Austin Journal of Anesthesia and Analgesia

Austin Publishing Group

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Editorial

The Total Artificial Heart Experience at Virginia Commonwealth University Medical Center

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Received: June 10, 2014; Accepted: June 18, 2014; Published: June 20, 2014

The Syncardia Cardio West Total Artificial Heart-t (TAH) (Syncardia Systems, Tucson, AZ) is a biventricular pneumatically driven pump designed to replace the native ventricles until a suitable donor for transplantation can be found. It offers several advantages over ventricular assist devices including the complete elimination of native ventricular andvalvular dysfunction, an immediate reduction in intracardiac filling pressures, and an absence of right/ left heart mismatch. We describe our experiences during the intraoperativeanesthetic management, including TEE evaluation of 66 patients during a 6 year period receiving the Cardio West TAH-t.

More than 5 million Americans are currently diagnosed with heart failure and nearly 300,000 deaths from this disease occur annually. For the most severe forms of the cardiac dysfunction, heart transplantation has emerged as the only effective therapy, with one and five year survival rates of up to 94 % and 78% respectively. Unfortunately, in recent years demand for donor hearts has doubled while the supply has decreased. The TAH-t has evolved into a viable option in a select group of patients as a bridge to transplantation. These are patients with severe biventricular failure who are on two or more inotropes with worsening end organ function. The presence of uncontrolled sepsis or other medical comorbidities that limit survival are contraindications to receiving a TAH-t.

The Syncardia Cardio West TAH-t is a biventricular pneumatic pulsatile pump, with two separate artificial ventricles that replace the patient's native ventricles and four valves. The two ventricles are similar to each other in construction and are made of plastic polyvinyl chloride. Taken together, the artificial ventricles weigh 160 grams and occupy 400 cubic cm of space in the chest. The two artificial ventricles differ in spacing and angulation of inflow and outflow valves and the entry sites for the conduits for the left and right sides. Each artificial ventricle has a rigid outer shell that houses a seamless blood-contacting diaphragm, two intermediate diaphragms, and an air diaphragm; all made of segmented polyurethane separated by thin coatings of graphite. Each artificial ventricle has a 27 mm inflow Medtronic –Hall valve and a 25 mm outflow Medtronic-Hall valve mounted on the housing. The diaphragm excursion courses from one wall of the housing to the other, allowing the ventricle to fill fully and eject 70 ml of blood per beat. A flexible polyurethane lined inflow connector called a "quick connect" is sewn to the atrial cuff of the recipient heart and then snapped onto the inflow valve mount of the artificial ventricle. On the outflow side, the Dacron outflow connectors are snapped onto the outflow valve mounts of the artificial ventricles after the distal connector anastomosis has been completed. Wire reinforced air conduits covered with Dacron in the transabdominal pathway are connected by long drive lines and to an external console. The Dacron velour covering the drive lines promotes tissue in growth and decreases the incidence of infection. These drive lines are exteriorized under the left costal margin.

The external console consists of two pneumatic drivers, one primary and one backup; air tanks; and a computer monitoring system equipped with alarms. Heart rate, percent systole (percentage of cardiac cycle occupied by systole), and left and right pressures are manually controlled. De airing must be done carefully with the aortic cross clamp on, by gradually allowing passive filling. Left and right sided cardiac outputs are continuously displayed in a trended fashion on the computer console with continuous digital display for each artificial ventricle. Separate ventricular volumes for each artificial ventricle are also continuously displayed on an integrated laptop computer. The primary driver is set to eject blood from each artificial ventricle during systole. This is achieved by setting the ejection pressure for the right ventricle 30 mm Hg higher than the PA systolic pressure. Similarly, the ejection pressure for the left ventricle is set 60 mm Hg higher than the systolic BP. The HR is set to 120-130 beats per minute. The CVP is maintained in the 10-15 mm Hg range and the MAP is usually maintained in the 70-90 mm Hg range. The TAH can generate a cardiac output of 7-8L/min. Once set, these parameters are rarely changed. The high CO generated contributes to increased "washing" of the device's blood contacting surface as well, thus reducing the risk of thromboembolism. Currently, portable pneumatic driver/consoles that provide pneumatic power are available, thereby facilitating discharge from the hospital and allowing for greater patient mobility.

Anesthetic management of these patients includes standard ASA monitoring and insertion of a radial artery catheter prior to induction. Central venous access via right internal jugular veinis performed under dynamic ultrasound imaging after intubation. A TEE probe is placed in every cardiac case at our institution. Induction must be carried out with caution as many of these patients are hemodynamically unstable. Inotropic support that these patients are maintained on pre operatively is continued intra operatively until the initiation of CPB. Induction is performed with fentanyl (5-10 mcg/kg) and etomidate (0.2 mg/kg) in divided doses. Atotal dose of versed (4-5 mg) is administered prebypass. A NDP muscle relaxant with minimal cardiovascular effects (vecuronium/ cisatracurium/) is used provided there is no difficulty with intubation. Anesthesia is maintained with a combination of isoflurane(0.6-1.0%) and fentanyl (5-10 mcg/kg). Preload is maintained with adequate administration of

Citation: Reddy PS. The Total Artificial Heart Experience at Virginia Commonwealth University Medical Center. Austin J Anesthesia and Analgesia. 2014;2(5): 1028.

crystalloids guided by our TEE assessment of biventricular function. Aminocaproic acid (10 gram bolus over 30 minutes followed by one gram per hour until skin closure) is employed at our institution. CPB for TAH implantation is similar to that of other open cardiac procedures.

TEE is employed during weaning from CPB to assess atrial de-airing prior to release of the aortic cross clamp. Since there is limited volume within the mediastinum, the TAH is capable of compressing native structures. Specifically, filling of the TAH can be limited by compression of the left pulmonary veins and inferior vena cava. TEE examination of the left pulmonary veins is best accomplished in the midesophageal 4-chamber (0 degree)TEE view. The left lower pulmonary vein can be viewed by advancing the probe and rotating the imaging plane between 100-130 degrees. The RA can be visualized in the mid esophageal bicaval view (100-105 degree) and the IVC-atrial junction examined by reducing the imaging plane to 80-100 degrees while advancing the probe. The Medtronic-Hall tilting disk AV valves can be imaged and their function verified with 2D and CF Doppler in the mid esophageal 4-chamber view 0 degree view. Adequate left and right sided cardiac outputs must be achieved prior to cessation of CPB. This is dependent upon on maintenance of intravascular volume sufficient to fill the TAH, patency of the pulmonary veins and IVC, and appropriate functional settings of the TAH. If the SBP remains low despite adequate volume resuscitation, we initiate a vasopressin drip (2-4 units/hour) to treat the vasoplegic syndrome. I routinely administer methylene blue 2mg/kg 30 minutes preinduction to decrease the incidence of the vasoplegic syndrome – and have found the requirement for less vasoconstrictor support during CPB. Post CPB, Heparin anticoagulation is reversed with Protamine and any other coagulopathy is reversed with FFP, Platelets and Cryoprecipitate. In cases of excessive bleeding, we administer Factor VII(90 mcg/kg)as the initial dose. The chest is left opened due to edema of the chest wall, stiff lungs and bleeding. The open chest is covered with a silicone membrane to avoid pulmonary and IVC compression and allow for evacuation of postoperative bleeding in the CVICU. We close the chest the following day and routinely use the TEE to assess for pulmonary vein flow and IVC compression. We have had no early or late infections associated with this approach.

Postoperative anticoagulation protocol includes an antiplatelet regimen (Dipyridamole and Aspirin) and Bivalirudin and then bridged to Warfarin on POD#3.

The first TAH implant was performed at our center in 2006. Since then, we have implanted 66 TAH-t. 50 of these patients have gone on to receive an orthotopicheart transplant. We have 7 patients currently on this device, 5 of who are mobile at home on the portable 'Freedom Driver' and 2 are in hospital hooked to the 'Big Blue' console. Average number of days from TAH-t implant to transplant is 107 days. Average number of days from TAH-t implant to discharge or heart transplant is 94 days.

Austin J Anesthesia and Analgesia - Volume 2 Issue 5 - 2014
ISSN : 2381-893X | www.austinpublishinggroup.com

Citation: Reddy PS. The Total Artificial Heart Experience at Virginia Commonwealth University Medical Center. Austin J Anesthesia and Analgesia. 2014;2(5): 1028.