Pulmonary Artery Catheter Placement Using Transesophageal Echocardiography

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Objective: **To assess the feasibility of pulmonary artery catheter placement using transesophageal echocardiography inclusive of a description of the technique.**

Design: **A prospective, proof-of-concept study.**

Setting: **Single university hospital.**

Participants: **Twenty patients with chronic thromboembolic pulmonary hypertension scheduled for pulmonary thromboendarterectomy.**

Interventions: **Pulmonary artery catheters were placed in 20 patients solely by transesophageal echocardiographic guidance.**

Measurements and Main Results: **Placement of the pulmonary artery catheter in the pulmonary artery with transesophageal echocardiography guidance in fewer than 10 minutes was considered successful placement. The time to placement was measured from advancement of the pulmonary artery catheter in the superior vena cava (20 cm) to a final location at the junction of the right pulmonary artery and main pulmonary artery. All 20 pulmonary artery catheters were placed successfully using transesophageal echocardiography guidance and the median time to placement was 43 seconds. In 9 of the 20 patients (45%), the catheter was placed successfully on the first attempt without any adjustments. However, in 9 others (45%), the catheter required manipulation under transesophageal echocardiography vision. In 3 patients (15%), the pulmonary artery catheter was observed to be coiled in the right atrium and in 1 instance (5%) manipulation of the catheter in the right ventricle was required to enter the outflow tract.**

Conclusions: **Transesophageal echocardiography is a viable adjunctive method to conventional pressure waveform placement of pulmonary artery catheters in potentially difficult patients.**

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KEY WORDS: pulmonary artery catheter, transesophageal echocardiography, chronic thromboembolic pulmonary hypertension, pulmonary thromboendarterectomy

INTRODUCTION

Pulmonary artery catheters (PAC) commonly are used in cardiac surgery to facilitate the management of critical patients. PACs traditionally have been placed using pressure waveform tracings. However, conventional waveform-based PAC placement can be challenging in patients with low cardiac output, right-sided chamber dilation, ventricular dysfunction, tricuspid regurgitation, tricuspid annuloplasty, and pulmonary hypertension.[1] While previous case reports briefly have described the visualization, guidance, and aid in the removal of misplaced catheters offered by transesophageal echocardiography (TEE), no formal technique or views for PAC placement have been published.[2–5] Utilizing TEE during PAC placement has many potential advantages including advancement and manipulation of the catheter under direct visualization, which may result in quicker and less traumatic placement. The addition of TEE also potentially can avoid complications of catheter placement including catheter kinking, endocardial or valvular damage, and arterial injury. Furthermore, inspection of right-heart structures prior to placement of a PAC may identify unexpected contraindications to placement such as thrombus, tumor, or endocarditis.[2,6,7] Given the potential benefits of TEE guidance, a formal study was needed to confirm and document its application. Therefore, the goals of this study were to prove the hypothesis that placement of PAC using TEE guidance was possible, and to formally describe the protocol for placement of PAC with TEE in a series of chronic thromboembolic pulmonary hypertension (CTEPH) patients who possessed significant right-heart pathology.

METHODS

The study was approved by the Institutional Human Research Protections Program. Twenty patients with a diagnosis of chronic thromboembolic pulmonary hypertension who were scheduled for pulmonary thromboendarterectomy (PTE) between October 2015 and March 2016 gave consent in the preoperative holding area on the day of surgery. Patients excluded from participation were individuals younger than 18, individuals not competent to give consent, and/or a contraindication to placement of a pulmonary artery catheter or TEE probe was present. Pulmonary artery catheterization and TEE are standard of care and routinely utilized in the management of PTE patients at the authors' institution.

After consent was obtained, a TEE probe was placed by the anesthesia care team after induction of anesthesia and intubation but prior to the placement of the PAC as per the standard care of a PTE patient.[8] Participants in the placement of the PAC were the "PAC Operator," a cardiac anesthesia fellow, and the "TEE operator," a cardiac anesthesiology attending with advanced PTEeXAM echocardiography certification. Both participants were blinded to the transduced catheter pressure waveform prior to and throughout catheter insertion. After the patient was returned to the supine position and the PAC had been flushed and zeroed, it was inserted to 20 cm by the PAC operator. This constituted the starting point of the timed placement. The TEE operator then guided the PAC by providing the PAC operator with specific recommendations for PAC manipulation that were based on the TEE images obtained. The PAC was advanced from the superior vena cava through the tricuspid valve utilizing a midesophageal modified bicaval view. The PAC then was maneuvered through the right

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ventricle and right ventricular outflow tract under TEE visualization in the midesophageal right ventricular inflow–outflow view. The ending point of the timed placement was identification of the air-filled PAC balloon at the junction of the main pulmonary artery and right pulmonary artery in the midesophageal ascending aortic short-axis view. This position is the institutional standard for placement in patients with CTEPH due to potential presence of thromboembolic material in the proximal pulmonary arterial branches. Once placement was deemed successful by echocardiography, a pulmonary arterial pressure tracing then was visualized and confirmed. Failure to place the balloon-tipped catheter in the final position of the main pulmonary artery within 10 minutes was deemed a failed attempt. The time from advancement from the 20-cm insertion point to the final location was recorded in seconds. Catheter adjustments made by the PAC operator at the request of the TEE operator to facilitate PAC placement also were recorded. The primary endpoint of this study was successful placement of the PAC by TEE, with the secondary endpoint being time to placement in seconds.

Additional demographic data (eg, sex, age), functional assessments (eg, ejection fraction, cardiac output, cardiac index, central venous pressure, pulmonary artery pressures, pulmonary vascular resistance, tricuspid regurgitation, right ventricular function), and anatomic measurements (eg, tricuspid annulus, right ventricle) were collected immediately after pulmonary artery catheter placement and prior to surgical incision.

Cardiac output/index were obtained by averaging three consecutive thermodilution injections at end-exhalation. Pulmonary vascular resistance was calculated, with an estimated pulmonary capillary wedge pressure of 10 mmHg per institutional protocol (thromboembolic material in patients with CTEPH may result in aberrant pulmonary capillary wedge pressure values; a value of 10 mmHg estimates the underfilled left ventricle [LV]). Corresponding vitals (eg, heart rate, systemic blood pressure) and any vasoactive medications administered at the time of data collection also were recorded.

Left ventricular ejection fraction was calculated using the biplane technique. Because there are no validated national recommendations regarding the assessment of tricuspid annular size, right ventricular size, or right ventricular function by TEE, the authors' standard institutional protocols were followed. Right ventricular function was assessed via tricuspid annular plane systolic excursion obtained via a modified transgastric right ventricular inflow view and M-mode. A tricuspid annular plane systolic excursion less than 16 mm was determined to represent right ventricular systolic dysfunction.[9] Right ventricle size was determined to be normal if the area was 60% of the size of the left ventricle on 2-dimensional imaging. Right ventricle (RV) dilation was determined to be mild when the RV area was >70%, moderate when the RV area equaled the LV, and severe when the RV area exceeded the LV area. In addition, the cardiac apex being shared by both ventricles or dominated by the RV also was used as a determinant of severe RV dilation.[10] Determination of the tricuspid annulus as either normal or dilated was based on the American Society of Echocardiography guidelines regarding RV basal diameter with the cutoff of 41 mm.[11] Right atrial size was obtained from the preoperative transthoracic echocardiographic assessment of right atrial volume. The right atrium was considered dilated if greater than 25 mL/m^2 for men and 21 mL/m^2 for women.[11] Tricuspid regurgitation was determined by the TEE operator based on American Society of Echocardiography recommendations.[12] Tricuspid regurgitation and right ventricle size were converted to a numerical scale (1 = normal, 2 = mild, 3 = moderate, 4 = severe) in order to facilitate statistical analysis. Statistical analysis was performed in Microsoft Excel 2011 (Microsoft Corp, Redmond, WA).

RESULTS

Between October 2016 and March 2016, twenty pulmonary artery catheters were placed in chronic thromboembolic pulmonary hypertension patients. The patients were 65% male, with a median age of 54 years. The median left ventricular ejection fraction was 65%, median cardiac index was 1.63 L/min/m^2, median mean pulmonary artery pressure was 41 mmHg, and the median pulmonary vascular resistance was 686 dyn●s/cm^5. Associated hemodynamic variables are listed in Table 1. Fifteen patients (75%) demonstrated right ventricular dysfunction, 18 patients (90%) displayed right atrial dilation, and 6 patients (30%) had tricuspid annulus dilation. The median tricuspid regurgitation was defined as mild (2.0) and median right ventricle size was moderately dilated (3.0).

All 20 PAC were placed successfully in the main pulmonary artery at the junction of the main pulmonary artery and right pulmonary artery under the cutoff time of 10 minutes (Table 2). The median time to placement was 43 seconds; the time to placement ranged from 16 to 370 seconds. In 9 of the 20 patients (45%) the PAC was placed successfully on the first attempt via flow direction and pressure waveform transduction without any adjustments. However, in 9 patients (45%) the catheter required manipulation under TEE guidance to avoid the right atrial appendage and engage the tricuspid valve. In 3 patients (15%) the PAC had to be removed and reinserted after

Table 1. Clinical Characteristics (n = 20 Patients)

Patient Demographic Characteristics	
Age (y)	54 (42.5, 70.0)
Male	13 (65)
Functional Characteristics	
Left ventricular ejection fraction (%)	65.0 (60.0, 70.0)
Cardiac output (L/min)	3.48 (3.03, 3.99)
Cardiac index (L/min/m^2)	1.64 (1.47, 2.15)
Mean pulmonary artery pressure (mmHg)	41.0 (36.0, 47.8)
Pulmonary vascular resistance (dyn●s/cm^5)	686.0 (565.5, 931.8)
Central venous pressure (mmHg)	12.0 (10.8, 15.2)
Mean systemic pressure (mmHg)	80.0 (71.0, 85.5)
Concurrent vasoactive infusions	0 (0)
Right-Heart Characteristics	
Right ventricular dysfunction	15 (75)
Tricuspid regurgitation ŧ	2.0 (1.0, 3.0)
Tricuspid annulus dilation	6 (30)
Right atrium dilation	18 (90)
Right ventricle dilation	3.0 (3.0, 4.0)

NOTE. Continuous variables are presented as median (25th, 75th percentile); categorical variables are presented as n (%). Grade: 1 = normal, 2 = mild, 3 = moderate, 4 = severe.