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# Body Position and Activity, But Not Heart Rate, Affect Pump Flows in Patients With Continuous-Flow Left Ventricular Assist Devices

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## ABSTRACT

**OBJECTIVES** The aim of this study was to determine the contribution of pre-load and heart rate to pump flow in patients implanted with continuous-flow left ventricular assist devices (cfLVADs).

**BACKGROUND** Although it is known that cfLVAD pump flow increases with exercise, it is unclear if this increment is driven by increased heart rate, augmented intrinsic ventricular contraction, or enhanced venous return.

**METHODS** Two studies were performed in patients implanted with the HeartWare HVAD. In 11 patients, paced heart rate was increased to approximately 40 beats/min above baseline and then down to approximately 30 beats/min below baseline pacing rate (in pacemaker-dependent patients). Ten patients underwent tilt-table testing at 30°, 60°, and 80° passive head-up tilt for 3 min and then for a further 3 min after ankle flexion exercise. This regimen was repeated at 20° passive head-down tilt. Pump parameters, noninvasive hemodynamics, and 2-dimensional echocardiographic measures were recorded.

**RESULTS** Heart rate alteration by pacing did not affect LVAD flows or LV dimensions. LVAD pump flow decreased from baseline 4.9 ± 0.6 l/min to approximately 4.5 ± 0.5 l/min at each level of head-up tilt ($p < 0.0001$ analysis of variance). With active ankle flexion, LVAD flow returned to baseline. There was no significant change in flow with a 20° head-down tilt with or without ankle flexion exercise. There were no suction events.

**CONCLUSIONS** Centrifugal cfLVAD flows are not significantly affected by changes in heart rate, but they change significantly with body position and passive filling. Previously demonstrated exercise-induced changes in pump flows may be related to altered loading conditions, rather than changes in heart rate. (J Am Coll Cardiol HF 2014;2:323–30)


The use of continuous-flow left ventricular assist devices (cfLVADs) in the management of end-stage heart failure is the standard of care in many tertiary centers globally, both as bridge to transplant and destination therapy (1-3). Refinement in pump design has led to more widespread use of the newer-generation axial and centrifugal continuous-flow pumps (2,4-6). Because these pumps

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**ABBREVIATIONS AND ACRONYMS**

**AV** = atrioventricular

**cfLVAD** = continuous-flow left ventricular assist device

**MAP** = mean arterial blood pressure

**RV** = right ventricle/ventricular

continuously drain the LV, they are sensitive to changes in pre-load and excessive pump speeds can result in suction events (7).

Current cfLVADs are set at a fixed pump speed determined at implant to provide sufficient delivery of blood from the LV (8). At constant pump speed, pump flow is determined by pre-load and afterload, systemic venous return, and arterial pressure (9). It has been shown in several studies that LVAD pump flows with continuous-flow devices increase in response to exercise (10–14). It is unknown the extent to which the increase in flow observed with exercise is due to an increase in heart rate or to changes in pump-loading conditions determined by venous return.

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To further investigate the separate contributions of heart rate and venous return, we examined estimated pump flow (l/min) and noninvasive hemodynamics at constant pump speed in stable cfLVAD patients under resting conditions. Although it has been hypothesized that increased heart rate (even in the setting of a closed aortic valve) may improve LV pre-load provided by the right ventricle (RV), whether this is relevant has not previously been examined. If it were found that increased heart rate enhanced LVAD pump flow, this would have major implications in ongoing management in this growing field.

## METHODS

Stable adult patients implanted with the continuous-flow HeartWare HVAD (HeartWare, Inc., Framingham, Massachusetts) were prospectively enrolled in 2 parallel studies. All patients were recruited from a single tertiary center (St. Vincent's Hospital, Sydney, Australia). These patients had New York Heart Association functional class IV symptoms pre-implant and were in Interagency Registry for Mechanically Assisted Circulatory Support profile I or II before LVAD implant and were on inotropic support and/or intra-aortic balloon pump/venoarterial extracorporeal membrane oxygenation. Criteria for study participation included being ambulatory for at least 3 months post-LVAD implantation. Patients were excluded from enrollment if they had sepsis requiring intravenous antibiotics.

**STUDY PROTOCOL.** The study was conducted according to the Declaration of Helsinki and Note for Guidance on Good Clinical Practice. The study was approved by the Human Research and Ethics Committee of St. Vincent's Hospital (Sydney, Australia). All patients provided written informed consent.

**PACING STUDY.** Patients were studied supine in the heart and lung transplantation ambulatory care unit. Heart rate and baseline mean arterial blood pressure (MAP) were measured using transcutaneous arterial Doppler ultrasound (811B, Bosco Medical, Murarrie, Australia) and a cuff sphygmomanometer. LVAD pump flow (l/min), power (W), and speed (rpm) were recorded. Standard transthoracic echocardiography (Acuson 128XP/5 system, Siemens Medical Solutions, Bayswater, Australia) was performed and M-mode measurements taken from the parasternal long-axis view. LV end-diastolic and end-systolic dimensions, status of aortic valve opening, and degree of aortic and mitral regurgitation were recorded. RV function was independently assessed on resting transthoracic echocardiography.

Pacemaker/defibrillator device interrogation and adjustment were performed by a trained device technician. Pacing settings were then increased by 10 beats/min above the baseline heart rate and continued to be increased by 10 beats/min every 2 min up to 40 beats/min above the baseline heart rate. All noninvasive, pump hemodynamic and echocardiographic measurements were repeated at each interval. The presence of LV "suck down" defined by a fall in the LV end-diastolic dimension by 80% below baseline was an indication to discontinue. All measurements were then repeated at the baseline heart rate, with device setting returned to baseline.

In patients who were pacing dependent, pacing settings were adjusted to 10 beats/min below the baseline heart rate every 2 min down to 30 beats/min below the baseline or until the minimum pacing rate was achieved (40 beats/min). Noninvasive, pump hemodynamic and echocardiographic measurements were repeated. Pacing settings were then adjusted back to the baseline settings with all measurements repeated.

**TILT-TABLE STUDY.** Patients were studied in the noninvasive testing laboratory of the coronary care unit; patients fasted for no more than 2 h prior to the procedure to avoid the confounding effects of relative dehydration and hypotension. Patients were then strapped onto a tilt-table supported around the waist and rested supine for 5 min prior to commencement of testing. Continuous electrocardiographic recordings of heart rate were obtained. Baseline MAP and LVAD pump flow, power, and speed were recorded. Standard transthoracic echocardiography was also performed, as for the pacing study.

The tilt-table was positioned at 30° head-up for 3 min. Patients were instructed to avoid any movement of the lower limbs to maximize venous pooling.