDS. In ARDS, ECMO provides life support without reliance on high-pressure high-oxygen mechanical ventilation for gas exchange, thereby reducing the release of inflammatory mediators from the damaged native lung, and buys time necessary for the lung to heal.
duration of ECMO support depends on the type of oxygenator used. With silicone-membrane or microporous hollow-fibre oxygenators, plasma leakage typically occurs after a few days, necessitating circuit changeover. However, with diffusion membrane oxygenators such as the QuadroxD (Jostra Medizintechnik AG, Hirrlingen, Germany), the hollow-fibre technology utilises a true non-microporous membrane and avoids plasma leak problem. The system is ideal for prolonged perfusion up to 14 days with the longest duration reported to be 46 days.

Like the IABP, the PCPS is also contraindicated in aortic dissection and severe aortic valve regurgitation. Potential complications associated with the use of ECMO include vascular complications, haemolysis, mechanical problems with clots or air in the system, oxygenator thrombosis and bleeding tendency with use of heparin.

In case of IABP failing to support the patient, PCPS or V-A ECMO can immediately provide adequate perfusion to all organs irrespective of the lung condition. However, PCPS cannot augment coronary blood flow and may increase left ventricular afterload. Combination of IABP and PCPS is clinically feasible and has been shown in animal models to have important advantages over PCPS alone, especially in ischaemic cardiomyopathy. Combined use of IABP and ECMO reduces left ventricular wall stress and oxygen consumption while increasing the end-systolic elastance and reduces tissue acidosis and myocardial necrosis.

**Ventricular Assist Devices (VAD)**

Patients with advanced heart failure in New York Heart Association class III and IV may be classified into seven clinical profiles in the Interagency Registry of Mechanically Assisted Circulatory Support (INTERMACS) to allow optimal selection for mechanical circulatory support, especially ventricular assist devices (VAD). 80% of such devices are being used in the two profiles with the highest levels of clinical compromise, namely those “crash and burn” patients (INTERMACS profile 1) and “sliding on inotropes” patients (INTERMACS profile 2). There are many types of VAD, with the first-generation VAD being pulsatile devices, the second-generation VAD being the axial flow pumps and the third-generation VAD being centrifugal pumps which are bearingless and designed for long-term support. In the past, use of the extracorporeal or implantable VAD requires surgical implantation in the operating theatre. Recently, VAD which may be inserted percutaneously have been developed for clinical use. For example, the TandemHeart Percutaneous Ventricular Assist Device (pVAD) is an extracorporeal continuous-flow centrifugal pump. A cannula is inserted through the femoral vein, across the interatrial septum and into the left atrium. The TandemHeart pump withdraws oxygenated blood from the left atrium and returns it to the femoral artery. The tip of the catheter contains a “pigtail” which rests in the left ventricle.

**Evolving Role of Mechanical Circulatory Support**

Nowadays, VAD is not only used as a bridge to heart transplantation in severe heart failure but increasingly used as a bridge to myocardial recovery or as destination therapy (i.e. for permanent use in patients who are not candidates for heart transplantation). There is evidence that, in some severe heart failure patients, prolonged complete unloading of the left ventricle (LV) with VAD may lead to structural reverse remodelling and functional improvement of the LV. This is true not only in myocarditis patients but also in non-ischaemic dilated cardiomyopathy patients. The time frame for myocardial recovery can vary from weeks to months. Currently the use of implantable long-term VAD is associated with major complications such as embolic stroke, mechanical device failure, infection and need for sternotomy. Development of bearingless centrifugal pumps, smaller devices and partial cardiac support system which can be implanted with a minimally invasive procedure will hopefully minimise some of the problems.

**Conclusion**

At present, IABP, ECMO and VAD are available as mechanical circulatory support for cardiogenic shock. The IABP is convenient to be applied but can only provide limited additional cardiac output, which may not be adequate for critical situations. ECMO can provide total circulatory support but suffers the drawback of extracorporeal circulation such as activation of cellular elements and the need of an oxygenator. The duration of use is limited to 2 to 6 weeks. Implantable VAD has the potential to provide...
weeks. Implantable VAD has the potential to provide longer-term support but the device is expensive and implantation requires surgical expertise. Percutaneous VAD and partial mechanical cardiac support, currently under investigation, are attractive alternatives because of ease of insertion but are not yet widely available.

References