Experience with the SynCardia total artificial heart in a Canadian centre

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Background: The SynCardia total artificial heart (TAH) provides complete circulatory support by replacing both native ventricles. Accepted indications include bridge to transplantation and destination therapy. We review our experience with TAH implantation during a period when axial flow pump became available.

Methods: We retrospectively analyzed the demographics, clinical characteristics and survival of all patients receiving the TAH.

Results: From September 2004 to November 2016, 13 patients (12 men, mean age 45 ± 13 yr) received the TAH for refractory cardiogenic shock secondary to idiopathic (56%) or ischemic (17%) cardiomyopathy and to other various causes (33%). Before implantation, mean ejection fraction was 14% ± 4%, 7 (54%) patients had previous cardiac surgery, 4 (31%) were on mechanical ventilation, and 3 (23%) patients were on dialysis. The mean duration of TAH support was 46 ± 40 days. Three (23%) patients died while on support after a mean of 15 days. Actuarial survival on support was 77% ± 12% at 30 days after implantation. Complications on support included stroke (n = 1, 8%), acute respiratory distress syndrome requiring prolonged intubation (n = 5, 38%) and acute renal failure requiring temporary dialysis (n = 5, 38%). Ten (77%) patients survived to be transplanted after a mean of 52 ± 42 days of support. Actuarial survival rates after transplant were 67% ± 16% at 1 month and 56% ± 17% at 1 year after transplantation.

Conclusion: The TAH provides an alternative with low incidence of neurologic events in extremely fragile and complex patients waiting for heart transplantation. Complex and unusual anatomic conditions explained the current use of TAH.

Contexte : Le cœur artificiel total (CAT) SynCardia offre un soutien circulatoire complet en remplaçant les 2 ventricules naturels. Parmi ses indications acceptées, mentionnons la transition pré-greffe et l'assistance permanente. Nous passons ici en revue notre expérience en matière d'implantation de CAT à partir de l'avènement des pompes à flux axial.

Méthodes : Nous avons analysé de manière rétrospective les caractéristiques démographiques et cliniques et la survie de tous les patients ayant reçu un CAT.

Résultats : De septembre 2004 à novembre 2016, 13 patients (12 hommes, âge moyen 45 ± 13 ans) ont reçu le CAT pour un choc cardiogénique réfractaire dû à la cardiomyopathie idiopathique (50 %) ou ischémique (17 %) ou à d'autres causes (33 %). Avant l'implantation, la fraction d'éjection était en moyenne de 14 % ± 4 %, 7 patients (54 %) avaient déjà subi une chirurgie cardiaque, 4 (31 %) étaient sous ventilation mécanique et 3 (23 %) étaient dialysés. La durée moyenne du soutien par CAT a été de 46 ± 40 jours. Trois patients (23 %) sont décédés malgré l'implantation du dispositif après une moyenne d'utilisation de 15 jours. La survie actuarielle pendant l'utilisation du dispositif a été de 77 % ± 12 % 30 jours suivant l'implantation. Les complications ont inclus : accident vasculaire cérébral (n = 1, 8 %), syndrome de détresse respiratoire aigüe nécessitant une intubation prolongée (n = 5, 38 %) et insuffisance rénale aigüe nécessitant une dialyse temporaire (n = 5, 38 %). Dix patients (77 %) ont survécu jusqu'à leur greffe après une moyenne d'utilisation de 52 ± 42 jours. Les taux de survie actuarielle après la greffe ont été de 67 % ± 16 % après 1 mois et de 56 % ± 17 % après 1 an suivant la greffe.

Conclusion : Le CAT est une solution de rechange qui s'accompagne d'une incidence faible de complications neurologiques chez des patients à l'état extrêmement fragile et complexe en attente d'une greffe cardiaque. Des complications anatomiques inhabituelles ont expliqué l'utilisation du CAT.

End-stage heart failure is a public health problem affecting an increasing number of patients each year. Although a variety of options exist for its treatment, heart transplantation remains the gold standard.[1] Unfortunately, the lack of donors is now leading to increased use of ventricular assist devices (VAD) as a bridge to transplant (BTT) or as destination therapy (DT).[2,3] Among patients with advanced heart failure, those with biventricular failure have the worst prognosis and very few available options while waiting for a compatible donor. They are usually more fragile preoperatively, with more comorbidities, including renal and hepatic dysfunction, than patients receiving sole left ventricular support.[1,2,4] Implantation of a total artificial heart (TAH) is an alternative to durable biventricular VAD (BiVAD) support.[5]

At the Montreal Heart Institute, we have used the SynCardia TAH since 2004 as a cardiac assist device in patients with critical biventricular failure, patients in whom apical canulation for left VAD (LVAD) support is contraindicated, and in patients with specific anatomical conditions precluding the use of a standard LVAD (e.g., patients with congenital diseases). We sought to review our experience with TAH implantation during a period when axial flow pump became available.

Methods

Between January 2004 and November 2016, 51 durable circulatory assist devices, mostly the HeartMate II device, have been implanted at our institution. Biventricular assistance was required in 13 (24%) patients, all of whom received the SynCardia TAH as a bridge to transplantation. The decision to implant a TAH over a simpler LVAD was made owing to the presence of conditions most often associated with multiorgan failure: severe preoperative right ventricular dysfunction, which was assessed through right heart catheterization, echocardiography and clinical examination; uncontrolled malignant ventricular arrhythmia; massive acute anterior infarction; severe left ventricular hypertrophic cardiomyopathy; and noncompaction left heart and congenital anomalies. Patients with a functional New York Heart Association (NYHA) class IV and a body surface area (BSA) equal to or greater than 1.7 m^2 or with an anteroposterior diameter greater than 10 cm (measured at T10 from the sternum to the anterior face of the vertebral body on CT of the chest) were eligible for TAH implantation.

SynCardia TAH

Implantation of the TAH consists of excision of both ventricles and the 4 native valves. Clinical experience with this device has been described previously.[6–9] Briefly, it is a pneumatic blood pump with 2 polyurethane ventricles and 4 monodisk mechanical prostheses (Medtronic-Hall, Medtronic Inc.). Each ventricle has a volume of 70 mL and comprises a silicone diaphragm separating blood from the pneumatic chamber. The pulsed injection of compressed air allows the movement of the diaphragm and thus the filling and evacuation of both ventricles. The 2 artificial ventricles are directly sutured to the patient's native atria and connected to an external console via 2 drivelines. Since 2006, the emergence of new hand-held consoles has made home discharge with TAH possible, but their use has been approved only recently in North America (2011 in Canada, and 2014 in the United States).[5]

Patient management

The TAH implantation technique is similar to a usual orthotropic transplant and has been described previously.[10–13] All patients who received a TAH were systematically anticoagulated with acetylsalicylic acid (ASA; 325 mg/d), warfarin (target international normalized ratio [INR] of 2.5–3.5) and dipyridamole.

Data collection

Clinical and laboratory data were collected retrospectively from our transplantation and heart failure database. We obtained informed consent from each patient, and our institution's ethics committee approved the study. All patients were followed prospectively at the cardiac transplantation and ventricular device clinic at our institution.

Statistical analysis

Statistical analyses were performed using the Statistical Package for Social Sciences version 20. Continuous data are presented as means ± standard deviations, and categorical variables are presented as frequencies (%). Survival data were analyzed using Kaplan–Meier estimates. We calculated the estimated survival without including patients at the time of transplantation to assess overall survival after positioning the device.

Results

Baseline characteristics

Between January 2004 and November 2016, 13 (25%) of our 51 patients receiving long-term mechanical circulatory support received a TAH. Patients' demographic and clinical characteristics and causes of heart failure are shown in Table 1. Most patients were men (12, 92%), and the patients' mean age was 45 ± 12 (range 21–68) years. They had a mean BMI of 25.9 ± 2.9 and an average body surface area of 1.93 ± 0.1. Four (31%) patients had prior cardiac surgery, including 2 heart transplantations, 1 mechanical mitral valve replacement and 1 congenital

heart surgery (failed Fontan). One patient was in constant refractory ventricular arrhythmia during the 48 hours preceding TAH implantation, 1 had an aortic aneurysm of the ascending aorta necessitating resection at the time of implantation, 1 had a severe form of hypertrophic cardiomyopathy precluding any trial of an insertion of an LV cannulation for LVAD support, 1 had a massive anteroapical myocardial infarction, and 1 had a nocompaction left ventricular cavity also precluding the insertion of an apical cannula.

Patients with biventricular failure who had a Right Ventricular Stroke Work Index (RVSWI) lower than 300 were evaluated for implantation of the TAH and rejected for a simple LVAD support. All patients had elevated serum creatinine and bilirubin measurements above normal values, suggesting the presence of multiorgan failure (Table 1).

Patient status before implantation

Five patients (38%) received mechanical respiratory support preoperatively for an average of 0.75 ± 1.3 days before implantation. Those 5 patients also had an intra-aortic balloon pump. One (8%) patient was on extracorporeal membrane oxygenation (ECMO) support after primary graft failure following transplantation. Three patients (23%) were on dialysis, initiated 7, 9 and 21 days before TAH implantation, respectively. Four (31%) patients had chronic renal failure before implantation (defined as either kidney damage or estimated glomerular filtration rate [eGFR] < 60 mL/min/1.73 m^2 for > 3 mo).

Table 1. Preoperative patient characteristics

Characteristic	Mean ± SD or no. (%)*
Age at implantation, yr	45 ± 12
Sex, male:female	12:1
BSA	1.93 ± 0.1
BMI	25.9 ± 2.9
Preoperative support	4 (33)
Mechanical ventilation	4 (33)
IABP	11 (91)
Inotropes	14.6 ± 2.9
Preoperative LVEF	4 (33)
Previous cardiac surgery	4 (33)
Preoperative ARF†	2 (16)
Preoperative dialysis	5 (33)
INTERMACS status 1 or 2	8 (67)
Etiology	
DCM (noncompaction of the left heart, uncontrolled VT, multiple LV mural thrombi)	6 (50)
ICM (acute anteroapical myocardial infarction)	2 (17)
Other (primary graft failure, mechanical MVR, Failed Fontan, hypertrophic cardiomyopathy)	5 (33)
Preoperative laboratory data	
Sodium, mmol/L	134 ± 7
Creatinine, μmol/L	156 ± 79
eGFR-MDRD, mL/min/1.73 m^2	70.6 ± 35.3
BUN, mmol/L	10.5 ± 0.6
Bilirubin, μmol/L	50.5 ± 9.2
Lactate, mmol/L	2.6 ± 1.8

ARF = acute renal failure; BMI = body mass index; BSA = body surface area; BUN = blood urea nitrogen; DCM = dilated cardiomyopathy; eGFR = estimated glomerular filtration rate; IABP = intra-aortic balloon pump; ICM = ischemic cardiomyopathy; INTERMACS = Interagency Registry for Mechanically Assisted Circulatory Support; LVEF = left ventricle ejection fraction; MDRD = Modification of Diet in Renal Disease; SD = standard deviation.

*Unless indicated otherwise.

†Delta creatinine > 100 μmol/L or > 50% baseline.

Surgical technique

The mean duration of clamping and of cardiopulmonary bypass were 85 ± 25 minutes and 103 ± 27 minutes, respectively. One (8%) patient had concomitant atrial septal defect closure, and another patient had a replacement of an aneurysmal dilatation of the ascending aorta.

Outcomes and complications while on TAH support

The patients were supported with TAH for a mean duration of 46 ± 40 (range 1–384) days. Three (23%) patients died while on support after an average of 16 ± 0.7 days. Their causes of death were multiple organ failure, acute necrotizing pneumonia and stroke, respectively. The 30-day estimated actuarial survival while on TAH support was 77% ± 12%.

Postoperative complications are listed in Table 2. Eight (62%) patients experienced substantial early postoperative bleeding, requiring multiple blood transfusions, and 5 (38%) patients required reoperation. Seven (54%) patients experienced acute renal failure, requiring temporary hemofiltration, with 1 patient remaining on chronic hemodialysis. Patients were weaned from mechanical ventilatory support after an average of 1.9 ± 1.6 days, and the mean length of stay in the intensive care unit length was 38 ± 32 days. Five (38%) patients required prolonged mechanical ventilator support for respiratory failure.

According to our institutional policy, patients were not allowed to be discharged home with a portable console

Table 2. Outcomes of total artificial heart support

Outcome	Mean ± SD or no. (%)
Duration of support, d	46 ± 40
Outcome	
Ongoing	0 (0)
Died on support	3 (23)
Transplanted	10 (77)
Neurologic events	
TIA (< 24 hr)	1 (8)
Stroke	1 (8)
Bleeding requiring reoperation	5 (38)
Infection	6 (46)
ARF requiring dialysis*	7 (54)

ARF = acute renal failure; SD = standard deviation; TIA = transient ischemic attack.

*Delta creatinine > 100 umol/L or > 50%.

when these became available in Canada in 2011. While on support, 1 (8%) patient experienced hemorrhagic (ischemic) stroke 15 days after transplantation, and 1 (8%) had a transient ischemic attack (TIA) (< 24 h and without sequelae) 6 days after surgery. Six (46%) patients experienced systemic infections, 1 (8%) a driveline infection, 1 (8%) bacterial mediastinitis, 1 (8%) fungal sepsis possibly related to the device, and 2 (15%) bacterial pneumoniae.

Overall survival after implantation of the TAH

After a mean follow-up of 807 ± 1230 days, 7 patients (54%) had died. The total estimated actuarial survival after device implantation (patients censored at the time of explant) was 77% ± 12% at 30 days.

Survival after transplantation

Ten (77%) patients were successfully transplanted after a mean of 51 ± 42 days of TAH support. Actuarial survival after transplantation was 67% ± 16% at 1 month and 56% ± 17% 1 year after transplantation.

Discussion

Replacing 2 native ventricles and 4 cardiac valves, the TAH provides a flow rate of 7–9 L/min, improving systemic perfusion and decreasing filling pressures. Although the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS)[3] reported only 301 TAH implantations for the period June 2006 to December 2014, TAH remains a valid option for patients with irreversible biventricular failure and in those with specific anatomical conditions. Indications for TAH include extensive acute anteroapical myocardial infarction, acute or chronic cardiac rejection, left ventricular insufficiency with previous mechanical valves in place, acquired inoperable left ventricular septal defect, multiple left ventricular mural thrombi, intractable ventricular arrhythmia, failure of Fontan correction, end-stage hypertrophic cardiomyopathy and noncompaction of the left heart.[14]

In this report, we reviewed our experience using the SynCardia TAH in BTT patients. This device was used in extremely sick patients (all patients were in INTERMACS I or II) with biventricular failure awaiting transplantation or with special conditions precluding the use of simpler axial flow pump LVAD. The posttransplant survival of this sicker population is expected to be lower than in our usual patients. The need for a TAH in our program was 24% (n = 13), which is higher than data reported by INTERMACS (4%, n = 697 of 15 745),[3] possibly because of the limited availability of this technology compared with the widespread availability of more traditional LVADs.

Survival to transplantation varies greatly, ranging between 26% and 79%, as reported by the CardioWest TAH investigators.[11,14] Moreover, in a recent report on more than 100 patients who received TAH, Copeland and colleagues[5] reported a survival to transplantation of 68% and a posttransplant survival of 77%, for a global survival from implantation of 52%.[5] La Pitié-Salpêtrière Hospital reported a similar success rate of BTT of 61% after a mean support duration of 97 ± 97 days.[15]

At our institution, the TAH is the preferred device for durable biventricular support in eligible patients awaiting transplantation. The BTT rate compares favourably with those reported in the literature.[10–12] Those results are mainly owing to rigorous patient selection and decision to proceed to temporary circulatory support, although these patients were at high risk of immediate death. Kirsch and colleagues[15] identified older age and preoperative mechanical ventilation as major risk factors while on support. Others have also reported preoperative mechanical ventilation as a risk factor for death while on support.[16] Indeed, the need for preoperative mechanical ventilation reflects the magnitude of cardiogenic shock and the patient's critical preoperative condition.

One (8%) patient had a stroke while on support. This incidence of neurologic events was similar to those reported around the world.[11–15] However, most of these studies are retrospective by nature and could have underestimated the incidence of stroke, because not all patients underwent systematic brain imaging. In the present study, we performed brain imaging on a clinical basis only. Furthermore, the TAH compares favourably with BiVAD devices in terms of early/mid-term survival or stroke.[4,17,18] This is likely because of the complete removal of both ventricles, the absence of residual thrombi and the use of shorter drivelines with large-diameter cannula. Also, local antithrombotic management could be associated with those low rates of neurologic events.

Our institutional policy is to keep the TAH recipients in the hospital until transplantation. However, the recent emergence of mobile consoles allows home discharge.[9,19] Only a few centres have reported their experience with these portable drivers. Demondion and colleagues[19] described 12 (44%) patients discharged home over a 4-year period, with an average wait of 88 days from TAH implantation to transplant.[19] Hence, the high costs associated with ICU stay and the economic burden on the hospital could be limited with an earlier home discharge for these patients. Furthermore, the authorization by the US Food and Drug Administration for implantation of a TAH as DT in 2014 as well as the development of a 50 mL pump for small adults or children (< 40 kg) could extend the indications for TAH beyond a BTT strategy.

The average survival of 57% 1 year after transplantation among patients who received a TAH is lower than that in patients who received the HeartMate II device in our experience.[20] A policy of routine discharge home with a hand-held console after TAH implantation may allow for

complete patient recovery before transplantation and better survival at 1 year.

Conclusion

Although the increasing dominance of LVAD continuous-flow pumps is now well established, the TAH remains a viable option in our strategy to support patients with biventricular failure and with special clinical or anatomical conditions.[21] This device offers an effective means of bridging critically ill patients to heart transplantation by replacing all native ventricles. The current availability of the hand-held consoles could improve the patient's condition at the time of transplantation, allowing out of the hospital care for patients during mechanical support with the TAH.

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