A randomized multicenter clinical study to evaluate the safety and efficacy of the TandemHeart percutaneous ventricular assist device versus conventional therapy with intraaortic balloon pumping for treatment of cardiogenic shock

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Background and Aim Despite major advances in the treatment of heart failure, cardiogenic shock (CGS) remains associated with substantial mortality. Recent data suggest that the TandemHeart percutaneous ventricular assist device (pVAD) may be useful in the management of CGS. The aim of this prospective randomized study was to test the hypothesis that the TandemHeart (pVAD) provides superior hemodynamic support compared with intraaortic balloon pumping (IABP).

Methods Forty-two patients from 12 centers presenting within 24 hours of developing CGS were included in the study and treated in an initial roll-in phase (n = 9) or randomized to treatment with IABP (n = 14) or TandemHeart pVAD (n = 19). Thirty patients (71%) had persistent CGS despite having an IABP in place at the time of study enrollment.

Results Cardiogenic shock was due to myocardial infarction in 70% of the patients and decompensated heart failure in most of the remaining patients. The mean duration of support was 2.5 days. Compared with IABP, the TandemHeart pVAD achieved significantly greater increases in cardiac index and mean arterial blood pressure and significantly greater decreases in pulmonary capillary wedge pressure. Overall 30-day survival and severe adverse events were not significantly different between the 2 groups.

Conclusion In patients presenting within 24 hours of the development of CGS, TandemHeart significantly improves hemodynamic parameters, even in patients failing IABP. Larger-scale studies are required to assess the influence of improved hemodynamics on survival. (Am Heart J 2006;152:469.e1-469.e8.)

Despite major advances in the treatment of heart failure for patients with mild, moderate, or severe symptoms, cardiogenic shock (CGS) is an area of relatively little progress. Cardiogenic shock occurs in a variety of settings such as myocardial infarction, post-cardiotomy shock, decompensated chronic heart failure, acute valve failure, and myocarditis. Depending on the clinical circumstances, inhospital mortality rates are reported in the range between 40% and 80%.[1] No study has yet shown a strategy to improve short-term (30 day) survival, although emergency revascularization enhances survival at 6 and 12 months compared with conservative medical treatment.[2-4] Insertion of an intraaortic balloon is considered to be standard of care in patients with medically refractory CGS[5,6] despite the fact that there are no randomized studies proving its efficacy.[7]

Accordingly, there have been multiple efforts to develop devices to provide more effective hemodynamic support while maintaining the clinically acceptable degree of invasiveness of the intraaortic balloon pumping (IABP).[8-11] One such device, the TandemHeart percutaneous ventricular assist device (pVAD), has recently been studied in the setting of CGS and was shown to improve all hemodynamic parameters and reduce serum lactate, indicating improved tissue oxygenation and reversal of the CGS state.[12]

The purpose of this study was to test the hypothesis that the TandemHeart pVAD would provide superior hemodynamic support compared with IABP. Correlation

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[e]See Appendix.
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between hemodynamic effectiveness and clinical outcome was examined, but because of the small sample size, definitive study of the influence on mortality was not a goal of this study.

Methods

This was a prospective randomized study, including 42 patients from 12 sites conducted between April 2002 and April 2004. The study was conducted under an investigational device exemption from the US Food and Drug Administration and with institutional review board approval at each participating center. The primary study objective was to test whether the TandemHeart device provided superior hemodynamic benefits compared with the IABP (detailed below) in patients with medically refractory CGS. The secondary objective was to compare survival 30 days after randomization.

Informed consent was obtained from each patient (or legal representative) before enrollment. Patients 18 years or older were eligible for inclusion if they presented within 24 hours of developing CGS. Patients were required to have an indwelling right catheter for measurement of pulmonary capillary wedge pressure (PCWP) and cardiac index. Cardiogenic shock was defined as cardiac index ≤ 2.2 L/m^2 per minute, mean arterial blood pressure (MAP) ≤ 70 mm Hg, PCWP ≥ 15 mm Hg, and evidence of end-organ hypoperfusion (eg, decreased urine output, altered mental status) or the need for administration of high-dose pressor and/or inotropic support to maintain the patient out of CGS. Patients already having an IABP were eligible if they still met hemodynamic criteria for CGS. The main exclusion criteria were isolated right side of the heart failure, coagulopathy, sepsis, severe peripheral vascular disease, stroke within 6 months, 2+ or greater aortic regurgitation, and ventricular septal rupture. Eligible patients were randomized to conventional treatment with an IABP or treatment with TandemHeart pVAD. Sites not having prior experience with the device were permitted to treat the first patient with the pVAD in a roll-in phase before initiation of randomization.

The TandemHeart pVAD System consists of 4 major components: (1) a 21F left atrial drainage cannula, (2) an extracorporeal centrifugal pump rotating at 7500 rpm (Figure 1), (3) a femoral artery cannula (15F-17F) that extends into the iliac artery, and (4) a microprocessor-based pump controller, all detailed previously.[10,12] The TandemHeart pVAD blood pump is powered by an electromagnetic motor that drives a plastic impeller at a speed of 3000 to 7500 rpm, which has been reported to provide blood flow rates up to 4 L/min (internal reports of CardiacAssist, Pittsburgh, PA). During normal operation, pump speed was set at the maximum speed (7500 rpm). If there was no pulsatility on the arterial pressure wave (indicating lack of ventricular ejection), pump speed was reduced and/or fluids were administered to allow filling pressure to rise and ensure the presence of some left ventricular ejection. The tip of the atrial drainage cannula is positioned under fluoroscopic guidance in the left atrium using standard transseptal techniques. Oxygenated blood is withdrawn from the left atrium and pumped into the femoral artery. Bilateral femoral artery access can be used with 12F to 14F arterial cannulae. Aortoiliac and femoral angiography was recommended before insertion to ensure adequate vessel size before arterial cannula insertion. An activated clotting time of >400 seconds is recommended during the placement of the transseptal cannula, and an ACT between 180 and 200 seconds is recommended during support.

Figure 1

Photograph of the TandemHeart centrifugal pump.

Data analysis and statistics

Hemodynamic parameters were measured twice at baseline (separated by approximately 30 minutes) and then according to a specified schedule. The 2 baseline values were averaged as were all of the values obtained for a given patient during the period of support. The study was designed to compare the frequency with which IABP or TandemHeart was able to reverse the hemodynamic profile of CGS. Specifically, an individual patient was considered to be successfully supported if all the following 4 criteria were met: (1) the patient did not die during support or within 24 hours of device removal, (2) cardiac index was ≥ 2.2 L/kg per minute, (3) PCWP was ≤ 24 mm Hg, and (4) MAP was ≥ 70 mm Hg, with all hemodynamic parameters reflecting the average values during support. Based on prior feasibility studies, the sample size calculation assumed that the success rate for IABP would be 40% compared with 70% in TandemHeart-treated patients. Accordingly, 45 patients per group were predicted to provide 80% power, with 0.05 one-sided significance. However, as detailed below, the study was stopped on the recommendation of the Data Safety Monitoring Board (DSMB) after enrollment of 42 patients.

Individual hemodynamic parameters were presented as means $\pm$ SDs. Within-group comparisons were made with paired t tests. Therefore, in the case of missing data (either baseline or follow-up right heart measurements), patients were not included in the analysis. Comparisons between groups are made with unpaired Student t test. Frequencies of baseline characteristics and rates of events were compared between groups using Fisher exact tests. Time courses of change of

Table I. Baseline demographic characteristics (no significant differences between groups)

	Roll-in	TandemHeart	IABP	P*
No.	9	19	14	
Age (y)	59.3 ± 17.9	65.7 ± 13.8	60.3 ± 10.7	.31
% Male	78%	74%	64%	.71
Height (cm)	176 ± 5	173 ± 12	171 ± 8	.62
Weight (kg)	87 ± 15	83 ± 13	84 ± 18	.64
BSA (m^2)	2 ± 0.2	2 ± 0.2	1.9 ± 0.2	.92
Ejection fraction (%)	21 ± 7	19 ± 14	22 ± 9	.63
BUN (mg/dL)	38 ± 21	33 ± 21.7	31 ± 26	.91
Cr (mg/dL)	2.4 ± 1.4	1.8 ± 0.8	1.6 ± 0.8	.5
HCT (%)	35 ± 4	37 ± 7	37 ± 8	.9
Serum lactate (mg/dL)	8.5 ± 9.1	4.1 ± 4	5.5 ± 4.7	.48
°Median	−6	−3.3	−2.6	.99
IABP before randomization	8 (89%)	11 (58%)	11 (79%)	.28

BSA, Body surface area; *BUN*, blood urea nitrogen; *CR*, creatine; *HCT*, hematocrit.
**P* values relate to comparisons between TandemHeart and IABP groups. Statistical tests are detailed in the Methods section.

Table II. Baseline hemodynamic profile

Hemodynamics	Roll-in	TandemHeart	IABP	P*
SBP (mm Hg)	88 ± 21	89 ± 24	89 ± 20	.92
DBP (mm Hg)	51 ± 15	53 ± 15	58 ± 17	.87
MBP (mm Hg)	61 ± 11	70 ± 16	67 ± 15	.72
PAS (mm Hg)	42 ± 13	44 ± 14	54 ± 18	.06
PAD (mm Hg)	24 ± 11	26 ± 9	30 ± 8	.25
PAM (mm Hg)	31 ± 10	31 ± 9	40 ± 9	.07
CO (L/min)	4.2 ± 1.4	3.5 ± 0.8	3.5 ± 1.9	.45
Cardiac index (L/m^2 per minute)	1.9 ± 0.7	1.8 ± 0.4	1.8 ± 0.6	.27
PCWP (mm Hg)	25 ± 14	25 ± 8	28 ± 6	.19

SBP, systolic blood pressure; *DBP*, diastolic blood pressure; *PAS*, pulmonary artery systolic pressure; *MBP*, mean blood pressure; *PAD* pulmonary artery distolic pressure; *PAM*, pulmonary artery mean pressure; *CO*, cardiac output.
**P* values relate to comparisons between TandemHeart and IABP groups.

hemodynamic parameters were compared using random effects linear regression analysis. Poisson regression was used to compare the number of adverse events per patient. Serum lactate values were compared with a Mann-Whitney *U* test. In all cases, tests were 2 sided and *P* values less than .05 were considered statistically significant. All data were recorded on case report forms that were sent to an independent clinical research organization (PPD Medical Device, New Hope, MN). The results presented in this report reflect values in the database as of June 16, 2004. Calculations were performed using Stata (Version 8.0).

Results

Forty-two patients were enrolled at 12 centers: 9 were treated in the roll-in phase, 14 were randomized to conventional treatment with IABP, and 19 were randomized to TandemHeart treatment. Baseline demographics (Table I) showed no significant differences between groups. Of the 42 patients, 26 were diagnosed with acute myocardial infarction (5 roll-in patients, 10 IABP patients, and 11 TandemHeart patients); of these, 22 had percutaneous coronary intervention (most of these were performed before enrollment in the study), 3 had coronary artery bypass, and 1 underwent a left ventricular assist device implant. Most of the remaining patients had decompensated chronic heart failure. Most of the patients in all groups had an IABP in place before enrollment and randomization.

Baseline hemodynamic parameters were also similar between groups and indicative of CGS (Table II). The duration of support (Table III) was longer in the roll-in patients but was similar in the randomized patients averaging approximately 2.5 days (median, approximately 2 days).

Hemodynamic effects

For randomized patients, the prospectively defined composite hemodynamic success criteria were satisfied in only 2 IABP patients (14%) compared with 7 TandemHeart patients (37%). The influence of treatment on individual hemodynamic parameters is summarized in Figure 2. Compared with IABP, patients receiving support with the TandemHeart pVAD had significantly greater increases in cardiac index and greater decreases in PCWP. Changes in cardiac output were directly proportional to changes in cardiac index and increased by 2.1 ± 1.3

Table III. Duration of support (hours, no significant difference between groups)

	Roll-in	TandemHeart	IABP
Mean	104	61	75*
SD	86	45	95
Median	86	48	46
Minimum	1	4	1
Maximum	263	147	114

*P = .55, not significant compared with that of the TandemHeart group.

($P < .05$ vs baseline), 1.2 ± 0.8 ($P < .05$ vs baseline), and 0.6 ± 0.6 L/min (P = not significant) in the roll-in, TandemHeart, and IABP groups, respectively. Mean arterial pressure did not change with IABP, whereas it was increased significantly by TandemHeart pVAD. The time courses of change of these parameters during the first 16 hours of support (a period over which there was consistent data collection in both groups) for patients in the randomized study are summarized in Figure 3.

Inotropic and pressor support

Pressor and inotropic agents where used in all patients before randomization. Doses and choice of agents were based upon physician standard of care. Use of pharmacologic agents after randomization was also at the physicians' discretion. Accordingly, types and doses of medications varied not only between patients, but also for an individual patient during the period of support. A detailed review of medication use indicated that patterns of pharmacologic support were very similar in all groups. For patients who died during support, pharmacologic support generally increased before death. For patients who were either weaned or bridged to another treatment, there was a trend for pharmacologic support to increase in about 50% of patients, to decrease in about 25% of patients, and to stay the same in approximately 25%.

Plasma free hemoglobin

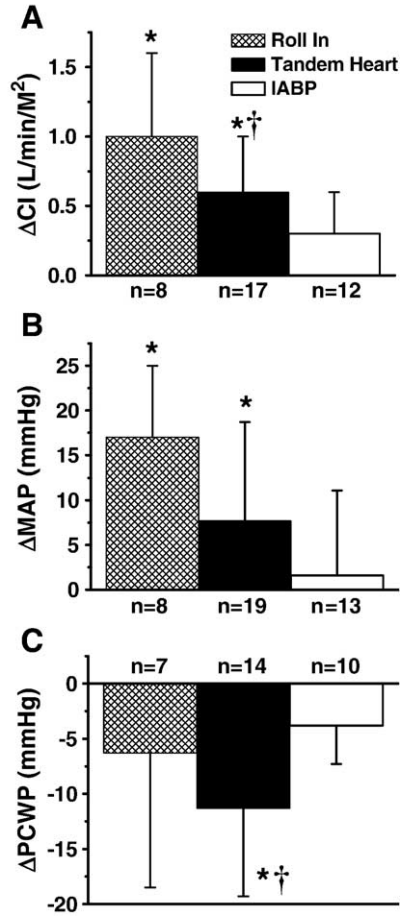
Plasma free hemoglobin (pHgb) values, obtained in a subset of patients, were highly variable and non–normally distributed (Table IV). There was a trend for peak values measured during support to be higher in the TandemHeart patients (both randomized and roll-in), but this was not statistically significant (P = .12 by Mann-Whitney U test). Hemolysis, defined as pHgb elevations above 40 mg/dL on more than 2 measurements taken at least 8 hours apart, was present in 1 patient in the TandemHeart group and in 1 IABP group.

Outcomes

The overall outcome of randomized patients is summarized in Figure 4. The proportion of patients dying while on support (or within 24 hours of device removal), being bridged to another treatment or capable of being weaned, was similar in the 2 groups; however, the relatively small number of patients in any group precludes meaningful comparisons. Overall 30 day survival (last row in Figure 4) was 64% (9/14) in the IABP group compared with 53% (10/19) in the TandemHeart group, which was not significantly different. Results were similar in the roll-in patients, with 5 of the 9 patients surviving at 30 days. If all the TandemHeart patients (roll-in and randomized) are pooled, the overall survival was 54%, which also did not differ significantly from the IABP group.

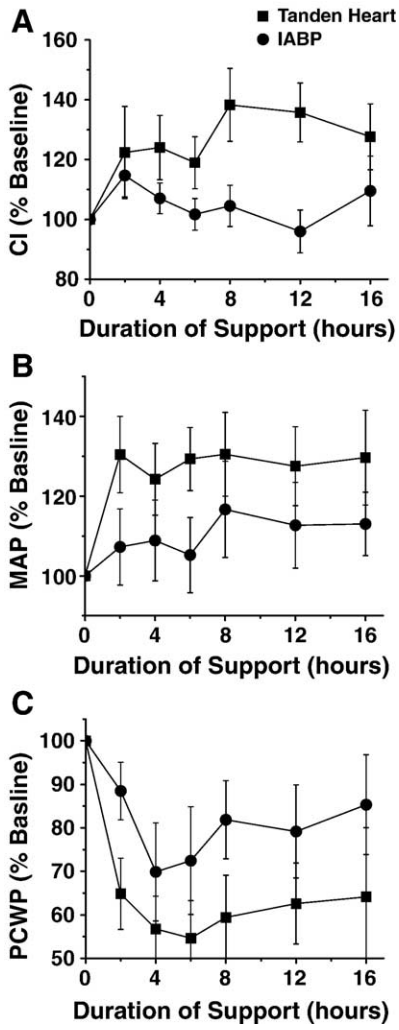
From the randomized group, 5 IABP and 7 TandemHeart patients were bridged to another therapy after enrollment in the study. In the TandemHeart group,

Figure 2



Changes in **A** cardiac index, **B** MAP, and **C** PCWP. Values reflect differences between baseline measurements and average measurements made in each patient during his/her entire period of mechanical support. The values of n reflect the number of patients for whom paired data were available. *Asterisk* (*), significantly different from baseline ($P < 005$); *dagger* (†), significantly different than IABP ($P < .05$).

Figure 3



Time course of change in hemodynamic parameters expressed as a percentage of patient's baseline in TandemHeart (squares) and IABP (circle) groups. Using random effects linear regression analysis, compared with IABP, TandemHeart resulted in a **A** 20% higher cardiac index (95% CI −5.8 to 46.1, $P = .13$), **B** an 18% higher MAP (95% CI −7.1 to 43.6, $P = .16$), and **C** an 18.5% lower PCWP (95% CI −41.9 to 4.8, $P = .12$).

these included 3 patients bridged to LVAD, 1 patient who underwent extracorporeal membrane oxygenation, 2 patients who underwent percutaneous coronary intervention with stent placement, and 1 patient who underwent mitral valve repair; 5 of these patients survived at least 30 days. In the IABP group, these included 4 patients bridged to left venticular assist device and 1 patient who underwent percutaneous coronary intervention; 3 of these patients survived at least 30 days.

Adverse events

A detailed summary of reported adverse events is provided in Table V. There was 1 instance of TandemHeart failure and 1 event where the device had to be removed because of a device-related problem (blood clotting within the cannula; ACT documented to be 182 seconds, which is less than the recommended values of 200-250 seconds). On average, TandemHeart patients experienced 3.1 events per patient compared with 2.6 events per patient in the IABP group (not significant at $P = .50$). There were no specific adverse events that related to the performance of the transseptal puncture or insertion of the transseptal cannula. Adverse events graded by the investigators as severe (serious adverse event) were reasonably balanced between groups, occurring with a frequency of 1.3 per patient in the TandemHeart group compared with 1.2 per patient in the IABP group and 1.1 per patient in the roll-in group.

Data Safety Monitoring Board

An independent DSMB reviewed the available data and concluded that the hemodynamic effects were superior in the TandemHeart group compared with IABP group, and that no definitive conclusion concerning overall outcomes (mortality) was achievable. In view of the slow rate of patient accrual, it was deemed unlikely that a sufficient number of patients could be enrolled in a reasonable time frame to achieve a more definitive answer concerning mortality. It was therefore suggested to stop the study.

Discussion

TandemHeart pVAD used in combination with standard pharmacologic therapy improves cardiac output, increases MAP, and reduces pulmonary wedge pressure in patients presenting within 24 hours of developing CGS. With the small number of patients studied, however, there was no survival benefit compared with conventional therapy with an IABP.

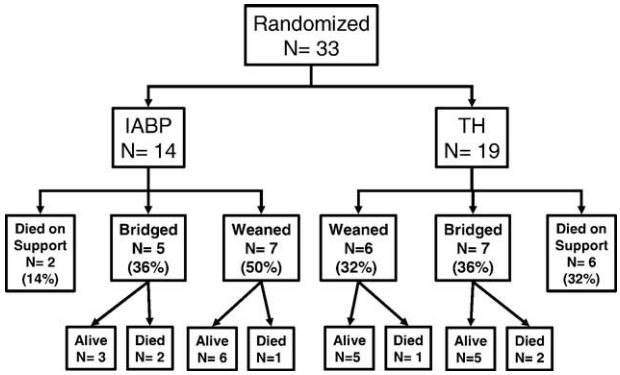
With more widespread use of primary percutaneous coronary intervention in the setting of acute myocardial infarction, the incidence of CGS appears to be declining. However, when it occurs, CGS is associated with high mortality (up to 80% in some groups), and few therapeutic advances have been made.[13] The first line of treatment of CGS is pharmacologic treatment aimed primarily at increasing peripheral resistance (pressors) and increasing cardiac contractility (inotropes). When possible, efforts to normalize pulmonary wedge pressure, which is typically elevated (with diuretics, nitrates) and maintain end-organ perfusion, are important therapeutic considerations. If hemodynamic parameters fail to normalize with pharmacologic treatment, an IABP is typically placed.[6] This explains why most of the patients enrolled in the present study already had an IABP in

Table IV. Plasma free hemoglobin*

	Baseline		Peak	
	Mean ± SD	**Median**	**Mean ± SD**	**Median**
IABP (n = 7)	9.1 ± 4.8	8.5	27.8 ± 58.9	4.5
TandemHeart (n = 9)	6.4 ± 6.4	4.0	55.9 ± 137.4	13.0
Roll-in (n = 5)	10.2 ± 4.8	11.4	57.4 ± 97.9	16.0

Values are expressed as milligrams per deciliter.
*Because of small sample size and large variability, there are no statistically significant differences between baseline and peak (*P* values detailed in text). Note the small changes in median values from baseline to peak and the large differences between mean and median values.

Figure 4



Outcome in patients randomized to treatment with either the TandemHeart assist device or IABP. "Died on support" includes patients dying within 8 hours of being weaned. The bottom row shows outcome 30 days after either weaning or bridge to another treatment. See text for further details. *TH*, TandemHeart.

place at the time of study enrollment. Indeed, from a logistic standpoint, it would be difficult to capture a large number of patients for enrollment into a CGS study before IABP implantation. Interestingly, however, neither pharmacologic treatment nor IABP have been proven through prospective randomized studies to improve outcomes in CGS.[14] Although registry data support the use of IABP in postinfarct CGS,[15,16] such data cannot differentiate between the effectiveness of an IABP and possible selection bias concerning which patients receive IABP treatment. Early revascularization is the only approach thus far shown to improve long-term survival.[3,2]

The use of mechanical circulatory support to treat CGS is predicated on the assumption that improving hemodynamics will improve mortality, which was not observed in the present study. However, the present study is grossly underpowered to assess an effect on mortality. In fact, assuming a 50% mortality in the control group, approximately 400 patients per group would be required to show a clinically significant 20% difference in mortality (with an $\alpha = .05$, power 80%, 2-sided test) between IABP and an alternate treatment such as the TandemHeart pVAD. Thus, the lack of observed mortality benefit with the TandemHeart pVAD should not be taken as a conclusion of the present study.

Moreover, Hochman[17] has suggested that reversal of the hemodynamic derangement of CGS may not address all the critical underlying pathophysiologic mechanisms. Other abnormalities, such as elevated inflammatory cytokines, elevate inducible nitric oxide synthase with resultant increased levels of NO, and peroxynitrite could contribute importantly to morbidity and mortality in CGS and does not appear to be reversed with restoration of a more normal hemodynamic state. This suggests that addition of other treatments aimed at inflammation in combination with effective hemodynamic support may result in better outcomes.

The use of pharmacologic treatments was not standardized before or during the study period. It was anticipated that pressor/inotropic support would decrease in the TandemHeart group, but this was the case in only about 25% of cases. Rather, pharmacologic support was used in combination with mechanical circulatory support and was adjusted frequently to maintain hemodynamics while attempting to wean the more invasive support device. Thus, although such support may help reduce toxic levels of inotropic/pressor support in some patients, the therapeutic goal achievable with a temporary support device may more realistically be to improve hemodynamics for a sufficient time so that the device can be weaned so that the patient can be maintained on reasonable doses of these pharmacologic agents. Alternatively, support of the patient until hemodynamics improves may allow the patient to be bridged to another more definitive therapy such as corrective surgery, transplantation, or LVAD.

The device proved to be reliable when used out to 6 days. With regard to adverse effects, distal leg ischemia, arrhythmias of all sorts, bleeding, and infection appeared more commonly in the TandemHeart pVAD group than in the IABP group, but did not require device removal or compromise hemodynamic support. There was a trend for peak pHgb values to be higher, but the absolute value of the difference between groups

Table V. All reported adverse events

Adverse event	Roll-in (n = 9), no. (%)	TandemHeart (n = 19), no. (%)	IABP (n = 14), no. (%)	P*
At least 1 adverse event	8 (88.9%)	18 (94.7%)	10 (71.4%)	.14
TandemHeart pVAD system failure	1 (11.1%)	1 (5.3%)	NA	
Need for surgical intervention to treat a device-related AE	0 (0%)	0 (0%)	1 (7.1%)	.44
Device removal because of any problem	0 (0%)	1 (5.3%)	1 (7.1%)	.99
Neurologic dysfunction	1 (11%)	6 (31.6%)	7 (50%)	.47
Non-CNS embolic event	0 (0%)	0 (0%)	1 (7.1%)	.42
Hemolysis	0 (0%)	1 (5.3%)	1 (7.1%)	.99
Thrombocytopenia	0 (0%)	3 (15.8%)	3 (21.4%)	.99
Hepatic dysfunction	0 (0%)	3 (15.8%)	4 (28.6%)	.42
Renal dysfunction	1 (11.1%)	4 (21.1%)	3 (21.4%)	.99
Right side of the heart failure	0 (0%)	1 (5.3%)	0 (0%)	.99
Cardiac tamponade	2 (22.2%)	2 (10.5%)	1 (7.1%)	.99
Deep venous thrombosis	0 (0%)	2 (10.5%)	1 (7.1%)	.99
Arrhythmias	2 (22.2%)	11 (57.9%)	5 (35.7%)	.3
Movement of transseptal cannula	0 (0%)	1 (5.3%)	0 (0%)	.99
Bleeding	1 (11.1%)	8 (42.1%)	2 (14.3%)	.13
Cannulation site infection	0 (0%)	3 (15.8%)	0 (0%)	.24
Damage to blood vessel(s)	2 (22.2%)	2 (10.5%)	0 (0%)	.5
Cannulation site hematoma	1 (11.1%)	1 (5.3%)	0 (0%)	.99
Distal leg ischemia	1 (11.1%)	4 (21.1%)	2 (14.3%)	.99
Systemic infection or sepsis	2 (22.2%)	4 (21.1%)	5 (35.7%)	.44
Total no. of events	14	58	37	
Average no. of events per patient	1.6	3.1	2.6	.5

AE, Adverse event; *CNS*, central nervous system; *NA*, not applicable.
**P* values relate to comparisons between TandemHeart and IABP groups. Statistical tests are detailed in the Methods section.

(28.5 mg/dL increase in mean value and 8.5 mg/dL increase in median value) was relatively small and not statistically significant.

From a physiologic standpoint, the TandemHeart pVAD withdraws blood from the left atrium and returns it to the femoral artery. This is effective at reducing PCWP (Figure 2) and also explains why the cardiac output during support is not increased by the blood being pumped by the device. This offloading has the potential additional benefit of reducing the work on the heart, which may allow recovery.

Limitations

The major limitation of the present study is the limited number of patients enrolled. Based on the rates of enrollment in prior studies of CGS,[2] it was prospectively anticipated that a study of this nature could not enroll enough patients to investigate a mortality benefit that, as noted above, would require several hundred patients. As such, the study was initially designed to evaluate the hemodynamic effect of the TandemHeart pVAD compared with IABP. Even in this regard, it was initially intended to enroll 90 patients. Demonstration of superior hemodynamics in the patients already enrolled, concordance of the present results with those of a preliminary report of a similar study performed at a single site in Germany,[18] and the slow rate of patient enrollment prompted the DSMB to suggest halting the study. In addition, most of the patients were enrolled after failure of IABP. This limits the ability to make conclusions about the hemodynamic effectiveness of the IABP because patients demonstrating a robust hemodynamic response to IABP support, which has been demonstrated in some prior studies,[19,20] would never be considered for enrollment into this study. However, the prior study by Thiele et al,[18] in which CGS patients (similar to those enrolled in the present study) were prospectively randomized to receive IABP or TandemHeart, showed no significant hemodynamic impact of IABP.

Summary

The TandemHeart pVAD improves cardiac index by approximately 0.6 L/m^2 per minute, reduced pulmonary wedge pressure by approximately 10 mm Hg, and increases MAP by approximately 8 mm Hg in patients presenting within 24 hours of the development of CGS, even in patients already failing IABP. This was at the expense of an increase in certain adverse events. The impact of device use on mortality in this diverse group of critically ill patients is not demonstrated by the present study.

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Appendix A

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The Data Safety Monitoring Board consisted of Drs Jeff Brinker (chair), Eric A. Rose, John Boehmer, and John Kennedy.