The optimal management strategy for patients with acutely decompensated heart failure has been limited to the use of various pharmacologic agents. However, with technological advances in mechanical devices, nonpharmacologic approaches now are available to supplement pharmacologic management. These devices range in sophistication and expertise and target various features of the acute heart failure patient, such as circulatory failure, volume overload, renal insufficiency, and respiratory failure. As more innovations and technologies emerge, these new devices may become a cornerstone of the management strategy in cardiac patients. (Crit Care Med 2008; 36[Suppl.]:S121–S128)

The use of IABP has been dominated by its use in advanced ischemic heart disease complicated by cardiogenic shock. The largest experience was reported from the Massachusetts General Hospital and included >4,000 patients supported since the 1960s (5). Overall mortality improved in this series of patients over time, but remained high at approximately 20%. The mortality was higher when the primary indication was nonischemic shock, an indication which was predominant in the last few years of this series (5). Use in acutely decompensated chronic heart failure has been limited to small case series from the 1970s and 1980s.

In most settings, IABP counterpulsation is used as a bridge to more definitive therapies such as coronary bypass surgery, transplantation, or placement of a ventricular assist device. Bridging to myocardial recovery also may be possible, current use for mechanical circulatory support; its development dates back to the 1950s (2). Its first successful clinical use was reported by Dr. Kantrowitz and colleagues (3) in 1968 in a patient with cardiogenic shock following a myocardial infarction. The American College of Cardiology/American Heart Association has given IABP a class I recommendation for use in pharmacologically resistant cardiogenic shock. IABP is effective in a variety of situations, including cardiogenic shock following myocardial infarction, circulatory support in the perioperative cardiac surgery period, high risk percutaneous coronary intervention, and heart transplantation (as a bridge treatment). Since the introduction of a percutaneously insertable version in 1979, IABP has become the most frequently used mechanical circulatory assist device in the world.

The physiologic theory behind aortic counterpulsation is that balloon inflation during ventricular diastole augments antegrade coronary perfusion and balloon deflation during ventricular systole decreases aortic impedance, which decreases resistance to ejection. These effects result in decreased myocardial wall stress and increased cardiac output; myocardial oxygen consumption may fall by >50% and stroke volume may increase by as much as 30% (4). Optimal IABP performance is dependent on multiple factors, including the position of the balloon within the descending thoracic aorta, the balloon displacement volume, the relationship of balloon to aortic diameter, the type of inflating gas, inflation/deflation timing, and hemodynamic variables such as circulating blood volume, blood pressure, and vascular resistance. Helium is used as the distending gas because it can be moved quickly in and out of the balloon given its low density, and it is inert if it escapes into the arterial circulation. Careful attention to balloon size and inflation/deflation timing is critical to optimize the hemodynamic benefit and to prevent complications. Concomitant systemic anticoagulation usually is required. Complications include thrombocytopenia, vascular compromise or injury, distal embolization, bleeding, and infection. Although most patient sizes can be accommodated, children are generally too small for support. Contraindications include significant aortic insufficiency, active infection, and advanced aortic-iliac disease.


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and IABP often is employed in the post-
trevascularization setting or in patients
suffering from inflammatory myocardial
injury.

**Extracorporeal Membrane
Oxygenation**

Extracorporeal membrane oxygen-
ation (ECMO) uses conventional cardi-
pulmonary bypass technology to support
the circulation with continuous nonpul-
satile cardiac output and extracorporeal
oxygenation. ECMO can be provided via
a venous-arterial cannulation setup that
provides both respiratory and circulatory
support or a venovenous cannulation
setup that provides only respiratory sup-
port. The circuit consists of a venous re-
servoir, a centrifugal pump, a membrane
oxygenerator, pre- and postmembrane oxy-
genator monitors, and a rewarming cir-
cuit. In small children, venous-arterial
ECMO typically uses the right internal
jugular vein and carotid artery for vascu-
lar access. In adults, the right atrium
and aorta are used in the operating room; the
femoral vein and artery are used for per-
cutaneous insertion.

ECMO is the most often used mechan-
cical circulatory support in neonatal and
pediatric units because it can be used in
children as small as a few pounds (6). It
can also be used in adults with respira-
tory and circulatory collapse, but is limited
by the need for aggressive anticoag-
ulation, full-time perfusionist support,
and generally large cannulae (arterial,
16- to 20-Fr, venous, 18- to 28-Fr) that
usually require surgical placement. Also,
long-term support is complicated by a
systemic inflammatory state that is seen
with cardiopulmonary bypass and may in-
clude multiorgan system failure, resis-
tant vasoplegia, coagulopathy, and stroke.
For these reasons, ECMO support in
the adult patient is limited to short
periods until either myocardial or pulmo-
nary recovery has occurred or more de-
finite circulatory devices (i.e., ventricu-
lar assist devices [VADs]) can be placed.
Concomitant IABP support is often used,
especially if ischemic heart disease is
present. Simultaneous decompression of
the left ventricle with atrial cannulation
also may be necessary to avoid recurrent
pulmonary edema.

There have been limited reports of
ECMO used outside of the context of the
operating room. In an early series, ECMO
was used for refractory cardiogenic shock
and/or cardiac arrest, in 38 patients aged
10–78 yrs. The device was implanted in
the catheterization laboratory, intensive
care unit, and the emergency room, and
patients were supported to myocardial re-
covery, transplantation, or placement of a
VAD (7). Ninety-two percent of patients
stabilized by achieving flows of >2.0
L/min per m² and support lasted up to
130 hrs. However, mortality remained
high and only 24% were considered long-
term survivors. Unfortunately, this mor-
tality is similar to contemporary postcar-
diomyotomy experiences. In a retrospective
examination of 219 patients supported
with ECMO following cardiac surgery in
Germany, 24% were eventually dis-
charged, with a long-term (5 yrs) survival
of 74% in these patients (8). In a Cleve-
land Clinic experience of 202 patients with
cardiac failure, 30-day survival was 38% (9).

The use of ECMO in acutely decomp-
ensated adult patients with chronic
heart failure has been limited to case
reports and has not been systematically
reviewed. Therefore, it appears that the
optimal use of ECMO in the nonoperative
setting is to provide short-term circula-
tory support when shock persists despite
IABP counterpulsation and maximal
pharmacologic support if an ECMO team
is available within a given institution. In
the pediatric population, it remains the
cornerstone of providing mechanical cir-
culatory support, although other circula-
tory assist devices designed for neonates
and children are in development (6).

**Ventricular Assist Devices**

VADs are mechanical blood pumps
that serve to either augment or replace
the function of either the left or right
ventricle. They are currently used for
three purposes: a) a bridge to myocardial
recovery in acute ventricular failure (i.e.,
postcardiomyotomy or shock complicating
myocarditis or myocardial infarction); b)
a bridge to heart transplantation in
chronic ventricular failure; and c) as per-
manent therapy for end-stage chronic
heart failure, also known as destination
therapy. Most currently available devices
are surgically implanted and require car-
diopulmonary bypass to implant. Percu-
taneous assist devices are in develop-
ment, and one is commercially available
e.g., TandemHeart).

The primary indication for VAD sup-
port is medically refractory heart failure,
usually defined by a cardiac index of <2.0
L/min per m², a pulmonary capillary
wedge pressure of >20 mm Hg, and a
systolic blood pressure of <80 mm Hg
despite maximal medical support includ-
ing pharmacologic agents and IABP. In
the case of acute heart failure in the in-
tensive care unit, the surgically im-
planted ventricular devices generally are
reserved for those patients who can be
medically stabilized in some fashion be-
fore proceeding onto cardiac surgery. The
decision to use the VAD as either a bridge
to recovery or transplant, or as destina-
tion therapy, must be clearly defined be-
fore surgical intervention. A more com-
plete discussion of the currently available
and investigational VADs is available in
other excellent contemporary reviews. In
the following discussion, we will limit
our discussion to percutaneous VADs as
they pertain to the management of acute
heart failure.

Percutaneous left VADs are attractive
alternatives to surgically implanted de-
vices because they can be placed quickly
and used to bridge a patient in shock
through multiorgan system dysfunction.
They also provide the healthcare team
time to obtain medical and psychosocial
details when there is a paucity of clinical
information available at the time of pre-
sentation. This concept of a “bridge to a
decision” is increasingly important in the
patient who presents with acute heart
failure during off hours. Surgical out-
comes with conventional VADs also are
improved when multiorgan system dys-
function can be reversed or stabilized
before subjecting the patient to cardiopul-
monary bypass. Currently, only one
device is FDA approved and in use; other
investigational devices are undergoing
study.

**TandemHeart**

The TandemHeart device (Cardiac
Assist, Pittsburgh, PA) (Fig. 1) is a left
atrial to femoral arterial bypass system
that can be inserted percutaneously and
is able to provide active flow via a centri-
fugal pump independent of native heart
rhythm (10, 11). Inflow to the pump is
provided through a 21-Fr polyurethane
transseptal cannula with a large end hole
at its distal tip and 14 side holes to facil-
itate decompression of the left atrium.
The centrifugal flow pump is a low prime
volume (10-mL) device that houses a six-
blade rotating impeller and is powered by
a direct current electromagnetic rotary
motor. The output is delivered via 16-
to 18-Fr cannula to the femoral artery
and systemic anticoagulation is required. The
The device can provide up to 5 liters per min of blood flow, is not gated to the patient’s native rhythm, and does not preclude the use of concomitant IABP. Contraindications to the device include advanced right ventricular failure, ventricular septal defect, aortic insufficiency, and severe peripheral vascular disease.

The TandemHeart has been studied in clinical trials and is more effective than IABP in improving hemodynamics. Dr. Thiele and colleagues (12) reported a randomized comparison of IABP support to the TandemHeart in 41 patients with cardiogenic shock following myocardial infarction who subsequently underwent percutaneous coronary intervention. The TandemHeart was more effective in improving the primary outcome and the cardiac power index (cardiac index \( \times \) mean arterial pressure \( \times 0.0022 \)), as well as lowering the wedge pressure and decreasing lactate production. However, these effects were not sustained and the 30-day mortality was similar in both groups (43% IABP vs. 45% TandemHeart). Furthermore, severe bleeding and acute limb ischemia were more common in the TandemHeart group. In another small randomized trial of cardiogenic shock (primarily due to acute myocardial infarction), Dr. Burkhoff and colleagues (13, 14) reported significant improvements in cardiac index, mean arterial blood pressure, and wedge pressure in patients supported with the TandemHeart. These benefits also were apparent in those with persistent shock despite IABP support. However, overall 30-day survival was not improved. The TandemHeart device also has been successfully used to support patients with severe left ventricular dysfunction while they are undergoing percutaneous recanalization of complex coronary lesions (15).

**Impella Recover**

The Impella Recover percutaneous ventricular assist device (Abiomed, Danvers, MA) (Fig. 2) is a microaxial system that can be used for either left or right ventricular assist to provide short-term circulatory support for several days. The device comes in two sizes, the LP 2.5 with a 12-Fr pump diameter capable of 2.5 L/min of flow and the LP 5.0 with a 21-Fr diameter that can provide up to 5 L/min; both systems are mounted on a 9-Fr pigtail catheter. The inflow cannula with its pump is inserted across the aortic valve under fluoroscopic guidance. The device sits across the aortic valve and draws blood through a distal port from within the ventricle, thereby actively unloading the ventricle. Blood is then pumped into the aorta through a proximal port of the device, which sits in the ascending aorta. Surgically implantable versions also are available. The device is powered by an integrated electric motor and only modest intensity anticoagulation is required (16, 17). The device is contraindicated in patients with prosthetic aortic valves, severely calcified aortic valves, and severe peripheral vascular disease.

The Impella has been primarily studied in Europe and remains investigational in the United States. Published studies to date have been limited to nonrandomized experiences. Using the surgically placed Impella LD device, Dr. Siegenthaler and colleagues (18) reported the outcomes of 24 postcardiotomy patients with persistent low output syndrome in a surgical case series. The majority of patients required concomitant IABP support. When compared with a historical control group requiring IABP support postcardiotomy, survival was similar. However, survival with the Impella was greater than IABP support when residual cardiac function was able to provide at least 1 L/min of cardiac output.

The percutaneous device appears safe in human studies. In 19 patients (63%...
with left ventricular ejection fractions <25%) undergoing high risk angioplasty, the device was associated with no significant aortic regurgitation, blood loss, or peripheral vascular complications. However, the device was used only for a few hours to support the procedure and hemodynamic data were not collected. Biventricular use also has been reported (19). A U.S. clinical trial is currently in progress.

**Continuous Aortic Flow Augmentation**

The continuous aortic flow augmentation Cancion system (Orqis, Lake Forest, CA) (Fig. 3) is unique among current circulatory devices in that it does not provide direct augmentation of cardiac output, but rather recirculates arterial flow into the descending aorta drawn from the iliac artery (20). In low output syndromes, decreased aortic flow may stimulate downstream renal and vascular signals that lead to renal dysfunction and increases in vascular resistance. These signals may be the result of endothelial dysfunction and impaired nitric oxide induced by a reversal of flow along the aortic walls. By providing modest (1.5 L/min) continuous antegrade aortic flow and conserving forward flow during the entire cardiac cycle, vasodilation may be improved in downstream vascular beds with subsequent falls in systemic vascular resistance and pulmonary capillary wedge pressure.

The Cancion system consists of a magnetically levitated centrifugal pump (priming volume, 32 mL) that draws blood from a percutaneously placed 12-Fr cannula in the left common femoral artery and returns blood to the descending aorta via a pigtail outflow cannula in the right femoral artery placed distal to the subclavian artery origin. The continuous output is superimposed on the pulsatile native cardiac output without gating. The entire blood capacity of the system is 108 mL. Systemic anticoagulation with intravenous heparin is required.

The first reported use of the device was in 2003, when the device successfully supported a 62-yr-old man with ischemic cardiomyopathy and heart failure refractory to inotropic support (21). The device was used for 3 days and was subsequently electively explanted. The largest reported experience with the device involved 24 heart failure patients from multiple centers in Europe and the United States (20). Patients in the study had to have been hospitalized with an acute decompensation of chronic heart failure and either unresponsive to or unweanable from inotropic support (21). The device was used for up to 5 days. There were significant improvements in the pulmonary capillary wedge pressure (28.5 ± 4.9 to 19.8 ± 7.0 mm Hg; p < .0001), cardiac index (1.97 ± 0.44 to 2.27 ± 0.43 L/min per m², excluding augmented aortic flow; p = .0013), and systemic vascular resistance (1413 ± 453 to 1136 ± 381 dyne·sec/cm²; p = .0008). Importantly, serum creatinine trended downward and this trend was sustained at 72 hrs. Based on these promising early results, the device is the subject of an ongoing randomized trial in heart failure, the Multicentered Trial of the Orqis Medical Cancion System for the Enhanced Treatment of Heart Failure Unresponsive to Medical Therapy.

**Ultrafiltration**

Ultrafiltration to manage the volume overloaded heart failure patient was proposed by Heinrich Bechold in 1907. In 1974, Dr. Silverstein and colleagues (22) reported the use of ultrafiltration in patients with biventricular heart failure complicated by advanced renal insufficiency. Dr. Asaba and colleagues (23) reported that ultrafiltration was well tolerated despite large volume fluid removal. Hemodynamic benefits include rapid lowering of filling pressures, decreases in pulmonary arterial pressures, and increases in cardiac index. There also are improvements in the neurohormonal profile with demonstrated reductions in norepinephrine, renin, and aldosterone (24, 25). These effects make ultrafiltration a particularly attractive alternative to diuretics, which are limited by the cardiorenal syndrome, neurohormonal activation, electrolyte disturbances, and a potential acceleration of heart failure.

Recent advances in ultrafiltration technology have led to a resurgence in interest in this therapy. The Aquadex FlexFlow Fluid Removal System (CHF Solutions, Brooklyn Park, MN) (Fig. 4) is a small device (about the size of an intravenous pump) that can produce up to 500 mL/hr of ultrafiltrate that is isotonic to plasma and uses a modest blood flow rate of 10–40 mL/min. The device contains a disposable polysulphone filter that contains a blood volume of 33 mL and can be used up to 24 hrs with heparin anticoagulation. The device also employs peripherally placed venous catheters rather than the standard large bore central venous catheter traditionally used for dialysis. This access allows the therapy to be delivered at the patient’s inpatient or outpatient bedside. Despite large volume fluid removal, there appears to be no clinically relevant impact on blood pressure, heart rate, or electrolytes. However, the rate of ultrafiltration likely is limited to the speed at which interstitial edema can be reabsorbed into the intravascular space; i.e., the plasma refill rate (26). These considerations may have relevance on the impact of ultrafiltration on renal function as assessed by blood urea nitrogen and serum creatinine during therapy. The system is FDA approved for the management of the volume overloaded patient.

Several early studies confirmed that the use of this device was as effective and safe as usual care (e.g., diuretic therapy). Dr. Jaski and colleagues (27) reported the...
of the Aquadex system in upper extremity veins of 23 patients with volume overload. Twenty-one of 23 patients achieved the removal of greater than one liter fluid removal in less than 8 hrs without significant adverse events. In the RAPID-CHF trial (28), 40 hospitalized patients with heart failure were randomized to a single 8-hr ultrafiltration session vs. usual medical care. Although there was significantly greater fluid removal with ultrafiltration (4650 vs. 2838 mL; \( p = .001 \)) and it was well tolerated, the primary end point of weight loss at 24 hrs was not met (2.5 vs. 1.8 kg; \( p = .240 \)).

Ultrafiltration may be particularly relevant in the diuretic-resistant patient. In the Acute Decompensated Heart Failure National Registry, 20% of patients admitted with heart failure have either no change or an increase in weight during their hospitalization, presumably due to diuretic resistance. One trial tested the hypothesis that early peripheral venovenous ultrafiltration in patients with decompensated heart failure complicated by renal insufficiency and diuretic resistance would be safe, effective, and shorten hospital stay (29). Ultrafiltration was initiated within 4.7 ± 3.5 hrs of admission before the use of intravenous diuretics and continued until euvolemia. A total of 8654 ± 4205 mL were removed with ultrafiltration. Twelve patients (60%) were discharged in ≤3 days. One patient was readmitted in 30 days. Weight (\( p = .006 \)), MN Living with Heart Failure scores (\( p = .003 \)), and Global Assessment of Functioning (\( p = .00003 \)) improved after ultrafiltration and at 30 and 90 days. Median B-type natriuretic peptide levels decreased after ultrafiltration (from 1230 to 788 pg/mL) and at 30 days (815 pg/mL) (\( p = .035 \)). Blood pressure, renal function, and medications were unchanged.

The most compelling data regarding the safety and efficacy of peripheral ultrafiltration comes from the Ultrafiltration Versus Intravenous Diuretics for Patients Hospitalized for Acute Decompensated Heart Failure (UNLOAD) trial (30). This prospective, randomized, multicenter trial compared the early use of the Aquadex venovenous ultrafiltration system with intravenous diuretics in 200 heart failure patients admitted with volume overload. The two primary end points were weight loss and dyspnea score at 48 hrs; secondary end points included functional capacity, heart failure hospitalizations, and unscheduled visits. Safety end points included renal function, blood pressure, and electrolytes. Patients were followed for 90 days after hospitalization. The patients were well matched: The age was 63 yrs, 71% had ejection fraction <40%, and 69% were men. The population was typical of a volume overloaded heart failure cohort with an average blood urea nitrogen 33 mg/dL, serum creatinine 1.5 mg/dL, and brain natriuretic peptide 1300 pg/mL. Overall, 65% to 70% were on ACE inhibitors and the average admitting furosemide-equivalent dose was 120 mg to 130 mg per day (range, 20–800 mg). Weight loss was greater in the ultrafiltration group (5.0 ± 3.1 kg vs. 3.1 ± 3.5 kg; \( p = .001 \)), although both groups had similar improvements in dyspnea score. Importantly, ultrafiltration had a significant impact on resource utilization at 90 days with fewer rehospitalizations (18% vs. 32%; \( p = .037 \)), days in the hospital (1.4 ± 4.2 vs. 3.8 ± 8.5; \( p = .022 \)), and unscheduled visits (21% vs. 44%; \( p = .009 \)). There were no significant differences in renal function, death (nine in ultrafiltration, 11 in usual care), or other adverse events. Outcomes beyond 90 days are not known.

For the volume overloaded patient with acute heart failure in the intensive care unit, peripheral ultrafiltration does appear effective and safe in treating volume overload and may be especially useful when blood pressure, renal insufficiency, and/or diuretic resistance complicate the clinical picture.

Noninvasive Positive Pressure Ventilation

Acute cardiogenic pulmonary edema is a manifestation of acute heart failure characterized by severe respiratory distress, hypoxemia, and in its late stages, hypercapnia. It also is associated with high adrenergic tone, increased myocardial oxygen consumption, and increased work of breathing. While many patients may respond to conventional medical treatments using diuretics, oxygen, and vasodilators, “invasive” mechanical ventilatory support (e.g., endotracheal intubation) often is required and may be preferable if respiratory distress cannot be alleviated quickly. However, endotracheal intubation may be complicated by aspiration, laryngeal injury, barotrauma, and pneumonia. In 1936, a “pulmonary plus pressure machine” was used with a tight-fitting face mask to treat patients with cardiogenic pulmonary edema in an attempt to spare the need for intubation (31). Noninvasive ventilation for respiratory failure has improved as technological advances in masks and ventilators have occurred. It has been well studied in acute respiratory failure and is effective in reducing the need for endotracheal intubation (32).

There also are acute hemodynamic benefits. In patients with chronic heart failure, positive airway pressure increases intrapleural and pericardial pressure, which decreases venous return (i.e., preload) and transmural myocardial pressure (i.e., afterload). Subsequently, there are reductions in ventricular diameter and functional mitral regurgitation and improvements in cardiac output (33). When sleep-disordered breathing complicates chronic heart failure, noninvasive positive pressure ventilation (NIPVV) increases ejection fraction, lowers sympathetic activation, and improves functional capacity (34, 35). However, NIPPV effects are volume dependent.
and will decrease venous return and cardiac output in hypovolemic subjects. Improvements in pulmonary mechanics include greater alveolar recruitment with decreased shunting and increase in pulmonary compliance.

Noninvasive positive pressure ventilation can be delivered using either continuous positive airway pressure (CPAP) or variable positive airway pressure that is dependent on the respiratory phase (BIPAP). Oxygen is generally delivered using a tight-fitting mask or helmet attached to a ventilator. The amount of pressure delivered is titrated to effect and comfort. CPAP is relatively simple to use; oxygen is delivered at a given pressure; e.g., 10 cm H₂O, independent of respiratory phase. An expiratory valve is used to maintain constant intrathoracic pressure. BIPAP support is a more complex mode that requires a ventilator, operator experience, and adequate patient coordination to deliver pressure support that varies with inspiration and expiration. Oxygen delivery is initiated at low pres-

Figure 5. Continuous positive airway pressure decreases the rate–pressure product and increases the stroke volume index in patients with acute pulmonary edema. Circles, oxygen alone. Triangles, oxygen plus continuous positive airway pressure. Values are significantly different at 3-hr time point (38). RPP, rate–pressure product; BPM, beats per minute.

Figure 6. In a meta-analysis, noninvasive ventilation for acute pulmonary edema lowered mortality. Reprinted with permission (36).
sures and gradually incremented as tolerated (e.g., expiratory pressure 5 cm H$_2$O and inspiratory pressure 12–25 cm H$_2$O). Providing additional inspiratory pressure support may be particularly helpful in patients developing fatigue and hypercapnia. BIPAP also appears to decrease the need for endotracheal intubation, but it is not clear if it offers any particular benefit over CPAP (36).

The use of NIPPV in acute pulmonary edema has been effective and safe in clinical trials in reducing the need for intubation and improving physiologic measures of oxygen exchange. However, these studies have enrolled small numbers of patients (generally <100), have used both CPAP and BiPAP support, and were performed in either intensive care units or emergency departments. In one of the earliest randomized experiences of NIPPV in acute pulmonary edema (37), 39 patients were randomly assigned to CPAP or conventional oxygen therapy. After 30 mins, respiratory rate (oxygen alone 32 ± 6 to 33 ± 9 breaths/min vs. CPAP 35 ± 8 to 27 ± 6 breaths/min; p = .008), arterial carbon dioxide tension (oxygen alone 64 ± 17 to 62 ± 14 mm Hg vs. CPAP 58 ± 8 to 46 ± 4 mm Hg; p < .001), and arterial pH (oxygen alone 7.15 ± 0.11 to 7.18 ± 0.18 vs. CPAP 7.18 ± 0.08 to 7.28 ± 0.06; p < .001) were improved with CPAP when compared with oxygen alone. However, at 24 hrs, there were no significant differences between the groups in any of the respiratory indices. Although CPAP was more effective than oxygen alone in preventing endotracheal intubation (oxygen alone 7/20 vs. CPAP 0/19; p = .005), there was no significant difference in in-hospital mortality (oxygen alone 4/20 vs. CPAP 2/19; p = .36) or length of stay.

In one of the larger CPAP trials (38), CPAP also improved hemodynamic measures. In this trial of 100 patients in a coronary care unit, all of whom underwent concomitant pulmonary artery catheterization, CPAP resulted in a lower rate-pressure product and higher stroke volume index (Fig. 5). Again, there were no differences in mortality or length of stay. In a similar fashion, BIPAP also appears as effective in preventing endotracheal intubation as CPAP but is not superior (36).

The impact on total mortality has not been clear because of limited trial size and the inability to blind the investigators and patients. However, in a recent meta-analysis involving 15 randomized trials of CPAP, BIPAP, or both, NIPPV did decrease mortality by 45% (relative risk [RR], 0.55; 95% confidence interval [CI], 0.40–0.78; p = .72 for heterogeneity) in addition to decreasing the need to intubate by 57% (RR, 0.43; 95% CI, 0.32–0.57; p = .20 for heterogeneity) (Fig. 6) (36).

When patients present to the intensive care unit in acute pulmonary edema, NIPPV should be a strong initial consideration when significant respiratory distress is apparent. CPAP or BIPAP decreases the need for intubation, improves hemodynamic profiles, and may improve mortality.

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