Cardiac Contractility Assessment in Rotary Blood Pump Recipients Derived from Pump Flow

P. Naiyanetr[1,3], F. Moscato[1,3], M. Vollkron[1], P. Zrunek[1], G. Wieselthaler[2]. H. Schima[1,3]

[1] Department of Biomedical Engineering and Physics, Medical University of Vienna, Vienna, Austria, [2] Department for Cardiothoracic Surgery, Medical University of Vienna, Vienna, Austria, [3]Ludwig-Boltzmann-Cluster for Cardiovascular Research, Vienna, Austria

Abstract—**A new cardiac contractility index derived from pump flow (I_Q) has been developed for rotary blood pumps (RBPs) recipients, to determine preservation and eventual recovery of the remaining cardiac function. Pulse flow indices were used for comparison with I_Q during pump speed changes.**

Pump flow was recorded in animal experiments and clinically in RBP recipients (MicroMed DeBakey LVAD®) at different pump speeds. I_Q was derived from the maximal derivative of pump flow versus QP2P relationship (dQ/dt_{max} vs. QP2P) during speed variations. I_Q was compared to classical indices. Further, simple currently used parameters such as peak to peak of pump flow (QP2P) and pulsation index (PI = QP2P divided by mean pump flow) were calculated.

I_Q was speed-independent for both pumps, and correlated well in animal experiments with classical invasively measured contractility index. Simple parameters (QP2P and PI) depended on speed and could be used only for estimation of percentage of support, but not for characterization of cardiac contractility.

In conclusion the cardiac contractility index I_Q can be derived from pump flow (I_Q) only. It allows easy and non-invasive continuous access to cardiac function.

Keywords— **Cardiac contractility index, Rotary blood pump, Cardiac recovery, Pulsitility index and LVAD**

I. Introduction

Nowadays, rotary blood pumps (RBPs) are not only used as a left ventricular assist devices (LVADs) for bridge to transplantation in end stage heart failure patients but also for a bridge to recovery (BTR) and destination therapy (DT) [1-9]. A reliable monitoring tool for cardiac contractility in RBP recipients is extremely important for diagnostics and therapeutic decisions on heart protection and eventual weaning strategies.

Several cardiac contractility indices have been established: the maximal derivative of left ventricular pressure (dP/dt_{max}), the dP/dt_{max} versus instantaneous developed isovolumetric pressure (dP/dt_{max} vs. IP), the dP/dt_{max} versus end diastolic volume (dP/dt_{max} vs. EDV), the preload recruitable stroke work (PRSW), the end systolic elastance (E_{es}), and the maximal elastance (E_{max}) [10-16]. They all require the determination of intraventricular pressure and/or volume, which needs complex and mostly invasive procedures.

However, with current RBPs technology, the pump flow signal is available either measured or estimated in most of the pumps. We could develop a new cardiac contractility index (I_Q) derived from this signal only. In a previous paper, we demonstrated the correspondence of I_Q to classical indices both in computer simulation and animal experiments [17]. In the following, these results are summarized and first clinical data are presented.

II. Materials and Methods

A. Definition of I_Q

The new pump flow derived contractility index (I_Q) is the slope of the linear relationship between the maximal derivative of pump flow and the peak-to-peak valued of pump flow (dQ/dt_{max} vs. QP2P). The I_Q is calculated as:

$$I_Q = \frac{dQ/dt_{\max}}{QP2P - Q_0} \qquad [s^{-1}] \qquad (1)$$

In the formula, dQ/dt_{max} is the maximal derivative of pump flow, QP2P is the peak-to-peak value of the pump flow in each heart cycle, and Q_o is the extrapolated value-axis intercept of dQ/dt_{max} vs. QP2P regression line. Q_o is calculated via speed variation.

B. In-vivo study

In animal experiments, a MicroMed-DeBakey LVAD® was implanted in seven healthy sheep (102 ± 20 kg). The study protocol was approved by the animal ethics committee of the Medical University of Vienna. The sheep were instrumented with a pressure-tip catheter (Millar Instruments Inc, Houston, USA) to measure the LVP, an ultrasonic flow probe (Transonic Systems Inc, Ithaca, USA) to measure pump flow, and a conductance catheter (CD Leycom, Zoetermeer, The Netherlands). Cardiac contractility was changed by pharmacological interventions with verapamil, first to reduce the contractility from the control condition and then, with noradrenalin to increase contractility

O. Dössel and W.C. Schlegel (Eds.): WC 2009, IFMBE Proceedings 25/VII, pp. 434–437, 2009.
www.springerlink.com

again. The detail of experiment setup was presented in our previous work [17-18].

The I_Q was compared then with a ventricular-pressure derived index that has been reported to be relatively load independent [14]:

$$dP/dt_{\max} \; vs. IP = \frac{dP/dt_{\max}}{IP - b_0} \; [s^{-1}] \quad (2)$$

In the formula, dP/dt_{max} is the maximal derivative of invasivly measured LVP, IP is the instantaneous developed isovolumetric pressure (or pressure at time of dP/dt_{max}) in every heart cycle, and b_o is the extrapolated value-axis intercept of $dPdt_{max}$ vs. IP regression line.

C. Application to clinical data

Subsequently, I_Q was derived from clinical data, coming from a previous study with the Micromed-DeBakey LVAD® [19]. Patient data included reactions to speed adjustment within 7.7 to 9.46 krpm. The flow signal was recorded from the built-in flowmeter using data acquisition hardware (DS1103, dSPACE, Paderborn, Germany) at a sampling frequency of 100 Hz and resolution of 16 bits. The flow signal was filtered with a FIR filter (with a Hamming window of 32 samples) at a cutoff frequency of 15Hz.

I_Q was also compared to flow pulsatility and flow pulsatility index, which in daily clinical practice are used as indicators of remaining heart action:

$$QP2P = Q_{\max} - Q_{\min} \quad [l/min] \quad (3)$$

$$PI = \frac{Q_{\max} - Q_{\min}}{Q_{mean}} \quad [-] \quad (4)$$

Here, QP2P is the peak-to-peak value of pump flow, Q_{max} is the maximal pump flow, Q_{min} is the minimal pump flow, PI the pulsatility index, and Q_{mean} the average of pump flow in each heart cycle.

III. Results

Both, in the animal experiment and in human data, the indecency of the index to speed variation could be proven by the linear relationship between dQ/dt_{max} vs. QP2P at different speed levels (Example fig. 1). In animal experiments, I_Q was proven to be sensitive to pharmacologically induced changes of cardiac contractility in a manner similar to dP/dt_{max} vs. IP (Fig. 2).

The plots of I_Q, QP2P and PI versus pump speed (calculated beat by beat) are shown in Fig. 3, Fig.4 and Fig.5, respectively. The independent of mean I_Q on speed variation and the strong dependence of QP2P and PI on such variation can be seen.

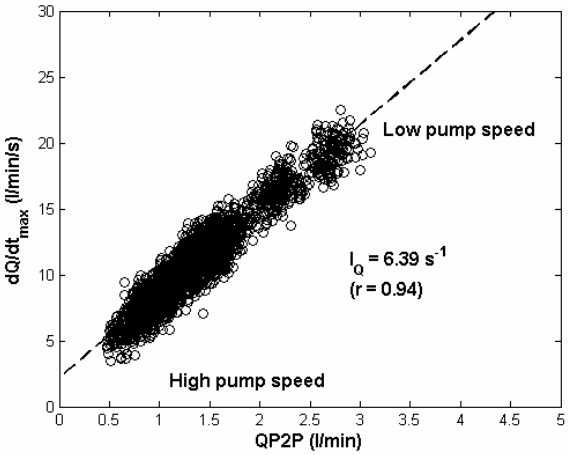

Fig. 1 dQ/dt_{max} vs. QP2P relationship in a patient at varying speed (7.7-9.5 krpm),

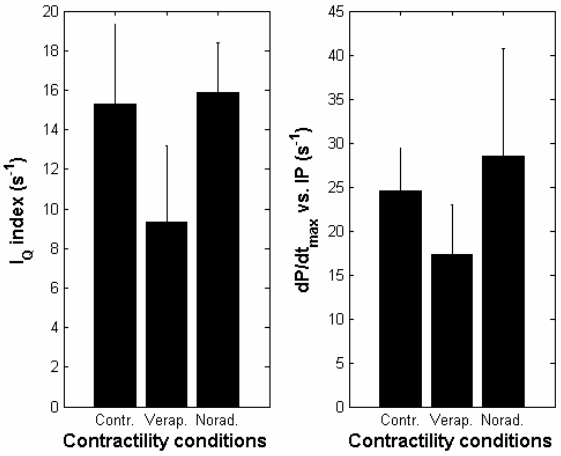

Fig. 2 I_Q compared to the classic index dP/dt_{max}vs.IP in the animal experiment with pharmacologically induced varying contractility (Contr.: control condition; Verap.: verapamil administration; Norad.: noradrenalin administration).

IV. Discussion and conclusion

This study demonstrates that the I_Q index is sensitive to cardiac contractility changes, but independent on pump speed and independent on preload and afterload changes (for details see [17]), which are inevitable prerequisites for a contractility index. Certainly the clinical data presented here, are preliminary and further clinical studies in various states and types of underlying disease should be performed. Certainly, the method can be applied also to pumps with

indirectly determined flow pattern, provided that the frequency contents of the calculated flow signal allow proper estimation of dQ/dt_{max}.

Advantageously, the index can be derived purely from pump-data, only requiring minor speed variations from time to time. Due to this simple procedure, it can be applied even quasi-continuously. It can certainly not substitute occasional Ultrasound inspections, which deliver far more details on the local distribution of contractile muscular tissue, but should allow new and immediate insights into the trends and variability of cardiac contractility in different therapeutically regimens.

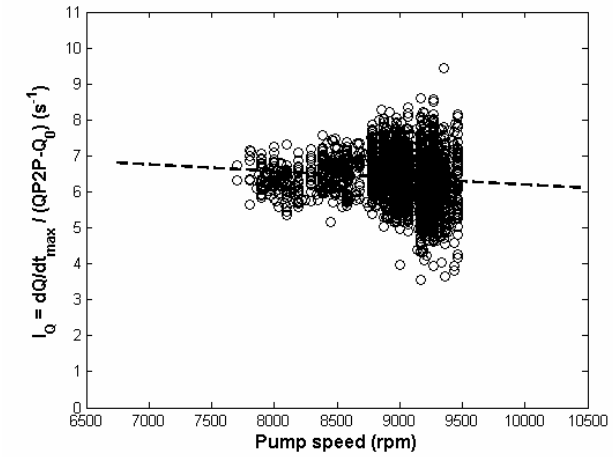

Fig. 3 Derived from the same data as shown in fig 2, the independence of the index to pump speed is demonstrated. Due to beat-to beat variation the mean over several beats should be taken.

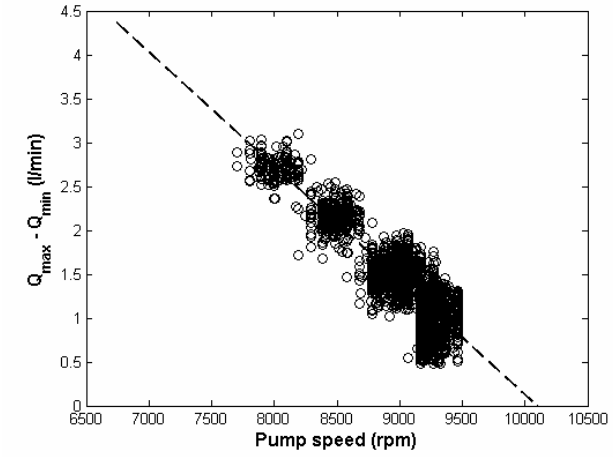

Fig. 4 Peak-to-peak of pump flow (Q_{max}-Q_{min}) at stable cardiac condition depends strongly on pump speed. (r = -0.88, p< 0.001).

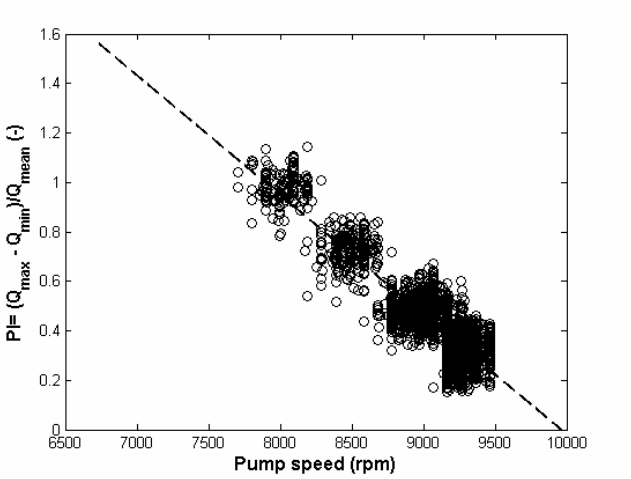

Fig. 5 Also pulsatility index PI depends at stable cardiac condition strongly on pump speed (r = -0.89, p< 0.001).

REFERENCES

1. Birks EJ, Tansley PD, Hardy J, et al. (2006) Left ventricular assist device and drug therapy for the reversal of heart failure. N Engl J Med 355:1873-84.
2. Burkhoff D, Klotz S, Mancini DM. (2006) LVAD-induced reverse remodeling: basic and clinical implications for myocardial recovery. Journal of Cardiac Failure 12:227-238.
3. Mueller J, Wallukat G. (2007) Patients who have dialted cardiomyopathy must have a trial of bridge to recovery (Pro). Heart Fail Clin 3:299-315
4. Maybaum S, Mancini D, Xydas S, et al. (2007) Cardiac improvement during mechanical circulatory support a prospective multicenter study of the LVAD working group. Circulation 115: 2497-2505.
5. Long JW, Healy AH, Rasmusson BY, et al. (2008) Improving outcomes with long-term "destination" therapy using left ventricular assist devices. J Thorac Cardiovasc Surg 135:1353-1361
6. Lietz K, Long JW, Kfoury AG, et al. (2007) Outcomes of left ventricular assist device implantation as destination therapy in the post-REMATCH era: implications for patient selection. Circulation 116:497-505
7. Freilich M, Stub D, Esmore D et al (2009) Recovery from anthracycline cardiomyopathy after long-term support with a continuous flow left ventricular assist device. J Heart Lung Transplant. 28(1):101-3.
8. O.H Frazier, J.K. Kirklin (2006) ISHLT Monograph Series 1: Mechanical Circulatory Support , Elsevier (chapter 9)
9. Dandel M, Weng Y, Siniawski H et al. (2008) Prediction of cardiac stability after weaning from left ventricular assist devices in patients with idiopathic dilated cardiomyopathy. Circulation. 118 (14 Suppl):S94-105.
10. Mason DT (1969) Usefulness and limitations of the rate of rise of the intraventricular pressure (dp/dt) in the evaluation of myocardial contractility in man. Am J Cardiol 23:516-27
11. Glower DD, Spratt JA, Snow ND, et al. (1985) Linearity of the Frank-Starling relationship in the intact heart: the concept of preload recruitable stroke work. Circulation 71: 994-1009
12. Little WC. (1985) The left ventricular dP/dt_{max}-end-diastolic volume relation in closed-chest dog. Cir Res 56: 808-815.

13. Little WC, Cheng CP, Mumma M et al (1989) Comparison of measures of left ventricular contractile performance derived from pressure-volume loops in conscious dogs. Circulation. 80(5):1378-87.
14. Kass DA, Maughan WL, Guo ZM. Et al (1987) Comparative influence of load versus inotropic states on indexes of ventricular contractility: experimental and theoretical analysis based on pressure–volume relationships. Circulation 76:1422–1436
15. Burkhoff D, Mirsky I, Suga H. (2005) Assessment of systolic and diastolic ventricular properties via pressure-volume analysis: a guide for clinical, translational, and basic researchers. Am J Physiol Heart Circ Physiol 289:H501-512.
16. Suga H. (2003) Cardiac energetics: from E(max) to pressure-volume area. Clin Exp Pharmacol Physiol 30: 580-5.
17. Naiyanetr P, Moscato F, Vollkron M et al. Continuous assessment of cardiac function during rotary blood pump support: A Contractility index derived from pump flow. Submitted to J Heart Lung Transplant (JHLT-D-09-00010)
18. Naiyanetr P, Moscato F, Vollkron M et al (2008) Estimation of cardiac contractility during rotary blood pump support using an index derived from left ventricular pressure. IFMBE Proceeding EMBEC08"4th European Medical & Biological Engineering Conference, IFMBE European Conference on Biomedical Engineering" Antwerp Belgium, pp. 1885-1887.
19. Schima H, Vollkron M, Jantsch U et al.(2006) First clinical experience with an automatic control system for rotary blood pumps during ergometry and right-heart catheterization.J Heart Lung Transplant.25(2):167-73.

Author: Phornphop Naiyanetr
Institute: Department of Biomedical Engineering and Physics.
Medical University of Vienna,
Street: AKH-4L, Waehringer Guertel 18
City: Vienna (1090)
Country: Austria
Email: n0569673@students.meduniwien.ac.at