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PERCUTANEOUS DEVICE THERAPY TO PREVENT AND TREAT ACUTE DECOMPENSATED HEART FAILURE

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Introduction

Acute decompensated heart failure (ADHF) is the most common cause for hospitalization among Medicare beneficiaries and is associated with substantial morbidity and mortality. Approximately 4% of patients will die during their hospitalization and 44% will be re-admitted within six months.[1,3] In a subset of patients with relative hypotension and cardiorenal syndrome (renal dysfunction at the time of admission or worsening renal function during therapy), the inpatient mortality rate for ADHF increases to 21%.[1]

The associated economic costs are equally as staggering, with two-thirds of the annual $25 billion heart failure costs attributable to managing ADHF. Given the poor clinical outcomes of patients with ADHF and the high healthcare-related costs, there is an urgent need to adopt aggressive strategies that may favorably alter the course of this increasingly common and potentially deadly condition. This review will highlight the evolving role of percutaneous device therapy to monitor hemodynamics, reduce ventricular filling pressures, and improve end organ perfusion in patients with advanced ADHF.

Device Therapy to Monitor Hemodynamics

Intracardiac Hemodynamic Monitoring Systems

While the exact underlying pathophysiology of ADHF is unknown, elevated diastolic pressures play a pivotal role in the presentation of both systolic and diastolic ADHF.[4] The physiologic premise to support the potential clinical use of intracardiac hemodynamic monitoring systems (ICHMs) relates to the hypothesis that as significant hemodynamic changes occur in the ambulatory setting, the ability to detect impending decompensation (i.e., increasing diastolic ventricular filling pressure) may allow for timely intervention to minimize ADHF hospitalizations. Two current investigational ICHMs include the Chronicle device (Chronicle, Medtronic Inc., Minneapolis, Minnesota) and

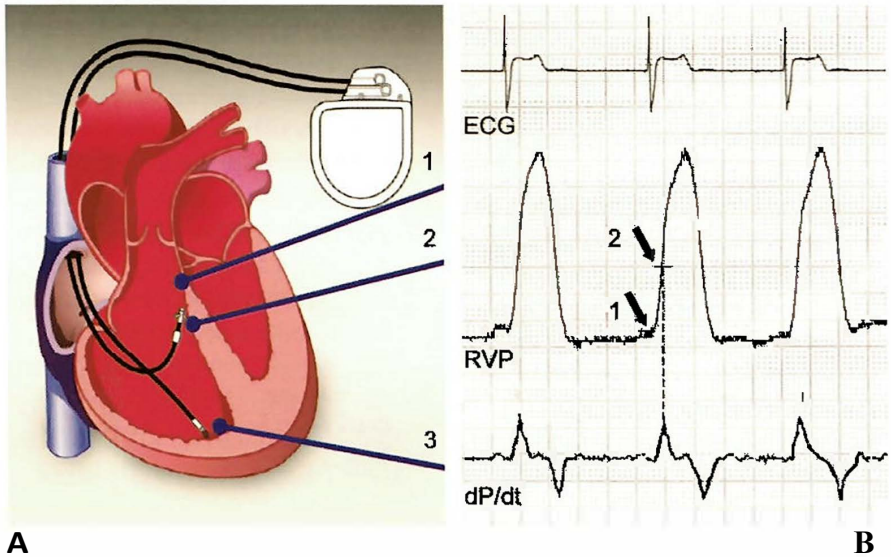
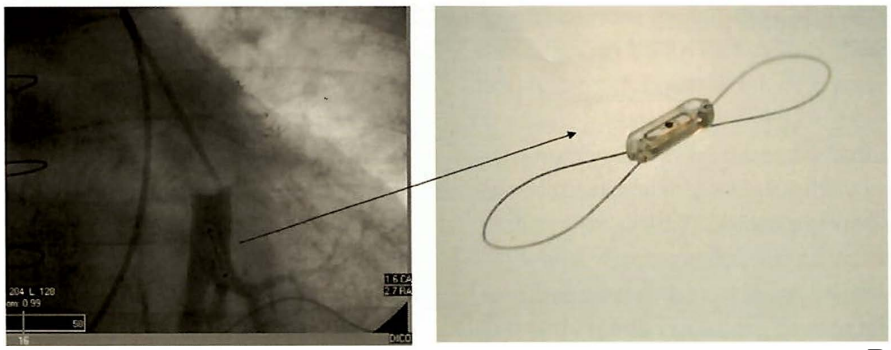


Figure 1. Medtronic Chronicle Implantable Cardioverter Defibrillator

(A) Lines 1 and 2 show the pressure-sensing lead in the right ventricular outflow tract or high septum, and line 3 shows the high-voltage lead positioned in the apex.

(B) Chronicle pressure measurements. Arrow 1 demonstrates right ventricular end diastolic pressure at ORS detection (estimate of right atrial pressure), and arrow 2 demonstrates right ventricular systolic pressure at peak dP/dt (estimate of pulmonary artery diastolic pressure). ECG=electrocardiogram. RVP=right ventricular pressure; dP/dt=change in right ventricular pressure over time.



A B

Figure 2. The CardioMEMS Heart Failure Sensor

(A) Pulmonary angiography during heart failure sensor implantation in the \eft pulmonary artery. Selective angiography shows unimpaired pulmonary artery blood flow around the flow sensor.

(B) The CardioMEMS Hearl Failure Sensor consists of electronic components housed within a hermetically sealed, fused silica capsule. Two wire loops of nitinol prevent sensor distal migration.

the Cardio-MEMS Heart Failure Sensor (CardioMEMS Inc., Atlanta, Georgia). The former consists of a programmable device and a transvenous lead that has a sensor incorporated near its tip to measure intracardiac pressure. The implantation procedure is similar to that of a single-lead pacemaker system, with the device positioned subcutaneously in the pectoral area and the transvenous lead positioned in the right ventricular outflow tract or septum (Figure 1). The Chronicle-ICHM is capable of continuously monitoring and storing heart rate, right ventricular systolic and diastolic pressure, maximal positive and negative rate of change in right ventricular pressure (dP/dt), right ventricular pre-ejection and systolic time intervals, and estimated pulmonary arterial diastolic pressure (ePAD).[5] The ePAD is defined as the right ventricular pressure at the time of pulmonary valve opening, which occurs at the time of maximal dP/dt. A strong correlation (r=0.84) has been shown to exist between ePAD and actual pulmonary artery pressures measured under a variety of physiological conditions.[6]

The potential benefit of this device has been examined in COMPASS-HF (Chronicle Offers Management to Patients with Advanced Signs and Symptoms of Heart Failure).7 This study was a prospective, multicenter, randomized, single-blind, parallel-controlled trial of 274 New York Heart Association functional class III or IV heart failure (HF) patients who received a Chronicle-ICHM. All patients received optimal medical therapy, but the hemodynamic information from the monitor was used to guide patient management only in the Chronicle group. While the ICHM-guided care did not significantly reduce total HF-related events compared with optimal medical management, a retrospective analysis of the time to first HF hospitalization showed a 36% reduction (p =0.03) in the relative risk of a HF-related hospitalization in the Chronicle group. In addition, the two safety end points were met, with no pressure-sensor failures and system-related complications noted in only 8% of the patients who underwent implantation.

Combining this pressure sensing system with an implantable cardioverter defibrillator (ICD) for those patients that meet the approved indication of an ICD is a unique opportunity to monitor hemodynamics. REDUCEhf (Reducing Events in Patients with Chronic Heart Failure) is an ongoing prospective, multicenter, randomized, parallel-controlled trial designed to assess the safety of the Chronicle ICD system (a single-chamber ICD with a hemodynamic monitoring system) and the effectiveness of a management strategy guided by intracardiac pressure information among ICD-appropriate patients.[8]

In contrast to the Chronical device, the Cardio-MEMS Heart Failure Sensor (HFS) consists of a three-dimensional coil and a pressure-sensitive capacitor encased within a hermetically sealed, fused silica capsule completely covered in medical grade silicone. Distal migration is prevented by two wired nitinol loops. The device is 15 mm long and 3 mm wide and is supplied pre-loaded, attached to a tether wire within a delivery catheter with fluoroscopy guidance (Figure 2). The coil and capacitor housed within the HFS form a miniature electrical circuit that resonates at a specific frequency. Pressure applied to the sensor causes deflections on the pressure-sensitive surface and results in a characteristic shift in the resonant frequency. The coil allows for electromagnetic coupling to the sensor by an external antenna, which is held against the patient's side or back in the approximate area of deployment of the sensor. The antenna provides power to the device, continuously measures its resonant frequency, and converts the frequency shifts in a real-time pressure waveform.

Verdejo et al. demonstrated that the HFS provides an accurate

method for systolic and diastolic pulmonary artery pressure assessment in the intermediate follow-up of HF patients in comparison to swanz ganz catheter measurements (r2=0.96 baseline, r2=0.90 follow-up, $p < 0.01$; and r2=0.88 at initial implant, r2=0.48 at follow-up, $p < 0.01$ for the respective systolic and diastolic pressure assessments).[9] Potential advantages include the simplicity of device implantation and the absence of both a wire lead and battery replacement.

Implanted Devices to Measure Impedance

Impedance is a measure of the degree a substance resists the flow of electrical current of a given voltage, and it can be measured and followed in patients with pacemakers or defibrillator devices. Fluid and blood provide much lower resistance to currents than thoracic tissue. Those regions of the body with relatively higher fluid content (i.e., pulmonary edema with ADHF) will present with lower impedance. Changes in impedance can be detected as current generated from the pacing wire travels across the thoracic organs toward the device. Estimates of thoracic fluid content, however, depend on the placement of the electrodes and may not correlate with invasive hemodynamic measurements. For this reason and due to the lack of specificity in the impedance signal, there is heterogeneity in the treatment response (i.e., increased diuretic therapy) for abnormal impedance measurements.10 Moreover, as illustrated by Tang et al., early studies limited by small sample sizes have not provided meaningful outcome measures to justify widespread adoption of this technology to tailor heart failure therapy based on impedance measurements.[10]

While ambulatory monitoring of heart failure has relied on right-side heart sensors, a recent investigation in an ADHF-canine model measured impedance signals afforded by various electrode configurations of an implanted chronic resynchronization therapy system.[11] These investigators found that impedance decreased gradually at varying rates during progression into HF and that it was significantly lower during HF than baseline at different magnitudes of change.[11] In addition, left ventricular (LV)-dependent impedance vectors were associated with a faster rate of change, greater reduction in magnitude, better correlation with LV end-diastolic volume, and stronger association with left atrial pressure than were vectors solely dependent on right-sided cardiac measurements highlighting the potential of this technology. Validation and human outcome-based studies are warranted.

Pulmonary Artery Catheterization

One of the most common uses of the pulmonary artery catheter (PAC) is in patients with advanced ADHF. These patients may benefit from "tailored therapy"- an approach to guide the dosing and titration of intravenous diuretics, vasoactive medications, and oral therapies to optimal measured hemodynamics. Prospective non-randomized studies of tailored therapy have demonstrated this approach to be associated with better survival, improved symptoms and exercise capacity, and decreased hospitalization.[12-14]

The ESCAPE trial (Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness) was a multicenter initiative with the primary aim to determine whether use of the PAC to guide therapy in patients with severe symptomatic systolic ADHF would lead to improved morbidity and mortality.15 The study randomized 433 patients to clinical assessment and a PAC or to clinical assessment alone. The clinical target in both groups was resolution of clinical congestion, and targets in the PAC group were a pulmonary capillary wedge pressure of 15 mmHg and a right atrial pressure of 8 mmHg.

Therapy in both groups led to substantial reduction **in** symptoms, jugular venous pressure, and edema. Use of the PAC did not significantly affect the primary end-point of days alive and out of the hospital during the first six months (133 days versus 135 days; hazard ratio 1.00, 95% confidence interval 0.82-1.21; P = 0.99). Furthermore, there were no significant differences **in** time to death or hospitalizations, deaths, or days hospitalized, and there were no clinical subgroups in which benefit or harm was shown. The results of the ESCAPE trial showed that use of the PAC in patients with ADHF did not lead to improved clinical outcomes. The potential positive impact of the hemodynamically guided therapy may have been diminished by the strategy trial design along with the lack of a specific treatment algorithm. In addition, key exclusion criteria **in** ESCAPE included a creatinine of 3.5 mg/dl, prior use of higher doses of inotropic agents, and use of mechanical circulatory support devices or mechanical ventilation. Excluding these critically ill patients makes it difficult to extrapolate the ESCAPE results to advanced ADHF populations. The trial also did not include patients failing standard medical therapy or patients with a confusing volume and/or perfusion status or patients with significant

DEVICE MECHANISM	DESCRIPTION	UTILIZATION STATUS
Aquadex 100	Ultrafiltration	Available
Intra-aortic balloon pump	Pneumatic pump	Available
Impella recover	Axial flow pump	Available
TandemHeart	Centrifugal pump	Available
Extracorporeal membrane oxygenation	Centrifugal pump	Available
Cancion system	Centrifugal pump	Clinical Trial

Table 1. Percutaneous devices for the treatment of patients with advanced ADHF.

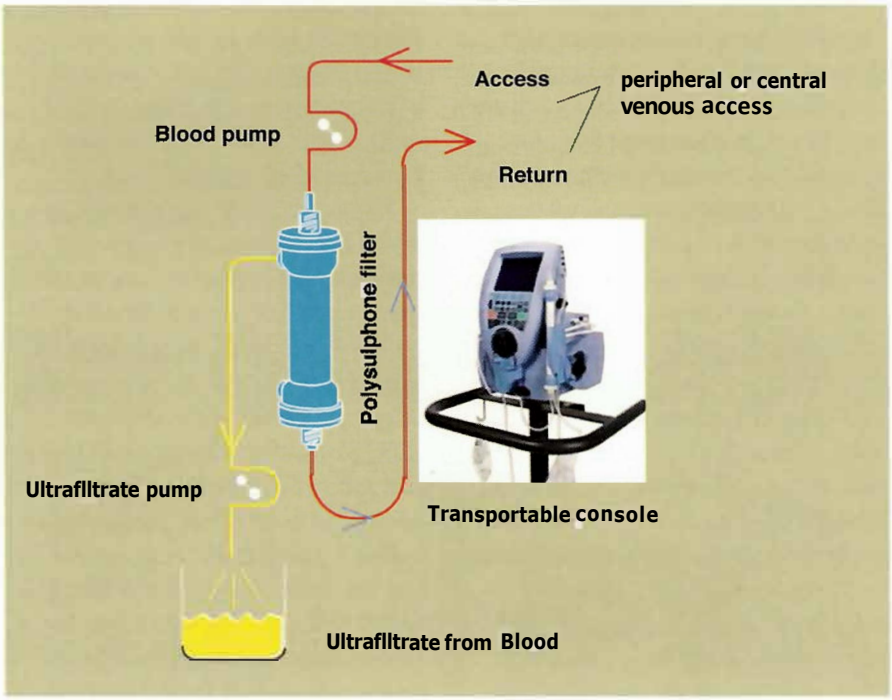


Figure 3. Simplified Veno-Venous Ultrafiltration Aquadex 100 device for ultrafiltrate (isotonic salt and water) removal using a low extracorporeal blood volume (~33 ml).

pulmonary hypertension in the context of cardiac transplantation candidacy.

Based on the overall results of the ESCAPE trial, there is no indication for routine use of PACs to adjust therapy during hospitalization for decompensation of chronic HF. There are, however, clinical situations in which the PAC may be useful, for example, when initial therapy fails and the additional information is needed to help refine a management approach, when the patient's volume and perfusion status are unclear, or if clinically significant hypotension or worsening renal function develops during therapy. The data from the PAC may help clinicians in these situations to determine whether these problems are due to excessive diuresis or inadequate perfusion. Moreover, the PAC may be useful in patients with ADHF complicated with a low cardiac output state, when higher doses of inotropes and other vasoactive medications are used, to ensure optimal dosing of these drugs while minimizing deleterious side effects such as arrhythmias and hypotension.[16,17]

Ultrafiltration Device Therapy to Reduce Congestion

As HF continues to be a major heath problem, device therapy to treat ADHF is evolving (Table 1). Symptoms associated with ADHF are attributable to increased ventricular filling pressures and the resultant pulmonary and systemic venous congestion. Loop diuretics are the most commonly used medications to reduce congestion. Recently, however, the efficacy and safety of IV-administered diuretics has been challenged. In a large single-center study, high-dose diuretics (i.e., furosemide dose > 160 mg) were associated with higher mortality rates compared to cohorts receiving lower doses.18 Similarly, the ADHERE (Acute Decompensated Heart Failure National Registry) investigators demonstrated that patients with ADHF treated with low-to-moderate doses of IV loop diuretics have lower hospital mortality, fewer instances of worsening renal function, lower ICU utilization, and shorter hospital length of stay than patients treated with high-dose IV loop diuretics.[19,20]

Ultrafiltration is a novel alternative to loop diuretics for the management of fluid overloaded patients with ADHF. Slow continuous ultrafiltration results in effective isotonic fluid removal with the use of a transportable

console with a simple operator interface, use of disposable single-use extracorporeal blood circuit, and venous access that can provide 10 to 40 ml/min of blood (Figure 3). Rates of fluid removal typically range from 150 cc/hr up to 250 cc/hr, which equates to 3.6 to 6.0 liters removed per day.[21] In the EUPHORIA trial (Early Ultrafiltration in Patients with Decompensated Heart Failure and Observed Resistance to Intervention with Diuretic Agents), early ultrafiltration prior to IV diuretics in 20 high-risk ADHF patients with fluid overload and diuretic resistance permitted the discharge of 60% of the patients in less than three days.22 In addition, aggressive fluid withdrawal (-8,500 ml) with ultrafiltration in this study was not associated with worsening renal failure, electrolyte abnormalities, or symptomatic hypotension.

Subsequently, there have been two multicenter, prospective, randomized controlled trials that have assessed the feasibility, safety, and efficacy of early ultrafiltration versus usual care in the management of patients with ADHF. In the RAPID-CHF (Relief for Acutely Fluid Overloaded Patients with Decompensated Congestive Heart Failure) trial, 40 patients were randomized to the use of high-dose loop diuretics or a single 8-hour course of early ultrafiltration with the Aquadex system 100.[23] The results showed that ultrafiltration was well tolerated, associated with a greater trend toward greater weight loss and fluid removal at 24 hours compared to usual care, and significantly improved symptoms of congestion. The larger, multicenter, UNLOAD (Ultrafiltration versus IV Diuretics for Patients Hospitalized for Acute Decompensated Congestive Heart Failure) trial further compared the safety and efficacy of loop diuretics to ultrafiltration in 200 patients.[24] At 48 hours, ultrafiltration resulted in greater weight loss (5.0 + 3.1 kg vs. 3.1 + 3.5 kg) and net fluid loss (4.6 vs. 3.3 liters) than in the usual care group (p=0.001). In addition, at 90 days the ultrafiltration group had fewer patients rehospitalized for HF (16 of 89 [18%] vs. 28 of 87 [32%]; p=0.037), HF rehospitalizations (0.22 + 0.54 vs. 0.46 + 0.76; p=0.022), rehospitalization days (1.4 + 4.2 vs. 3.8 + 8.5; p=0.022) per patient, and unscheduled visits (14 of 65 [21%] vs. 29 of 66 [44%]; p=0.009). An important criticism of UNLOAD relates to comparing a less than aggressive diuretic regimen as usual care to ultrafiltration, where rate and duration of volume removal were not specified in the study protocol. The UNLOAD investigators, however, note that 43% of patients in the usual care group lost at least 4.5 kg during hospitalization, a weight loss greater than that observed in 75% of patients enrolled in ADHERE. At this time, ultrafiltration is an available, safe, and effective technique to reduce congestion in patients with ADHF. The latest ACC/AHA treatment guidelines state "ultrafiltration is reasonable for patients with refractory congestive not responding to medical therapy," with this form of therapy updated to a class IIa recommendation with a level of evidence B. A prospective, randomized, multicenter trial is currently underway to evaluate the safety and efficacy of ultrafiltration compared to usual care in patients with advanced ADHF complicated by the cardiorenal syndrome.

Device Therapy to Improve End Organ Perfusion

Intra-aortic Balloon Pump Support

A significant subset of patients with advanced heart failure, despite aggressive medical therapy, present with impending or overt cardiogenic shock in a variety of settings, including myocardial infarction, decompensated advanced chronic HF, and complicated acute de nova heart failure (i.e. myocarditis). Associated in-hospital mortality rates for this subset of patients can be extremely high. Inotropic therapy or intra-aortic balloon pump (IABP) support is generally reserved for patients with advanced heart failure and evidence of hypoperfusion and hypotension refractory to standard therapy. While multiple clinical trials have demonstrated the unfavorable results of inotropic therapy,[25, 26] IABP support in patients with post-myocardial infarction-ADHF has been shown to be safe and effective.[27-29]

Although IABP use has not generally been advocated as part of the standard armamentarium for treating ADHF, several small studies have shown that IABP support can be used successfully and safely used in patients with advanced ADHF awaiting urgent heart transplantation or permanent ventricular device support.[30-32] A particularly useful form of IABP support is placing the device through the brachial or left axiliary artery to allow for ambulation while awaiting heart transplantation.[30] The primary beneficial effects of a properly timed IABP in an ADHF setting include diastolic aortic pressure augmentation, LV afterload reduction, LV volume and LV end-diastolic pressure reduction, an increase in cardiac output and ejection fraction, and an associated increment in coronary flow.[29] However, the studies utilizing IABP as a treatment option for advanced ADHF are observational, not randomized.

Continuous Aortic Flow Augmentation

Continuous aortic flow augmentation (CAFA) using the Candon system (Orqis Medical) is a novel investigational approach to treating patients with advanced ADHF. Preclinical investigation in a canine heart failure model demonstrated that superimposing additional continuous flow on existing pulsatile flow within the descending aorta caused a progressive decrease in left ventricular volumes and cardiac filling pressures and an increase in ejection fraction over four hours of treatment.[33] The purpose is not to directly augment cardiac output but, rather, to favorably alter arterial flow characteristics to achieve downstream vasodilation that in **turn** improves cardiac unloading and renal function.[34] The CAFA system includes a pair of percutaneous 12F arterial femoral catheters, a left iliac inflow catheter, and a right-sided, pigtail-shaped outflow catheter positioned in the proximal portion of the descending thoracic aorta (Figure 4A). The effect is approximately 1.5 L/min of flow delivered via an extracorporeal magnetically driven centrifugal flow pump with a pump speed range of 3,200 to 4,600 revolutions per minute.

The impact of CAFA on both hemodynamics and clinical responses in patients with advanced ADHF was examined in the randomized, controlled MOMENTUM (Multicenter Trial of Orqis Medical Candon System for the Enhanced Treatment of Heart Failure Unresponsive to medical therapy) trial.[35] The patient population represented the sickest population ever studied in a randomized ADHF control trial as reflected by baseline hemodynamics (pulmonary capillary wedge pressure - 29 mmHg, cardiac index - 2.1 L/min/m^2), renal function (serum creatinine 1.7 mg/dl) and two-month mortality rates (-33%) similar to that observed in investigations of destination ventricular assist devices. The trial confirmed a hemod$_{y\,n}$amic effect in the device group with short-term CAFA compared to the control group (pulmonary capillary wedge pressure decrease from 28.8 + 6.3 mmHg to 24.9 + 7.2 mmHg in the device group, between-group P=0.074, and an increase in cardiac index from 2.05 + 0.53 to 2.44 + 0.52 L/min/m^2, between-group P < 0.0001). The trial, however, did not demonstrate longer-term clinical

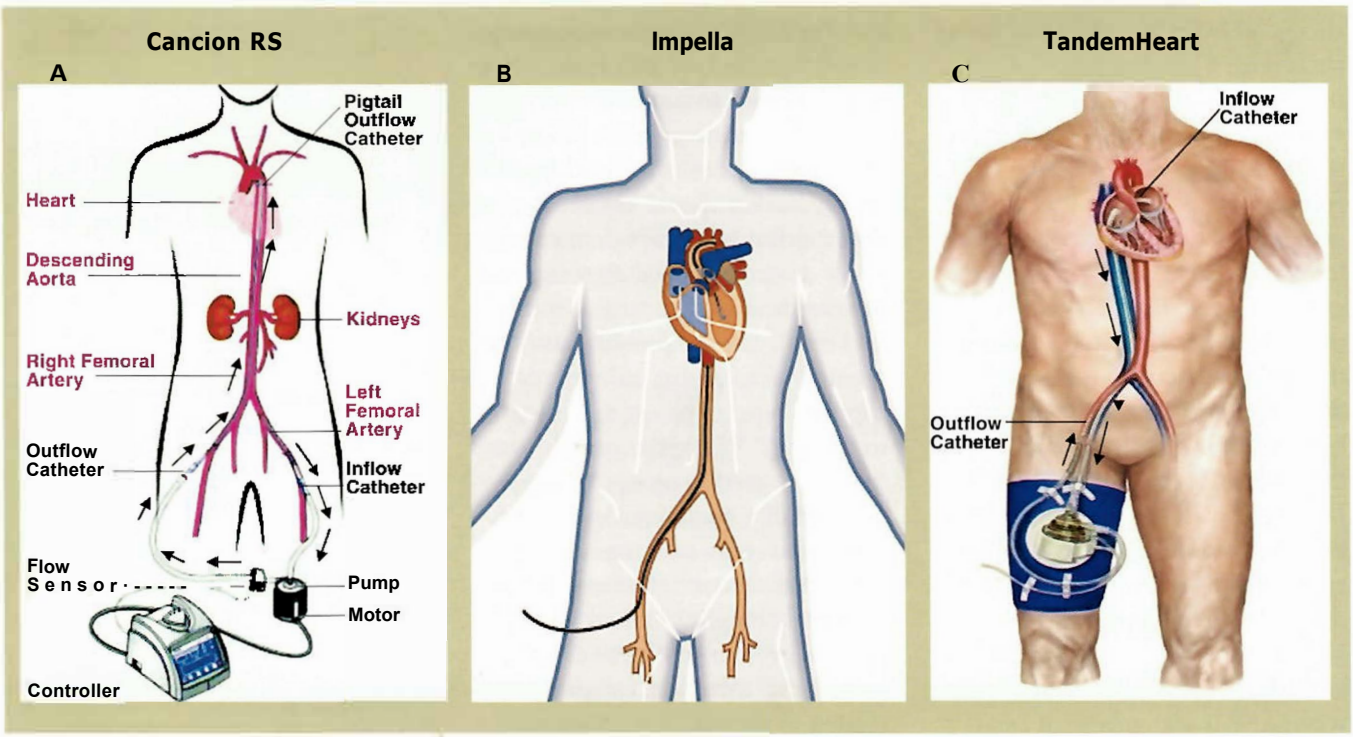


Figure 4. Percutaneous Devices to Improve End Organ Perfusion in complicated ADHF

(A) Cancion system for continuous flow augmentation with the inflow cannula (12F) is placed in the femoral artery and returns blood via a centrifugal pump to the proximal portion of the descending thoracic aorta by a pigtail outflow catheter (B) Impella recover LP2.5 system uses a micro axial pump mounted on a 9F catheter to unload the left ventricle and provide up to 2.5 L/min of blood flow in the thoracic aorta. (C) The TandemHeart system with the 21F inflow cannula is inserted through the femoral vein and placed across the interatrial septum into the left atrium to return oxygenated blood via a centrifugal pump into the femoral artery (15-17F). Arrow indicates direction of blood flow.

benefit because enrollment ended early due to an inability to demonstrate significant benefit of the primary composite end point in face of excess device group bleeding. These hemodynamic and clinical observations provide insight to guide future investigations of the potential clinical value of a longer-term CAFA device.

Impel/a

The l$_{m p}$ella (Recover LP 2.5 and LP 5.0 support systems, Impella Technologies of Abiomed Corporation) is a newer investigational percutaneous assist device for patients with advanced ADHF. The Impella Recover LP 2.5 device uses a catheter-based micro rotary blood pump connected to a mobile driver (Figure 4B). The pump is inserted via the femoral artery and placed retrograde through the aortic valve. The microaxial pump continuously aspirates blood from the left ventricle and expels it to the ascending aorta with a maximal flow of 2.5 L/min.[36] Similar to the TandemHeart system, the Impella device has been successfully used as a bridge to recovery for patients with cardiogenic shock during percutaneous interventions or post-cardiac surgery and as a bridge to heart transplantation.[37, 38] In contrast to the TandemHeart, the approach does not need transseptal puncture, making it easier to deploy. The ISAR-SHOCK (Impella LP 2.5 vs. IABP in Cardiogenic SHOCK) trial was the first study to show this percutaneous device technology, in a randomized manner, was feasible and safe and provided superior hemodynamic support compared with IABP in patients with cardiogenic shock caused by acute myocardial infarction.[39]

Tandem Heart

The TandemHeart ventricular assist device by CardiacAssist'[0] provides direct augmentation of cardiac output by a percutaneous approach, with the inflow cannula inserted through the femoral vein and placed across the interatrial septum into the left atrium and the outflow cannula placed in the femoral artery (Figure 4C). The TandemHeart is a continuous flow centrifugal assist device with an extracorporeal pump that withdraws oxygenated blood from the left atrium and propels it by a magnetically driven impellar pump (speed range 3,000 to 7,500 revolutions per minute) to the femoral artery for retrograde perfusion up to 4.5 L/min. For patients with acute de novo cardiogenic shock, this device has provided short-term support as a "bridge-to-recovery" and as a bridge to permanent LVAD placement (bridge to bridge), and it has acted as a "bridge-to-heart transplant" for patients in refractory cardiogenic shock as a means to stabilize and optimize perioperative risk prior to surgery.[41-44]

In a prospective, randomized study in patients with cardiogenic shock, Burkhoff et al. demonstrated that the TandemHeart percutaneous assist device achieved significantly greater increases in cardiac index and mean arterial pressure and greater decreases in pulmonary capillary wedge pressure compared to the IABP. While their study was underpowered to assess an effect on mortality, there were no significant differences in serious adverse outcomes between the two groups. Potential complications, however, include groin bleeding and/or hematoma, infection, coagulopathy related to the need for anticoagulation, ischemic and/or bleeding neurologic events, limb ischemia, and the creation of an atrial septal defect after removal of the 21F transseptal cannula.

Percutaneous Extracorporeal Membrane Oxygenation

Extracorporeal life support with percutaneous venoarterial extracorporeal membrane oxygenation (ECMO) has also been used to resuscitate patients in severe refractory cardiogenic shock as a bridge to LVAD (bridge-to-bridge) and as a bridge to transplant (Figure 5).[45, 46] The benefit of ECMO support compared to left-sided percutaneous ventricular assist devices (TandemHeart, Impella pump) is rapid, upfront, complete circulatory support and rapid improvement in oxygenation that may be clinically indicated if coexisting overt right-sided heart failure and severe, refractory hypoxia are present. The utility of ECMO as a means of circulatory support is, however, limited by a high rate of thromboembolic complications and significant device-associated mortality.[47, 48] Also, ECMO does not completely decompress the left

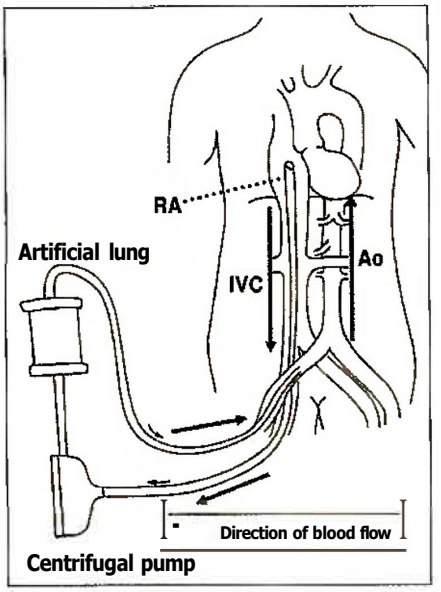


Figure 5. Percutaneus Extracorporeal Membrane Oxygenation

The inflow cannula withdraws deoxygenated blood from the right atrium via a centrifugal pump to the artificial lung, then to the iliac artery. RA=right atrium; IVC=inferior vena cava; Ao=aorta.

ventricle and is associated with increased LV after load, which may prevent myocardial recovery in patients with acute de novo, nonischemic ADHF.[47] Comparative, prospective, randomized studies with percutaneous ECMO and left-sided ventricular assist devices in patients with refractory cardiogenic shock are lacking due to the inherent difficulties in studying such a sick patient population.

Conclusions

As heart failure continues to be a major heath problem, device therapy to prevent and treat ADHF is evolving. There is growing interest in new devices that optimize the clinical recognition and management of impending heart failure decompensation to minimize ADHF episodes. Early trials examining intracardiac hemodynamic monitoring systems have demonstrated high accuracy to detect right-sided intracardiac pressure along with a good safety profile. However, there is no data regarding which measurement (right ventricular or pulmonary artery pressures) provides the best guide in ambulatory heart failure patients; more importantly, beneficial outcome-based studies are at this time lacking. Large multicenter trials are underway to establish the clinical and possible economic benefit of !CHM-guided care in this patient population. While the routine use of a pulmonary artery catheter to guide therapy for patients hospitalized with ADHF is not recommended, the hemodynamic assessment is useful in patients being evaluated for heart transplantation or for patients not responding to aggressive medical therapy.

Ultrafiltration, a novel and safe technique to reduce congestion in patients with ADHF, is an attractive therapy given the increasingly recognized adverse effects of diuretic therapy. Possible indications for ultrafiltration include diuretic resistance and refractory volume overload with or without worsening renal function despite aggressive standard medical therapy. A broad range of investigational and approved devices have been used for ADHF complicated by impending or overt cardiogenic shock. IABP support represents first-line treatment in part based on its widespread use, ease of placement, and safety profile. The Impella and TandemHeart percutenaous ventricular assist devices offer greater hemodynamic support than IABP therapy and can potentially be used as a bridge to recovery, permanent LVAD placement, or heart transplantation in those with refractory cardiogenic shock. These percutaneous ventricular assist devices require relatively large inflow and outflow cannulas, systemic anticoagulation, patient immobility, and in the case of the TandemHeart, expertise in interatrial septal cannulation. The hope is that newer devices in the future will continue to create more favorable therapeutic options for patients dying from advanced ADHF.

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