Case report

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Case Report: Disparate flow in HeartMate II patient with extensive left ventricle repair

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Abstract

This case study reports the operative management of a 63-year-old male patient following implantation of the HeartMate II (HMII) left ventricular assist device (LVAD), with a non-compliant left ventricle (LV) and a reduced right ventricular (RV) end-diastolic volume. Intraoperatively, the patient had a thin, fragile LV wall with laminated clot; a ventricular septal defect was encountered during removal of the clot. Along with an aortic valve repair, the LV and the septum were reconstructed with multiple bovine pericardium patches, thus, moderately reducing the RV and LV stroke volume. A difference in cardiac output via a Swan-Ganz catheter (approximately 1.5 l/min) was observed as opposed to the HMII's estimated flow. The result was later replicated and verified *in vitro* via the Donovan Mock Circulation System (DMCS), where about 2 l/min lower flow on the HMII system was observed. In conclusion, the HMII flow rate displayed can be inaccurate and should only be used for trending.

Keywords

mechanical circulatory support (MCS); left ventricular assist device (LVAD); Donovan mock circulation system (DMCS); HeartMate II (HMII); ventricle repair/reconstruction

Introduction

In spite of all the medical advances and interventional treatments, cardiovascular disease (CVD) is still the leading cause of death in the United States of America (USA).[1] The common pathway of all CVD is advanced heart failure (HF) which affects about 5.8 million Americans and accounts for nearly 250,000 deaths each year.[2] It is the leading cause of hospital admission in the USA, the number one Medicare DRG (diagnostic related group) and is the disease state with the greatest cost burden to the health care system.[3,4]

With the persistent shortage of donor hearts, mechanical circulatory support (MCS) technology has become the standard-of-care for advanced heart failure as a bridge-to-recovery or modeling, bridge-to-transplantation and destination therapy.[5–8] One major form of MCS device is the left or right ventricular assist device (L/RVAD), a mechanical pump that offloads the heart by propelling blood from the ventricle to either the ascending aorta or the pulmonary artery via axial or centrifugal flow methods.The patient herein had been supported through multiple MCS devices; ranging from temporary LVAD support as bridge-to-decision or recovery with the Impella CP (Abiomed Inc., Danvers, MA, USA) and the CentriMag (Thoratec Corp., Pleasanton, CA, USA) to final destination-therapy with the HeartMate II (Thoratec Corp.).

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Case History

History of the present illness

A 63-year-old male patient with ischemic cardiomyopathy (body surface area: 2.0 m^2) was transferred to The University of Arizona Medical Center from another institution with refractory heart failure (LV ejection fraction of less than 10% from extensive myocardial infarction). Prior to the transfer, he was admitted for an elective placement of a biventricular implantable cardioverter defibrillator (ICD). He was intubated for significant desaturations and started on an epinephrine drip for cardiogenic shock. Impella CP support was initiated. The patient was flown to our facility while on the Impella CP support and immediately taken to the catheterization lab for a percutaneous LVAD placement from his right groin with a TandemHeart Trans-septal Cannula (Cardiac Assist Inc., Pittsburgh, PA, USA) for 3 reasons: 1) the patient needed more flow support, 2) the Impella was clotted and 3) the patient had laminated clot in his left ventricular apex. The CentriMag LVAD was established with 3.3 l/m at 3300 rpm. The Impella CP was removed one day later. The patient was stabilized and his end-organ function recovered with marginal renal function.

Operative management

Ten days later, the patient underwent aortic valve repair for his moderate aortic valve insufficiency, closure of the atrial septal defect, left atrial appendage ligation, a right MAZE procedure, central cardiopulmonary bypass and placement of an intracorporeal HMII LVAD. It was found that the patient had a thin, fragile LV wall and a necrotic septal wall with a fresh laminated clot that appeared to be of the same pathologies presented. The ventricular septal defect (VSD) was encountered during LV clot exploration. The VSD was repaired with a bilayer of bovine pericardium patch using Ethibond 3-0 MH (medium half) Prolene-pledgeted sutures. The extremely thin LV was also reconstructed with multiple bovine pericardia, resulting in a reduced LV and RV size, thus, compromising end-diastole volume (Figure 1). After de-airing and weaning from bypass with milrinone, inhaled nitric oxide (iNO) and dobutamine, the patient was hemodynamically stable after 290 minutes of bypass time and 32 minutes of cross-clamp time. Postoperatively, the patient achieved hemostasis and was hemodynamically stable at a speed of 9400 rpm, flow of 4.4 l/min, pulsatility index (PI) of 3.5 and pump power (PP) of 5.1 watts; displayed by the controller. However, a disparate flow in the HMII was observed. The HMII LVAD would display a flow rate of about 4.5 l/m which was about 1.5 l/m less than the Swan-Ganz catheter displayed, which had a cardiac index of 3.0 (6 l/m) or more. During this disparate flow, the aortic valve was never opened due to the repair via Park's stitch method, suggesting that the Swan-Ganz catheter was measuring the flow of the HMII.

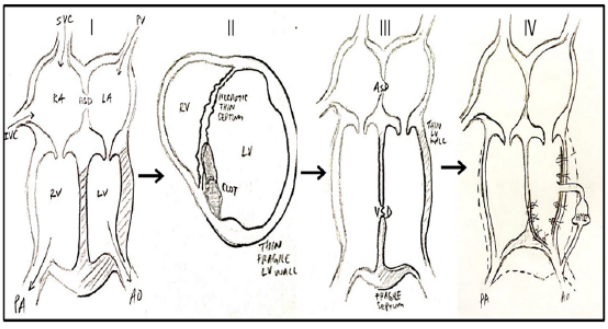

Figure 1. Depiction of the left ventricle repair using bovine pericardium patches and Ethibond 3-0 MH Prolene-pledgeted sutures. I: normal heart with an atrial septal defect made from the trans-septal cannula, II: Cross –sectional view showing clots, III: encounter of ventricular septal defect with clots removed, IV: reduced right and left ventricle after bovine pericardium patched.

Discussion

The HMII system displays pump power (PP), pulsatility index (PI), adjustable rpm speed and an estimated flow rate. The flow estimation is a calculated number based on a linear regression model involving the speed and power consumption.[9] However, Lund et al.[10] found, from a study of five HMII patients, that flow is inaccurate if the pump operates below 8000 rpm. In another 20 patient study, Slaughter et al.[11] recently reported that about 15-20% difference (0.8 l/m) in flow was observed intraoperatively between the HMII flow estimation and the direct flow measured by an ultrasonic flow probe. These findings were evaluated based on a compliant heart, such that the flow difference was marginal. Furthermore, they required Institutional Review Board approval and a cohort of patient enrollment where a reliable *in vitro* simulation could be used to demonstrate the point to gain further understanding of clinical picture and to make better clinical judgment under a complicated clinical scenario. The patient had extensive left ventricular and septal wall reconstruction, resulting in a non-compliant LV and a reduced RV fill volume, which may have magnified the discrepancy in the flow estimation displayed by the HMII from the true cardiac output measured by the Swan-Ganz catheter. This disparate flow is about a 2-fold increase when compared to the findings from Slaughter et al. The finding was later replicated and verified *in vitro* via the Donovan

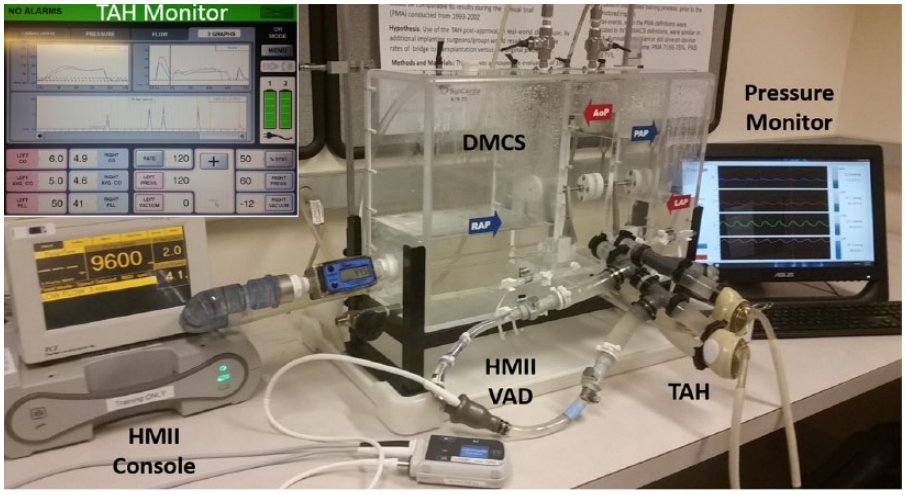

Figure 2. The *in vitro* simulation system. The system consists of a Donovan Mock Circulatory System (DMCS) and 70 cc Total Artificial Heart (TAH; SynCardia Systems Inc., Tucson, AZ) operating in reduced output conditions and driven by a Companion 2 Driver (SynCardia Systems Inc.). The DMCS hydraulically simulates the systemic and pulmonary portions of the human vasculature and contains four chambers that represent four blood-contacting domains: 1) right atrium, 2) pulmonary artery, 3) left atrium and 4) aorta.[12] The TAH is a pneumatically driven, pulsatile heart that pumps fluid from the systemic venous chamber into the pulmonary arterial chamber through the right ventricle and from the pulmonary venous chamber to the systemic arterial chamber through the left ventricle.

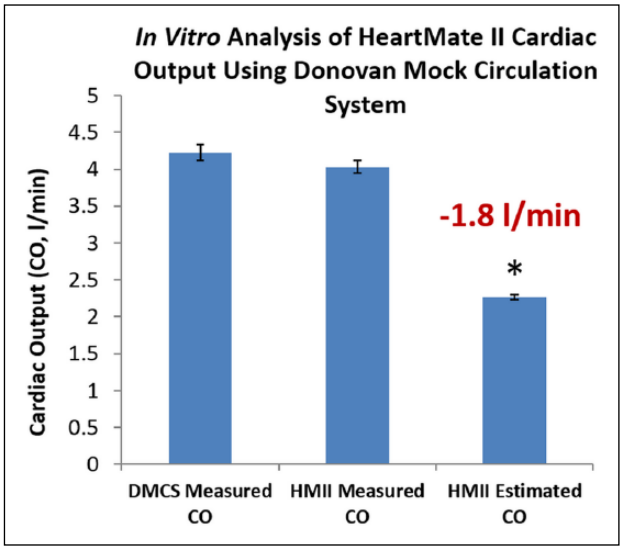

Figure 3. *In vitro* analysis of the HeartMate II (HMII) simulated at 9600rpm. DMCS tank settings: 50% systole with 60 mmHg right pressure, −12 mmHg vacuum and 120 beats per minute (BPM). Aortic pressure (afterload) was not altered. Mean cardiac output (CO) was reported as liters per minute (l/min) with standard error of the mean. *p-value <0.05.

Mock Tank System (Figure 2, 3) where about 2 l/min lower flow on the HMII controller was measured through the use of a SynCardia Total Artificial Heart (SynCardia Systems Inc., Tuscon, AZ, USA) and the DMCS.[12–13] These findings have clinical implications where clinicians should interpret the estimated flow with caution and only use it for trending purposes. Further, an echocardiogram ramp study is warranted should a clinician want to optimize settings, assess the pump and analyze native heart function if an absolute value of cardiac output is not available.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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References

1. Roger VL, Go AS, Lloyd-Jones DM, et al. Heart disease and stroke statistics–2011 update: a report from the American Heart Association. *Circulation* 2011; 123: e18–e209.
2. Lloyd-Jones D, Adams RJ, Brown TM, et al. Heart disease and stroke statistics–2010 update: a report from the American Heart Association. *Circulation* 2010; 121: e46–e215.
3. Hunt SA., Baker DW, Chin MH, et al. ACC/AHA guidelines for the evaluation and management of chronic heart failure in the adult: executive summary a report of the American College of Cardiology/American Heart

Association task force on practice guidelines. *Circulation* 2001; 104: 2996–3007.
4. O'Connell J. The economic burden of heart failure. *Clin Cardiol* 2000; 23: 6–10.
5. Frazier OH, Khalil HA, Benkowski RJ, Cohn WE. Optimization of axial-pump pressure sensitivity for a continuous-flow total artificial heart. *J Heart Lung Transplant* 2010; 29: 687–691.
6. Djoussé L, Driver J, Gaziano J. Relation between modifiable lifestyle factors and lifetime risk of heart failure. *JAMA* 2009; 302: 394–400.
7. Rose EA, Gelijns AC, Moskowitz AJ, et al. Long-term use of a left ventricular assist device for end-stage heart failure. *N Engl J Med* 2001; 345: 1435–1443.
8. Stevenson LW, Pagani FD, Young JB, et al. INTERMACS profiles of advanced heart failure: the current picture. *J Heart Lung Transplant* 2009; 28: 535–541.
9. HeartMate II LVAD operating manual. *Thoratec, Inc*. Pleasanton, CA, USA 08/2009.
10. Lund LH, Gabrielsen A, Tirén L, Hallberg A, El Karlsson K, Eriksson MJ. Derived and displayed power consumption, flow, and pulsatility over a range of HeartMate II left ventricular assist device settings. *ASAIO J* 2012; 58: 183–190.
11. Slaughter MS, Bartoli CR, Sobieski MA, et al. Intraoperative evaluation of the HeartMate II flow estimator. *J Heart Lung Transplant* 2009; 28: 39–43.
12. Crosby JR, DeCook KJ, Tran PL, et al. Physiological characterization of the SynCardia total artificial heart in a mock circulation system. *ASAIO J*. 2015; 61: 274–278.
13. Crosby JR. Expanding the performance envelope of the total artificial heart: physiological characterization, development of a heart failure model, and evaluation tool for mechanical circulatory support devices. PhD Thesis, University of Arizona, USA, 2014.