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Original Studies

Feasibility Study of the Use of the TandemHeart® Percutaneous Ventricular Assist Device for Treatment of Cardiogenic Shock

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Background: The mortality of cardiogenic shock (CGS) remains high despite currently available pharmacological and mechanical treatment options. The standard of care in medically refractory situations has been the insertion of an intra-aortic balloon pump. The purpose of this study was to investigate the feasibility, safety, and hemodynamic impact of the TandemHeart® percutaneous left ventricular assist device (pVAD) in CGS. Methods: Thirteen patients from five centers in the US with the diagnosis of CGS were enrolled in the study. Hemodynamic measurements, including cardiac index (CI), mean arterial pressure (MAP), pulmonary capillary wedge pressure (PCWP), and central venous pressure (CVP) were performed presupport, during support and after device removal. Patients were monitored for 6 months. Results: The pVAD was successfully implanted in all 13 patients, with duration of support averaging 60 ± 44 hr. During support, CI increased from 2.09 ± 0.64 at baseline to 2.53 ± 0.65 (P = 0.02), MAP increased from 70.6 ± 11.1 to 81.7 ± 14.6 (P = 0.01), PCWP decreased from 27.2 ± 12.2 to 16.5 ± 4.8 (P = 0.01), and CVP from 12.9 ± 3.7 to 12.6 ± 3.6 (P = NS). Ten patients survived to device explant, 6 of whom were bridged to another therapy. Seven patients survived to hospital discharge and were all alive at 6 months. The two most common adverse events were distal leg ischemia (n = 3) and bleeding from the cannulation site (n = 4). Conclusion: The TandemHeart® PTVA System may be a useful complementary treatment for patients with CGS, especially as a bridge to another treatment. Further study is needed to definitively establish safety and efficacy. © 2006 Wiley-Liss, Inc.

Key words: myocardial infarction; left ventricular assist device; cardiogenic shock

INTRODUCTION

Cardiogenic shock (CGS) results in inadequate end organ perfusion and is associated with high mortality despite a variety of new pharmacological and mechanical treatment options for heart failure [1–9]. For patients presenting with CGS following myocardial infarction, reported rates of mortality range between 55 and 80% despite aggressive pharmacological therapy and use of the intra-aortic balloon pumping (IABP) [10–14]. Patients with CGS due to ventricular rupture and acute mitral valve rupture following myocardial infarction have mortality rates approaching 100% [15–19]. Accordingly, a minimally invasive therapeutic intervention capable of enhancing cardiac output and blood pressure is needed for treating CGS patients refractory to conventional therapies.

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The TandemHeart® percutaneous left ventricular assist device (pVAD, CardiacAssist, Pittsburgh) is a circulatory support device intended for short term circulatory support of patients with CGS. This device is placed under fluoroscopic and hemodynamic guidance in a cardiac catheterization laboratory, and is designed to unload the left ventricle while improving cardiac output and blood pressure. Recent reports by Thiele et al. describe the initial, single center clinical experience with this device in patients with CGS following revascularization in the setting of an acute myocardial infarction (MI) [20–22]. These publications document improved hemodynamics and end-organ perfusion during pVAD support [20].

The potential role of the TandemHeart® pVAD in stabilizing patients presenting with CGS prior to therapeutic intervention, however, has not been explored. Accordingly, the purpose of this multicenter feasibility study was to test the safety and hemodynamic effects of the TandemHeart® pVAD as a bridge to recovery and/or a bridge to next therapy in patients with CGS.

METHODS

Patient Selection

Thirteen patients were enrolled from five centers in the United States. Patients were required to have cardiogenic shock (CGS), defined as systolic blood pressure $\leq$90 mm Hg (or require high dose pressors to maintain systolic blood pressure >90 mm Hg), cardiac index (CI) $\leq$2.2 l/min/m^2, pulmonary capillary wedge pressure (PCWP) $\geq$15 mm Hg, and evidence of end organ hypoperfusion (e.g. urine output $<$ 30 ml, cold extremities or altered mental status). The major exclusion criteria were cardiac arrest requiring resuscitation for $\geq$30 min, anoxic brain damage, coagulopathy, allergy to heparin, sepsis, isolated right heart failure, significant peripheral vascular disease (PVD), creatinine $>$ 5 mg/dl, or total bilirubin $>$ 5 mg/dl.

System Description

The TandemHeart® System consists of four major components: (1) a 21 Fr. left atrial drainage cannula, (2) a centrifugal pump that can deliver 3.5–4.0 l/min at 7,500 rpm, (3) a femoral artery cannula (15–17 Fr.) that extends into the iliac artery and (4) a microprocessor-based pump controller [20,22]. The atrial drainage cannula is positioned in the left atrium using standard transseptal techniques. Oxygenated blood is withdrawn from the left atrium and is pumped into the femoral artery. Bilateral femoral artery access can also be used in patients with small arteries or PVD, using 12–14 Fr. arterial cannulae. Heparin is administered through the pump head and systemically to maintain an activated clotting time (ACT) level of 200 sec. The system was inserted in the cardiac catheterization laboratory under fluoroscopic and hemodynamic guidance.

Patients were either weaned from TandemHeart® support, transferred to another therapy (e.g., PCI or cardiac surgery), or expired during support. Patients were weaned from the device when they remained clinically stable and able to maintain CI $>$ 2.2 l/min/m^2, mean arterial pressure (MAP) $>$ 70 mm Hg, and PCWP $<$ 24 mm Hg without inotropic support during stepwise decreases of pump speed to a minimum of 0.5 l/min for 1–2 hr.

Hemodynamic Monitoring

Hemodynamic indices such as CI, MAP, PCWP, and central venous pressure (CVP) were monitored presupport and at ~8 hr intervals during support. An additional set of measurements was made after device removal in surviving patients.

Statistical Analysis

Data are presented as the mean $\pm$ SD, and results were compared using Student's paired t test. $P < 0.05$ was considered statistically significant.

RESULTS

Patients Characteristics

The device was successfully implanted in all of the 13 enrolled subjects. Subjects' age ranged from 48 to 78 years and averaged 66.3 $\pm$ 9.4 years. There were 4 women and 9 men. Baseline hemodynamic conditions were indicative of CGS with a low CI (2.10 $\pm$ 0.61 l/min/m^2), a high wedge pressure (27.2 $\pm$ 12.3 mm Hg), and a systolic blood pressure of 108 $\pm$ 22 mm Hg achieved with significant pressor support. CGS was secondary to acute myocardial infarct ($n = 8$), decompensated idiopathic cardiomyopathy ($n = 1$), decompensated ischemic cardiomyopathy ($n = 1$), and postcardiotomy syndrome ($n = 2$). The system was used on a prophylactic basis in one patient to perform high risk (left main coronary artery) angioplasty following an acute myocardial infarction. Nine of the patients had persistent CGS despite being supported with an intraaortic balloon pump at the time of enrollment into the study.

Clinical Outcomes (Table I)

The duration of device support averaged 60 $\pm$ 44 hr (range 8–143, median of 47 hr). Three patients died during TandemHeart® support. Six of the patients were bridged to another therapy that included cardiac surgery ($n = 4$) or PCI ($n = 2$). Ten patients survived to device explant, including the 6 patients bridged to

TABLE I. Summary of Patients and Clinical Outcome

	Age	Gender	Diagnosis	IABP at enrollment	CI (l/min/m^2)	PCWP (mm Hg)	SBP (mm Hg)	Duration of use (days)[a]	Bridged to next therapy	Survival to		
										Explant	Hospital Discharge[b]	6 weeks
1	77	F	Post-AMI CGS	Yes	1.57	13	99	1	No	No	No	No
2	74	F	PCCS	Yes	1.51	NR	144	2	No	No	No	No
3	59	M	Postcardiotomy	Yes	2.05	NR	103	3	No	Yes	Yes	Yes
4	56	M	Post-AMI CGS	Yes	2.2	15	96	3	OPCABG	Yes	Yes	Yes
5	71	M	Post-AMI CGS	No	2.2	NR	112	4 hr	No	Yes	Yes	Yes
6	61	M	End-stage CHF, MR	Yes	3.5	29	76	2	MV repair	Yes	Yes	Yes
7	72	F	End-stage CHF	Yes	2.2	25	110	6	No	Yes	No (3 days)	No
8	74	M	Post-AMI CGS	No	2	45	94	6	CABG/MVR/AVR	Yes	Yes	Yes
9	48	M	Post-AMI CGS	Yes	1.5	14	109	3	No	Yes	No (7 days)	No
10	72	F	Post-AMI CGS	Yes	1.35	26	97	4	No	No	No	No
11	58	M	Post-AMI CGS	Yes	3.05	45	113	1	PCI	Yes	Yes	Yes
12	78	M	Post-AMI CGS	No	1.91	33	94	1	AVR	Yes	No (4 weeks)	No
13	62	M	Post-AMI-PCI	No	2.31	NR	159	1	MRA, PTCA	Yes	Yes	Yes
Avg	66.3	69% M		69% Yes	2.1	27.2	108.2	2.8		77%	58%	58%
SD	9.4				0.6	12.2	21.9	1.8				

AMI, acute myocardial infarction; AVR, aortic valve repair; CABG, coronary artery bypass graft; CGS, cardiogenic shock; CHF, chronic heart failure; DCM, idiopathic dilated cardiomyopathy; MR, mitral regurgitation; MRA, mechanical rotational atherectomy; MVR, mitral valve repair; OPCABG, off-pump coronary artery bypass graft; PC-CGS, postcardiotomy cardiogenic shock; PCI, percutaneous coronary intervention.

[a]Rounded to nearest number of days.

[b]For patients surviving to explant but not to hospital discharge, the time shown in parentheses indicate the duration of survival following device explant.

another therapy. Seven of these patients survived to hospital discharge; all of these patients were alive at the 6 months final follow-up visit.

Hemodynamic Effectiveness

Key hemodynamic parameters measured prior to, during and after TandemHeart® support are summarized in Figure 1. The values shown in these graphs during support are the mean (±SD) of the individual subject mean values during support; the N's are the number of patients from whom data were available. Average CI increased to over 2.5 l/min/m^2, MAP increased to greater than 80 mm Hg, and PCWP decreased markedly from more than 27 mm Hg to an average of less than 17 mm Hg. CVP trended lower, but was not significantly affected. The relationship between pump flow and cardiac output from all available measurements during TandemHeart® support from all subjects are shown in Figure 2A. The points fall above the line of identity indicating that the TandemHeart® enhances output of the native heart. As shown in Figure 2B, a majority of CI measurements are greater than 2.2 l/min/m^2 (horizontal line, the cutoff for the hemodynamic definition of CGS).

End Organ Perfusion

End organ perfusion was assessed by determining the serum levels of creatinine and total bilirubin. Baseline serum creatinine level averaged 1.6 ± 0.8 mg/dl prior to support (available from 11 subjects) and did not change significantly, averaging 1.3 ± 0.4 mg/dl during support (available from 11 subjects; $P = 0.14$). There was no change in the total bilirubin values for these subjects, which averaged 1.0 ± 0.8 mg/dl at baseline (available from 11 subjects) and 1.2 ± 1.2 mg/dl during support (available from 12 subjects, $P = 0.5$).

Effect on Blood Elements

An assessment of hemolysis was made by measuring plasma free hemoglobin prior to and during TandemHeart® support. Baseline measurements were available from 7 patients, and there were 18 measurements made during TandemHeart® Support.. Plasma free hemoglobin as a measure of hemolysis did not change significantly from pre- to postinsertion of the TandemHeart™ (7.0 ± 9.9 mgm/dl vs 5.5 ± 3.8 mg/dl, $P = 0.7$). These data show that there was no statistically significant difference in plasma free hemoglobin during support suggesting that there is no significant hemolysis. Similarly, there was no significant difference in platelet count before or during support (255 ± 201 vs 186 ± 92 $P = 0.1$) with baseline measurements available from 11 subjects and 33 measurements made during Tandem Heart® support. Although information on hemoglobin

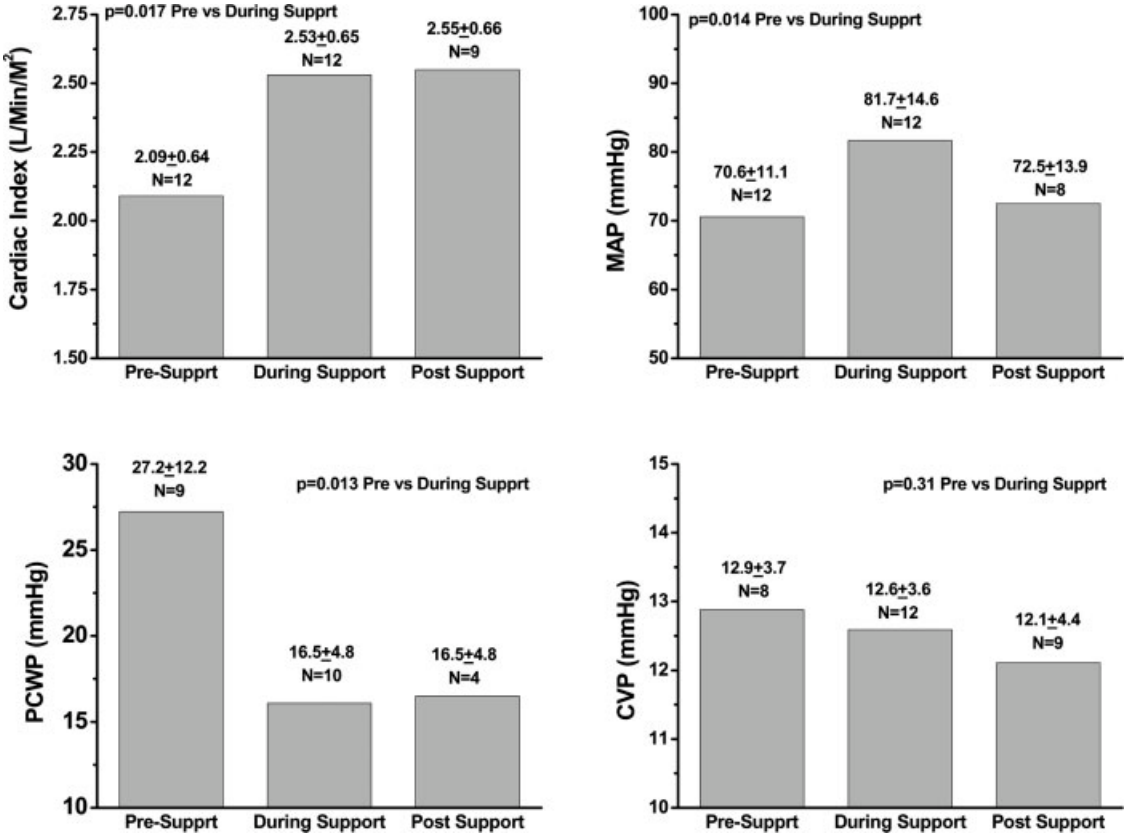

Fig. 1. Summary of hemodynamic data.

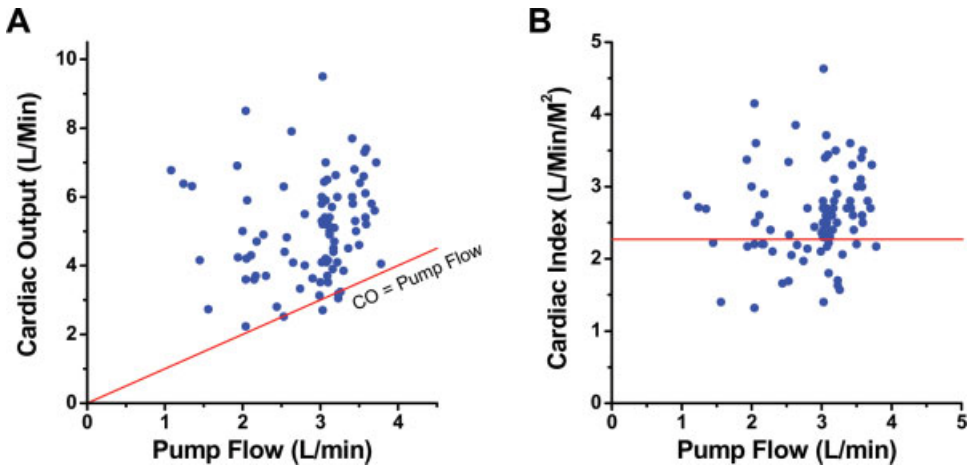

Fig. 2. Cardiac output (A) and cardiac index (B) as a function of pump flow for all data available from all subjects. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

and hematocrit before and after device support is not available on all patients, eight patients required transfusion (range 1–11 units PRBC's, mean 4 units, median 3 units) with transfusion being more common in those patients with bleeding complications as noted in Table II.

Adverse Events

Device-related adverse events and their frequencies are summarized in Table II. The two most common events were distal leg ischemia ($n = 3$) and bleeding from the cannulation site ($n = 4$). All the device related events resolved except for RV failure ($n = 1$) a

TABLE II. Device-Related Adverse Events

Frequency	Event
3	Leg ischemia
4	Bleeding from cannulation site
1	Dislocation of arterial cannula
1	Infection
1	Worsening of RV failure
1	Kinked arterial cannula
1	Complete heart block with ventricular asystole during transseptal procedure
1	Bleeding (increased) from chest tube, post-CABG
1	Asymptomatic ventricular tachycardia and rapid atrial fibrillation

relative contraindication to the use of the device and cannulation site infection ($n = 1$). These two events were unresolved at the time of patient death. There were three transient, nonfocal neurological adverse events noted in two of the subjects that were classified as being unrelated to the device, according the Data and Safety Monitoring Board (DSMB) of the study. There were no fixed or focal neurological defects that were noted in any of the patients that were classified as stroke by the DSMB.

The following case report (patient no. 8 Table I) exemplifies how the pVAD can reverse CGS and may be used as a bridge to a next therapy.

A 74-year-old male with a remote history of coronary artery bypass surgery presented to a community emergency department with progressively severe dyspnea. The patient was known to have aortic stenosis that was judged to be mild on last echocardiographic determination. The patient had been seen by his primary physician because of dyspnea. The patient was thought to have progession of his aortic stenosis and follow-up echocardiography and cardiac catheterization were suggested but the patient refused. The patient then presented to the emergency department with chest pain and progressively severe dyspnea, and he was hospitalized.

The initial chest X-ray revealed cardiomegaly and pulmonary edema. The ECG revealed sinus tachycardia and left bundle-branch block. Initial troponin I was increased slightly beyond the normal range. An emergency echocardiogram revealed critical aortic stenosis with a calculated aortic valve area of 0.6 $cm^{2.}$ The patient was intubated and started on intravenous vasopressors because of respiratory failure and severe hypotension. The patient was then referred to a tertiary care center for continued care.

Immediately following arrival, an emergency transesophageal echocardiogram confirmed severe aortic stenosis with aortic valve area of 0.6 $cm^{2,}$ unsuspected severe mitral regurgitation and severe left ventricular dysfunction with an ejection fraction of 20% and posterior hypokinesis. The patient was maintained on intravenous vasopressors and was treated with high dose intravenous diuretics without improvement.. Emergency cardiac catheterization and angiography revealed elevated right heart pressures with a pulmonary pressure of 70/45, a PCW pressure of 45 (mean) with V waves to 80 mm Hg. The CI was 2.0 l/min/m^2 with a PA saturation of 52%. The mean aortic valve gradient was 25 mm Hg with a calculated aortic valve area of 0.51 cm^2. Coronary angiography revealed a 70% left main coronary artery stenosis and a patent LIMA graft. The circumflex coronary artery was totally occluded with an occluded SVBG to the acute marginal vessel that filled via right-to-left collaterals. The right coronary artery had no hemodynamically significant stenoses. Surgical consult was obtained, and the patient was felt to be too high risk for emergency surgical repair or even placement of an implantable left ventricular assist device. An intra-aortic balloon pump was thought to be of no use in view of the severe aortic stenosis and the severe mitral regurgitation.

After informed consent had been obtained from the patient's family, a pVAD (TandemHeart®, CardiacAssist, Pittsburgh, PA) was inserted under fluoroscopic and hemodynamic guidance in the cardiac catheterization laboratory. The patient's hemodynamics improved immediately as follows:

	CO/CI	HR	SBP	PA	PCWP	PAsat (%)
PRE	4.2/2.0	130	80	75/45 v = 80	45	52
POST	5.2/2.5	70	110	45/19	19	72

Pre, before pVAD insertion; POST, after pVAD insertion; CO, cardiac output; CI, cardiac index; HR, heart rate; SBP, systolic blood pressure; PA, pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PAsat, pulmonary artery saturation.

The patient was transferred to the coronary unit for further monitoring where he remained for the next 4 days on the pVAD. His blood chemistries improved, and the patient was then taken to the operating room where he underwent aortic valve replacement, mitral valve repair, and coronary artery bypass grafting to the circumflex marginal artery. The TandemHeart® was used to successfully wean the patient from cardiopulmonary bypass and was removed on the third postoperative day. The patient was ambulatory and discharged home on the 7th postoperative day.

DISCUSSION

The results of the present study demonstrate that the TandemHeart® pVAD improves hemodynamic effectiveness with an increased average CI from 2.1 to 2.5 l/min/m^2, an increased average MAP from 71 to

82 mm Hg and a decreased average pulmonary wedge pressure from 27 to 17 mm Hg. These data suggest that on average the device is able to reverse CGS and maintain patients out of shock while simultaneously reducing PCWP (thus reducing pulmonary congestion and unloading the heart) for the duration of support. Analysis of device flow throughout the duration of support in each subject indicates that the device operated as intended.

In a prior study, 18 CGS patients were supported with the TandemHeart® pVAD system [20]. Four of five (80%) patients with post MI ventricular septal defect (VSD) did not survive for 1 month after presentation, consistent with the previously documented high mortality rate, which is not improved by any known treatment modalities for post-MI VSD. An increased duration of support on the pVAD with the patient maintained out of CGS may possibly enhance survival in these very high risk surgical patients. Of the remaining 13 patients (no post MI VSD), 9 (69.6%) survived 1 month or more. The overall 30 day mortality, including post MI VSD's, was 44%. In this study by Thiele *et al*, the device was primarily used to treat hemodynamic instability after successful percutaneous revascularization in 15 of 18 (83%) patients. In contrast, the TandemHeart® pVAD system was used in the present study to support patients presenting with CGS prior to therapeutic intervention. In the patients described in this report 6 of 13 (46%) were bridged to another therapy (4 to cardiac surgery and 2 to percutaneous coronary intervention). Five of these 6 (83%) patients survived to the 6 week follow-up visit. In contrast, of 7 patients receiving TandemHeart® support who were not bridged to another therapy (e.g., idiopathic cardiomyopathy, post cardiotomy shock) only 2 (29%) survived. These two patients survived to hospital discharge and to the 6-week study end-point. These preliminary data are consistent with the known high rate of mortality in CGS. The fact that 9 of our 13 (69%) patients were refractory to IABP (i.e., CGS persisted despite IABP support) indicates the severity of the hemodynamic compromise in this group, and further suggests that the degree of hemodynamic support provided by the TandemHeart® pVAD is clinically meaningful.

In addition, the data of the present study suggest that the TandemHeart® pVAD system is reasonably safe as evidenced by successful implantation of device in all subjects enrolled, lack of device related adverse events, no reports of major device malfunction, no suggestion of hemolysis or adverse effect on platelet count, and no device related thromboembolic events. Three events of distal leg ischemia occurred, however, in three patients in this study. Two events were resolved by removing the device, and one event was resolved by the insertion of a perfusion cannula distally into the lower extremity artery. Two of these patients were female with BSA < 1.7 m^2, and one had diabetes mellitus. More careful selection of patients and the use of distal perfusion when necessary may obviate these peripheral vascular complications. The large cannulae do require some special considerations. Arterial compromise with the large cannulae can be avoided by performing preinsertion angiography and by picking the largest and least diseased artery for the cannula. In addition, the cannula can be down-sized to allow for a smaller artery with the understanding that this will result in decreased flow from the pump. If patients with arterial disease require a larger cannula, arterial insufficiency can be avoided by performing an antegrade cannulation of the superficial femoral artery and by placing a small catheter (4F) antegrade. The antegrade catheter is then perfused using a side-port from the arterial cannula. A kinked arterial cannula was noted in one patient by a decrease in flow through the pump with examination of the cannula revealing that it was kinked where it was sutured to the patient. This can be avoided by avoiding excessive tightening of the sutures and by using the grommets provided by the manufacturer that prevent this problem. The 21F venous cannula resulted in no significant problems and was inserted easily over the Inoue wire once the septum had been dilated with the progressive dilator. Correct positioning of the trans-septal cannula within the left atrium, however, is of critical importance. The cannula must be advanced far enough so that all of the side holes reside within the left atrium to avoid right-to-left shunting and arterial desaturation, but not too far to avoid contact with the left atrial wall. Left atrial pressure should be monitored and maintained at high normal levels to assure adequate filling and function of the assist device. The cannulae must be securely connected to the pump and to the patient as even temporary inadvertent disconnection could result in prompt exsanguination. The cannulae were secured to the patient with Hollister chest-tube patches and to the pump with plastic cinches similar to those that are used in the cardiothoracic operating room to secure cannulae when patients are on the heart-lung machine. Because of the large size of the cannulae, there is the potential for considerable blood loss at the time of insertion. Once experience is obtained; however, blood loss can be kept to a minimum.

Limitations

This study is limited by the small number of patients enrolled and absence of a control group. Therefore, no statistical analysis on survival can be made. The data do suggest, however, that the TandemHeart® is capable of reversing CGS even where an IABP has been unsuccessful. Recent data suggest that CGS is associated with an abnormal neuro-hormonal and inflammatory milieu and that a high percentage of

patients who survive CGS are functionally NYHA I [23]. If patients can be supported until the neuro-hormonal and inflammatory abnormalities resolve, there is a hope that these patients may have an improvement in survival, but this remains to be proven.

Conclusions

The data from this study suggest that the TandemHeart® pVAD system is potentially useful for treatment of CGS patients with a likely important role for bridging to another definite therapy. Blood pressure and cardiac output increased significantly, while PCWP was significantly decreased in these patients. Larger scale studies are required to clarify the safety and effectiveness of this device in various clinical scenarios.

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REFERENCES

1. Cohn JN, Johnson G, Ziesche S, Cobb F, Francis G, Tristani F, Smith R, Dunkman WB, Loeb H, Wong M, et al. A comparison of enalapril with hydralazine-isosorbide dinitrate in the treatment of chronic congestive heart failure. N Engl J Med 1991;325:303–310.
2. Packer M. Do angiotensin-converting enzyme inhibitors prolong life in patients with heart failure treated in clinical practice? J Am Coll Cardiol 1996;28:1323–1327.
3. Packer M, Bristow MR, Cohn JN, Colucci WS, Fowler MB, Gilbert EM, Shusterman NH. The effect of carvedilol on morbidity and mortality in patients with chronic heart failure.U.S. Carvedilol Heart Failure Study Group. N Engl J Med 1996;334:1349–1355.
4. Packer M, Coats AJ, Fowler MB, Katus HA, Krum H, Mohacsi P, Rouleau JL, Tendera M, Castaigne A, Roecker EB, Schultz MK, DeMets DL. Effect of carvedilol on survival in severe chronic heart failure. N Engl J Med 2001;344:1651–1658.
5. Packer M, Fowler MB, Roecker EB, Coats AJ, Katus HA, Krum H, Mohacsi P, Rouleau JL, Tendera M, Staiger C, Holcslaw TL, Amann-Zalan I, DeMets DL. Effect of carvedilol on the morbidity of patients with severe chronic heart failure: Results of the carvedilol prospective randomized cumulative survival (COPERNICUS) study. Circulation 2002;106:2194–2199.
6. Pitt B, Remme W, Zannad F, Neaton J, Martinez F, Roniker B, Bittman R, Hurley S, Kleiman J, Gatlin M. Eplerenone, a selective aldosterone blocker, in patients with left ventricular dysfunction after myocardial infarction. N Engl J Med 2003;348:1309–1321.
7. Rose EA, Gelijns AC, Moskowitz AJ, Heitjan DF, Stevenson LW, Dembitsky W, Long JW, Ascheim DD, Tierney AR, Levitan RG, Watson JT, Meier P, Ronan NS, Shapiro PA, Lazar RM, Miller LW, Gupta L, Frazier OH, Desvigne-Nickens P, Oz MC, Poirier VL. Long-term mechanical left ventricular assistance for end-stage heart failure. N Engl J Med 2001;345:1435–1443.
8. Bristow MR, Saxon LA, Boehmer J, Krueger S, Kass DA, De Marco T, Carson P, DiCarlo L, DeMets D, White BG, DeVries DW, Feldman AM. Cardiac-resynchronization therapy with or without an implantable defibrillator in advanced chronic heart failure. N Engl J Med 2004;350:2140–2150.
9. Menon V, Hochman JS, Stebbins A, Pfisterer M, Col J, Anderson RD, Hasdai D, Holmes DR, Bates ER, Topol EJ, Califf RM, Ohman EM. Lack of progress in cardiogenic shock: Lessons from the GUSTO trials. Eur Heart J 2000;21:1928–1936.
10. Holmes DR Jr, Bates ER, Kleiman NS, Sadowski Z, Horgan JH, Morris DC, Califf RM, Berger PB, Topol EJ. Contemporary reperfusion therapy for cardiogenic shock: The GUSTO-I trial experience. The GUSTO-I Investigators. Global utilization of streptokinase and tissue plasminogen activator for occluded coronary arteries. J Am Coll Cardiol 1995;26:668–674.
11. Goldberg RJ, Samad NA, Yarzebski J, Gurwitz J, Bigelow C, Gore JM. Temporal trends in cardiogenic shock complicating acute myocardial infarction. N Engl J Med 1999;340:1162–1168.
12. Anderson RD, Ohman EM, Holmes DR Jr, Col I, Stebbins AL, Bates ER, Stomel RJ, Granger CB, Topol EJ, Califf RM. Use of intraaortic balloon counterpulsation in patients presenting with cardiogenic shock: Observations from the GUSTO-I Study. Global utilization of streptokinase and TPA for occluded coronary arteries. J Am Coll Cardiol 1997;30:708–715.
13. Ohman EM, Hochman JS. Aortic counterpulsation in acute myocardial infarction: Physiologically important but does the patient benefit? Am Heart J 2001;141:889–892.
14. Sanborn TA, Sleeper LA, Bates ER, Jacobs AK, Boland J, French JK, Dens J, Dzavik V, Palmeri ST, Webb JG, Goldberger M, Hochman JS. Impact of thrombolysis, intra-aortic balloon pump counterpulsation, and their combination in cardiogenic shock complicating acute myocardial infarction: A report from the SHOCK Trial Registry. Should we emergently revascularize occluded coronaries for cardiogenic shock? J Am Coll Cardiol 2000;36:1123–1129.
15. Feneley MP, Chang VP, O'Rourke MF. Myocardial rupture after acute myocardial infarction. Ten year review. Br Heart J 1983; 49:550–556.
16. Bolooki H. Emergency cardiac procedures in patients in cardiogenic shock due to complications of coronary artery disease. Circulation 1989;79:1137–1148.
17. Madsen JC, Daggett WM Jr. Repair of postinfarction ventricular septal defects. Semin Thorac Cardiovasc Surg 1998;10:117–127.
18. Davis N, Sistino JJ. Review of ventricular rupture: Key concepts and diagnostic tools for success. Perfusion 2002;17:63–67.
19. Nishimura RA, Schaff HV, Gersh BJ, Holmes DR Jr, Tajik AJ. Early repair of mechanical complications after acute myocardial infarction. JAMA 1986;256:47–50.
20. Thiele H, Lauer B, Hambrecht R, Boudriot E, Cohen HA, Schuler G. Reversal of cardiogenic shock by percutaneous left atrial-to-femoral arterial bypass assistance. Circulation 2001;104:2917–2922.
21. Thiele H, Sick P, Boudriot E, Diederich K, Hambrecht R, Niebaur J, Schuler G. Randomized comparison of intraaortic balloon support versus a percutaneous left ventricular assist device in patients with revascularized acute myocardial infarction complicated by cardiogenic shock. Eur Heart J 2004;26:1276–1283.
22. Magovern JA, Sussman MJ, Goldstein AH, Szydlowski GW, Savage EB, Westaby S. Clinical results with the AB-180 left ventricular assist device. Ann Thorac Surg 2001;71 (Suppl 3):S121–S124; discussion S144–S146.
23. Hochman JS. Cardiogenic shock complicating acute myocardial infarction: Expanding the paradigm. Circulation 2003;107:2998–3002.