Transesophageal Echocardiographic Measurement of Cardiac Index by the Prosthetic Mitral Valve Method Is Not Similar to the Continuous Thermodilution Method Via a Pulmonary Artery Catheter

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Objective: To compare the agreement of cardiac index measurements between transesophageal echocardiography across the prosthetic mitral valve and the continuous thermodilution method through a pulmonary artery catheter (PAC-TD) in patients undergoing double-valve replacement.

Design: Observational prospective study.

Setting: University hospital.

Participants: Twenty-five patients undergoing double-valve replacement (12 men and 13 women, age 25-78 years, ASA III-IV, NYHA II-III, LVEF $\geq$45%). Patients were grouped according to their prosthesis (mechanical prosthesis *v* bioprosthesis).

Interventions: All patients underwent cardiac index assessment during double-valve replacement.

Measurements and Main Results: Cardiac index across the prosthetic mitral valve was measured simultaneously using transesophageal echocardiography (CI_{MV}) and PAC-TD (CI_{PAC}) at 15, 30, 45, and 60 minutes after weaning from cardiopulmonary bypass, and at 0, 15, and 30 minutes after incision closure. A correlation was present between CI_{MV} and CI_{PAC} in both groups (mechanical prosthesis: $r = 0.47$, $p < 0.01$; bioprosthesis: $r = 0.60$, $p < 0.01$). In the mechanical prosthesis group, the bias between techniques (CI_{PAC} *v* CI_{MV}) was -0.5 L/min/m^2 (95% CI: -1.97 to 0.97), and error was 55%. In the bioprosthesis group, the bias between both techniques was -1.3 L/min/m^2 (95% CI: -3.1 to 0.5), and error was 56%.

Conclusions: A relatively weak correlation and lack of agreement between values of CI_{PAC} and CI_{MV} were observed in patients undergoing double-valve replacement. Therefore, transesophageal echocardiography might not be interchangeable with PAC-TD for measuring cardiac output or cardiac index. A regression equation is needed to correct the probable value of CI_{PAC}. CI_{MV} might be useful as a quantitative or semi-quantitative cardiac output measurement.

KEY WORDS: *cardiac index, echocardiography, transesophageal, thermodilution, cardiac output, mitral valve*

THE CONTINUOUS thermodilution method via a pulmonary artery catheter (PAC-TD) is recognized as the gold standard for cardiac index measurement (CI_{PAC}).[1–4] Transesophageal echocardiography (TEE) provides a clinically useful measurement of cardiac output across the native mitral annulus method.[5,6] In patients with mitral valve replacement, the prosthetic mitral valves are easy to locate and have a known fixed effective orifice area; the measurement of flow by Doppler is therefore very convenient. It is assumed that the measurement by Doppler through the prosthetic mitral valve reflects the left ventricular cardiac output. However, there have been no reports of the measurement of cardiac index derived from TEE through prosthetic mitral valves (CI_{MV}). Measurement of stroke volume across the native mitral valve using Doppler and 2D TEE may be unreliable because of the variability of the mitral valve orifice area. Thus, the measurement might prove to be more reliable in the presence of a prosthetic mitral valve because the orifice area is precisely known.

Although the use of PAC-TD or TEE during cardiac surgery remains controversial, some studies have assessed cardiac output by TEE across the aortic valve or left ventricular outflow tract (LVOT),[4,7,8] but not across prosthetic mitral valves. PAC-TD and TEE might not be interchangeable.[4]

The hypothesis of this study was that cardiac index can be measured after cardiopulmonary bypass (CPB) using a mitral valve prosthesis continuity equation in patients during ventricular pacing. Therefore, the objective was to compare the agreement between CI_{MV} obtained by TEE across the prosthetic mitral valve (mechanical prosthesis valve or bioprosthetic valve) and CI_{PAC} obtained by PAC-TD (as the gold standard) in patients undergoing double-valve replacement.

METHODS

Patients

This study was approved by the institutional ethical review board of the authors' hospital, and each patient provided a written informed consent. This was a prospective study performed in 25 consecutive patients with atrial fibrillation and rheumatic heart disease, scheduled for first time mitral valve and aortic valve replacement, undergoing CPB, and monitored using both TEE and a pulmonary artery catheter between April and June 2013.

The inclusion criteria were (1) ASA physical status III-IV and preoperative NYHA status II-III; (2) absence of history or symptoms suggesting liver, kidney, respiratory, or systemic diseases; (3) normal blood pressure; and (4) normal findings on chest x-ray and routine blood tests.

The exclusion criteria were (1) age $>$80 years; (2) preoperative ejection fraction $<$45%; (3) contraindication to TEE; (4) moderate-to-severe tricuspid regurgitation; or (5) history of coronary artery disease, or preoperative use of inotropic agents.

All 25 patients were divided into 2 groups according to the type of prosthetic mitral valve replacement: mechanical

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prosthetic valve versus bioprosthetic valve. The final choice of prosthesis was made by the surgeons according to the patients' condition. The patients were aware of the surgeons' decision and signed an informed consent. The study population included 12 men and 13 women, NYHA II-III, and with a left ventricular ejection fraction $\geq 45\%$ (according to TTE).

Anesthetic and Monitoring Management

All patients were given phenobarbital sodium (0.1 g) and scopolamine (0.3 mg) by intramuscular injection 60 minutes prior to surgery. Anesthesia was induced with propofol (1.5-2.0 mg/kg), sufentanil (1 μg/kg), and rocuronium (0.5-1.0 mg/kg). Anesthesia was maintained with propofol (4-6 mg/kg/h), remifentanil (0.2-0.4 μg/kg/min), cisatracurium (2-3 μg/kg/min), and sevoflurane (0.5-1 MAC). Intraoperative bispectral index was maintained between 40 and 60. Before sternotomy and CPB and after weaning from CPB, supplemental bolus doses of sufentanil, 1 μg/kg, were administered for analgesia.

After CPB, all patients' ventricular rates were paced using a temporary dual-chamber pacemaker (Medtronic, Inc.) to 90 bpm on the right ventricular surface (pacing mode: DOO). Fluid volume was controlled by an infusion pump to maintain the central venous pressure at 8 to 12 mmHg and the mean arterial pressure >70 mmHg. Each patient routinely was given milrinone (2-2.5 mg) 5 minutes before cessation of the CPB. Values of intraoperative left ventricular ejection fraction were assessed intermittently by the Teichholz method, which measures the difference between the end-diastolic and end-systolic diameters by M-mode echocardiography, at the level of the mitral valve. LVEF can be calculated automatically according to this model using $V = 7D^3/(2.4 + D)$, where V is the ventricular volume in milliliters and D is measured in centimeters. If the LVEF was $>45\%$ and if the cardiac index by the thermodilution method ≥ 2.5 L/min/m^2, the patient did not receive inotropic support after weaning.

Determination of CI_{MV}

After general anesthesia induction and tracheal intubation, a 4.5-5.5 MHz multiplane TEE probe (PET-510MA, TOSHIBA, Japan) was inserted in the esophagus. Intraoperative TEE monitoring and data measurements were performed by the same experienced certified anesthesiologist for all patients. All surgeries were performed by the same 2 attending cardiac surgeons. In this study, the prosthetic mitral valves' effective orifice area was known,[9,10] and HR was paced to 90 bpm after CPB, with the assumption that both parameters remained constant during surgery.

Doppler measurements were obtained from 2D-TEE recordings with Doppler of the prosthetic mitral valve at the level of the midesophageal 4-chamber view. The TEE continuous-wave Doppler sample volume was placed in the left ventricular chamber at 0.5 cm beneath the prosthetic mitral valve to obtain the velocity profile of the mitral valve central flow and to record the transmitral velocity time integral. The angle between the ultrasound beam and blood flow was maintained as much as possible parallel or less than 20 degrees, and appropriate adjustments were made to obtain the best-quality Doppler display possible. These TEE measurements were performed at end-expiration with cessation of mechanical ventilation, and velocity time integral waves were continuously recorded. Three continuous cardiac cycles were measured, and each variable was averaged.

Three anesthesiologists were always present: One for patient management, one for TEE, and one for PAC-TD. All TEE recordings and analyses were performed by 1 anesthesiologist who was blinded to hemodynamic data. CI_{MV} based on prosthetic mitral valve is a cardiac index calculated according to the stroke volume, which was calculated using the continuity equations. CI_{MV} was determined based on the measurements averaged for 3 cardiac cycles (Fig 1).

Determination of CI_{PAC}

A pulmonary artery thermodilution catheter (CCO/SVO_2/RVEDV, 774HF, 7.5F catheter, Edwards Lifesciences Co.) was inserted through a percutaneous internal jugular vein. Cardiac output measurements were performed automatically by a commercial machine (Vigilance II, Edwards Lifesciences Co.). The continuous thermodilution cardiac output or cardiac index derived from PAC-TD (CI_{PAC}) mode was used to collect all data. The anesthesiologist performing PAC-TD was blinded to hemodynamic data. Three readings were obtained at each time point, and the average was used for analysis. If the difference between the lowest and highest values of the 3 measurements was $>10\%$, 2 additional cardiac output measurements were performed, and the extreme values were discarded.

The authors collected and calculated hemodynamic data, CI_{PAC}, CI_{MV}, velocity time integral$_{MV}$, heart rate, mean arterial pressure, central venous pressure, left ventricular ejection fraction, mean pulmonary artery pressure, and pulmonary artery occlusion pressure. The patients' hemodynamic data (except CI_{MV}) after anesthesia induction but before incision (T_0) were collected and considered to be the baseline value before surgery. The present study focused on 7 time points after mitral valve implantation: 15 (T_1), 30 (T_2), 45 (T_3), and 60 (T_4) minutes after termination of CPB when the patient's hemodynamics were relatively stable (no large variations in heart rate and blood pressure), and 0 (T_5), 15 (T_6), and 30 (T_7) minutes after closure of the incision. Therefore, 7 matched data (CI_{PAC} *v* CI_{MV}) were obtained from each patient. Mean arterial pressure, mean pulmonary artery pressure, central venous pressure, and pulmonary artery occlusion pressure were recorded simultaneously at end-of-expiration, except for the LVEF that was measured by the Teichholz method at 4 time points (T_0, T_1, T_3, and T_5).

Cardiac output was calculated as the heart rate multiplied by the effective orifice area and by the velocity time integral. Since the heart rate and effective orifice area were constant, changes in cardiac output were reflected by variations in the velocity time integral.

Statistical Analysis

A power analysis was performed. Based on the 95% cardiac index as being $\pm 1.96\sqrt{(3/n)}S$, the authors determined that a sample of >60 paired measurements provided a 95% cardiac index of approximately $\pm 0.44S$.[11]