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Continuous Transesophageal Echocardiographic (TEE) Monitoring During Port-Access™ Cardiac Surgery

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ABSTRACT

Background: Since the introduction of the closed-chest minimally invasive heart surgery using the Port–Access™ system a variety of monitoring techniques including fluoroscopy, transesophageal echocardiography (TEE) and invasive pressure measurements have been described. We investigated whether or not single TEE is feasible for perioperative monitoring of the placement, localization and proper function of the endovascular cardiopulmonary bypass (CPB) devices.

Methods: Fifty-one patients (35 mitral valve repair or replacement [MVR], 8 coronary artery bypass grafting [CABG], 5 atrial septal defects [ASD] and 3 left atrial myxoma) were subjected to Port-Access™ surgery (PAS). Intraoperative Omniplane-TEE (2D- and color-flow Doppler techniques) was used as the leading monitoring device for correct positioning of the endopulmonary vent catheter and the venous cannula, and for the visualization of the guide wire and the endoaortic occlusion catheter (Endoclamp™). After balloon inflation, its proper positioning and function during endoaortic occlusion, sufficient delivery of cardioplegia into the coronary ostia, absence of leakage flow and adequate venting were controlled. Left and right radial artery catheters as well as aortic root pressure measurements served as controls. Additional fluoroscopy was used as standby device.

Results: In 46 patients (90.1%) sufficient perioperative monitoring was provided by single TEE. In five cases additional intermittent fluoroscopy was necessary for correct positioning of the guide wire (CABG) and the Endoclamp™ (three MVR and one ASD). Dislocation of the Endoclamp™ into the left ventricle was observed once but was successfully corrected by TEE guidance. Weaning from CPB and de-airing were easily guided with TEE. We did not observe balloon-mediated aortic injury or aortic valve dysfunction, and myocardial recovery from CPB was uneventful. All cases of MVRs showed sufficient results (68% without evidence of regurgitation, 32% showed residual mitral valve incompetence of less than grade II). Neither perivalvular leakage (MV-replacement) nor shunt- (residual ASD) flow were detectable.

Conclusion s: We recommend single TEE as a safe and effective on-line imaging device for monitoring the endovascular CPB system during PAS. Fluoroscopy with its potential risk for the patients and the staff due to x-ray exposure should only be used in the presence of peripheral vascular disease or when echocardiographic imaging is insufficient.

INTRODUCTION

The Port-Access™ system (Heartport Inc, Redwood City, CA) was developed [Stevens 1996A] to perform closed-chest cardiac surgical procedures with the safety of cardiopulmonary bypass (CPB) thereby minimizing surgical trauma and improving recovery. The feasibility and safety of this catheter-based system has been shown in several experimental [Siegel 1996, Stevens 1996B, Pompili 1996] and clinical studies [St. Goar 1996, Falk 1996] and it is now introduced into clinical routine in many centers. However, due to limited surgical access to the heart, intense perioperative imaging consisting of transesophageal echocardiography (TEE), fluoroscopy, and multiple invasive pressure measurements, are necessary to assess cardiac function and to control the endovascular CPB device; this includes guiding the introduction and positioning of the endoaortic balloon occlusion catheter

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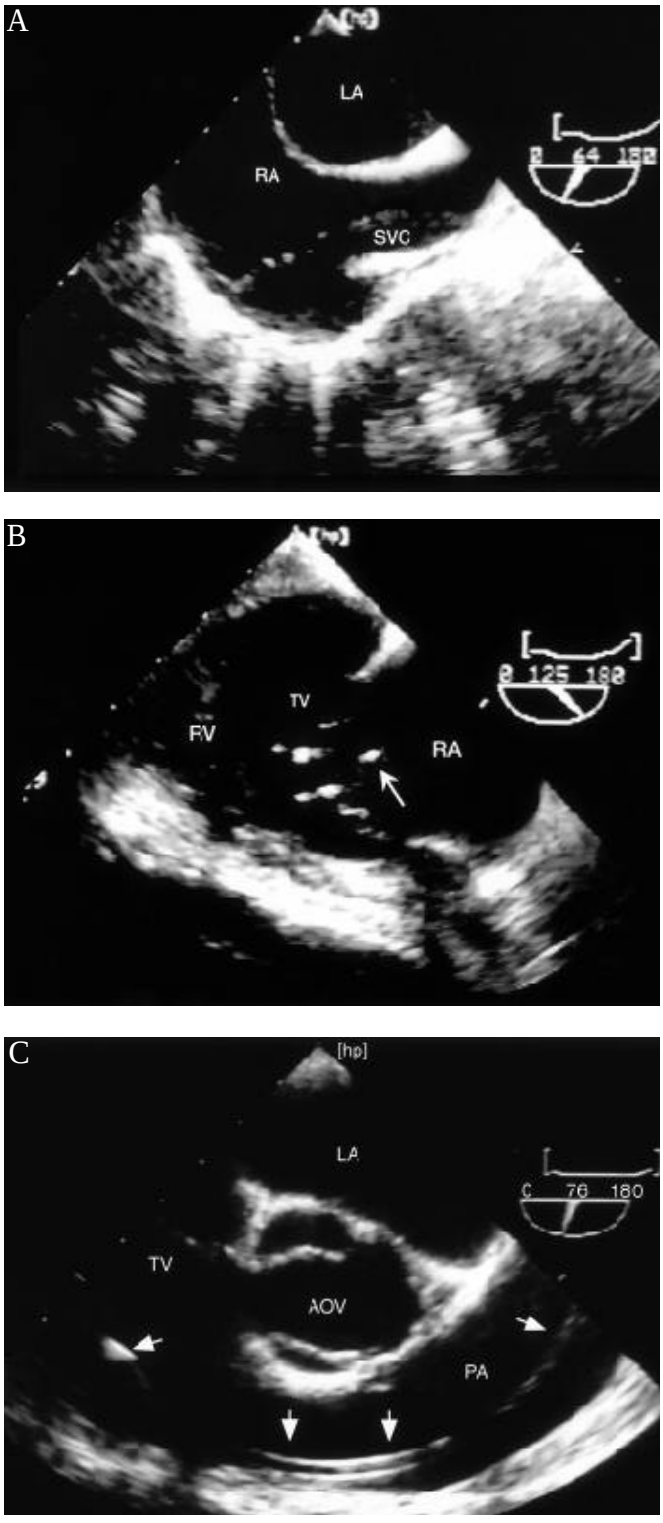

Figure 1. Transesophageal echocardiographic image from the gastroesophageal junction at different angles (65°, 125°, and 95°). Right atrium (RA), with the superior vena cava (SVC) showing the pulmonary vent catheter (PVC) when passing the RA (A) and entering the right ventricle (RV) through the tricuspid valve (TV). The tip of the PVC is indicated by the arrow (B). Final position of the PVC (arrows) in the pulmonary artery (PA) (C).

(Endoclamp™), pulmonary vent catheter (PVC), and venous cannula (VC) and continuously assessing their proper functioning [Siegel 1997]. In addition, the necessity of fluoroscopy may be a disadvantage because of multiple interruptions of the surgical procedure by intermittent fluoroscopic imaging and the potential risk of x-ray exposure to patients and staff.

The present study was performed to evaluate the safety and efficacy of continuous single TEE monitoring during Port-Access™ surgery (PAS) without additional fluoroscopic support.

MATERIALS AND METHODS

Patients

Fifty-one patients underwent PAS. Of these patients, 35 had mitral valve disease, eight had isolated or multi-vessel coronary artery disease (CAD), five had atrial septal defect (ASD), and three had left atrial myxoma. Exclusion criteria were:

- evidence of major peripheral vascular disease
- severe aortic valve incompetence
- a diameter of the ascending aorta greater than 4.0 cm
- signs of severe calcification and intimal lesions of the descending aorta.

After induction of anesthesia, patients were intubated with a double-lumen endotracheal tube allowing isolated right or left single lung ventilation. Surgical access was achieved through a left- (CABG) or right- (MVR, ASD, and myxoma) sided anterolateral minithoracotomy. The Port-Access™ system (Heartport Inc, Redwood City, CA) was used as described by Reichenspurner, et al [Reichenspurner 1998].

TEE was performed with a HP Sonos 2500 system using a 5.0/6.2 MHz omniplane probe (Hewlett Packard, Andover, USA). Aortic and mitral valve functions were reassessed and aortic root diameters were measured at three different points (at the sinu tubular junction [STJ], and 1 and 2 cm above STJ). Before TEE guiding and positioning of the different CPB catheters, the ascending and descending aortae were examined to exclude severe calcification, atheromatous debris, intimal lesions, thrombi, and signs of dissection.

Introduction and TEE-Guidance of the Pulmonary Vent Catheter (PVC)

The PVC was placed into the main pulmonary artery (PA) via the right jugular vein by TEE control. For this reason the right atrium (RA) at the junction of the superior vena cava (SVC) and inferior vena cava (IVC) was visualized on omniplane sections (angle 95°–110°) with the TEE probe positioned at the gastroesophageal junction (see Figure 1A). A slight clockwise rotation of the probe allowed successive imaging of the tricuspid valve (TV) which was helpful in the identification of the catheter tip as it entered the right ventricle (RV) (see Figure 1B). Its proper position in the main PA was finally controlled from an upper esophageal view (angle 90°–100°) showing RA, RV, PV and partially the main PA (see Figure 1C). Continuous pulmonary pressure curves obtained from the PVC served as control.

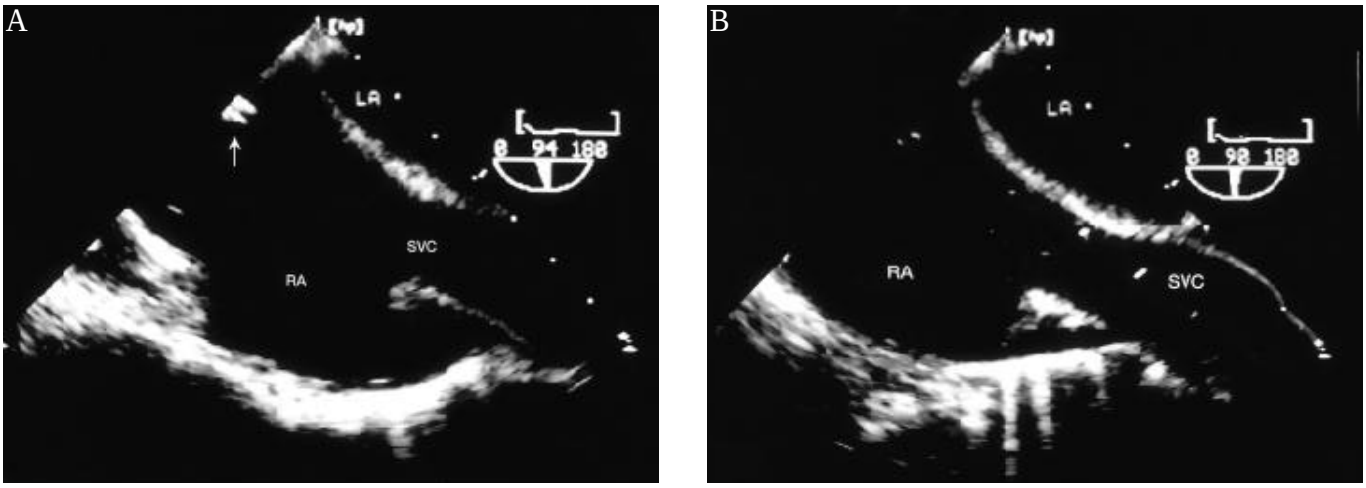

Figure 2. The arrow indicates the tip of the venous cannula located in the inferior vena cava. The cannula is forwarded in the SVC (A) and recognized by the hyperdense signals within the RA (B).

TEE-Controlled Placement of the Venous Cannula (VC)

For guidance in the placement of the VC (28F) via the femoral vein, the echo probe was again positioned as described above at the gastroesophageal junction (angle 95°–110°). The VC was continuously visualized in the IVC, traversing the RA and reaching the junction of the SVC and RA where its tip was finally placed (see Figures 2A and 2B ◎). Reduction of RV diameter and central venous pressure during initiation of CPB demonstrated adequate venous drainage.

TEE-Guided Positioning, Inflation and Monitoring of the Endoaortic Occlusion Catheter (Endoclamp™)

After dissection of the femoral artery through a small incision, a long guide wire (100 cm) was advanced retrogradely under TEE imaging through the descending aorta to the level of the aortic arch. For optimal viewing the probe was rotated counterclockwise and gradually withdrawn. To continuously follow the guide wire passing the aortic arch the TEE probe was withdrawn from the lower esophagus, rotated on its longitudinal axis and reintroduced when the catheter tip entered the ascending aorta (110°–125°). The tip of the guide wire was finally placed 1 to 2 cm above the STJ (see Figures 3A and 3B ◎). The Endoclamp™ was subsequently advanced over the guide wire, and its proper positioning in the ascending aorta was visualized in the manner described above. CPB was then initiated and the balloon of the Endoclamp™ was inflated with 20 to 30 ml radiologic contrast medium to allow immediate fluoroscopic control when necessary. Until full inflation of the balloon was achieved its position was carefully controlled in order to detect movement of the Endoclamp™ toward the aortic valve. Incomplete occlusion was detected by color-flow Doppler showing

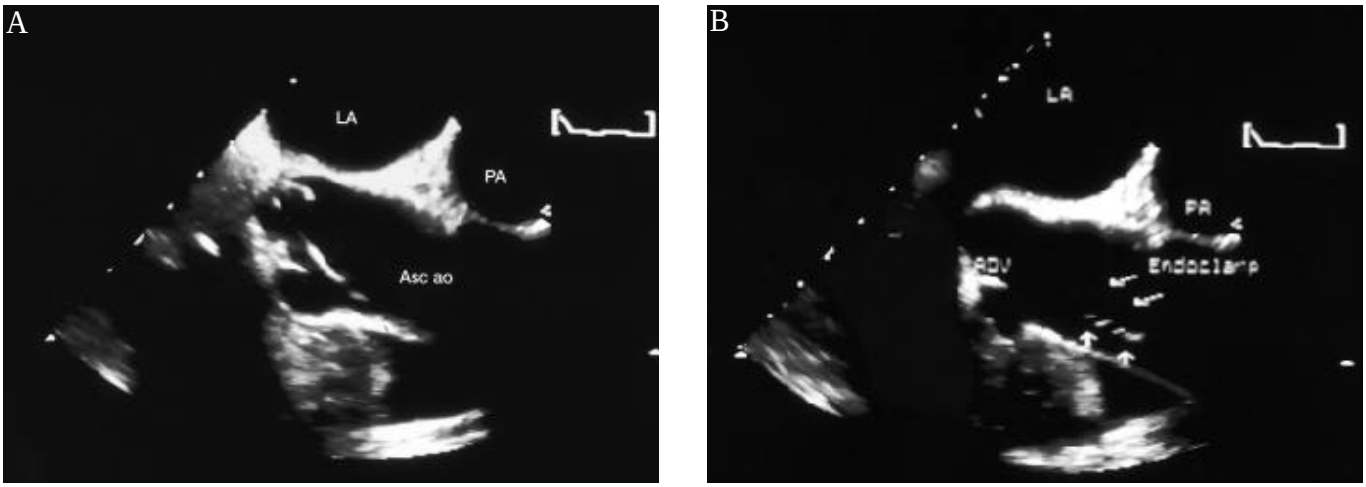

Figure 3. Transesophageal echocardiographic image (angles 110° – 125°) shows the guide wire located in the aortic root next to the left coronary ostium (A). The Endoclamp™ is advanced and finally placed 1 cm above the sino tubular junction (STJ) (B).

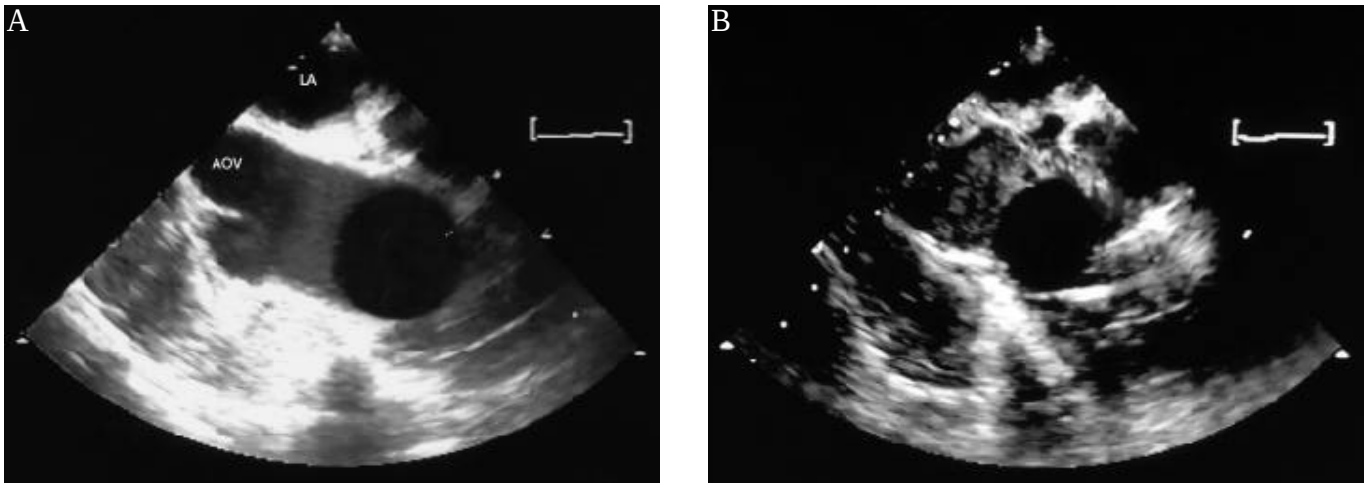

Figure 4.The Endoclamp™ is positioned and inflated 2 cm above the STJ (A).The blue color flow doppler signal above the inflated Endoclamp™ indicates leakage flow (B).

leakage around the balloon (see Figure 4 ◎). During endovascular CPB, proper positioning was verified continuously by TEE. In case of poor imaging the comparison of left, right and aortic root pressure measurements served as control, as described previously [Siegel 1997]. Increase in aortic root pressure indicated either leakage flow or movement of the Endoclamp™ toward the aortic valve. Differences between right and left radial artery pressures were observed when the balloon had migrated to the aortic arch with subsequent occlusion of the brachiocephalic artery

De-airing and Weaning from CPB by TEE-Monitoring

After aortic release of the endoaortic balloon de-airing was monitored by visualization of air-bubbles during continuous venting via the Endoclamp™ catheter and direct needle puncture of the ascending aorta. Imaging of the left atrium, the left atrial appendage, the left ventricle (LV), the aortic valve and the proximal part of the ascending aorta was performed from the upper esophageal level by steering the array through the arc. Venting was continued until the appearance of air had significantly decreased (visualization of isolated bubbles).

During weaning from CPB, left ventricular function was assessed from a transgastric level showing a short-axis view at 0º. As the ultrasound beam was steered through 90º to 100º a two-chamber view ensued. Finally at 120º a long axis image was visualized. All planes were used to detect regional wall motion abnormalities and to measure LV diameters with M-mode technique. Inotropes, vasodilators, and fluids were given as appropriate.

After weaning from CPB, the mitral and aortic valves, and the ascending aorta were carefully examined. This was performed by 2D-imaging, color-flow, continuous- and pulse-wave Doppler technique to exclude hemodynamically relevant regurgitation, or perivalvular leakage, and to assess transvalvular pressure gradients.

RESULTS

In 46 patients (90.1%) sufficient perioperative monitoring of the catheter-based CPB system was provided by single TEE without the need of fluoroscopic imaging. During five procedures additional intermittent fluoroscopy was necessary for adequate positioning of the guide wire (one CABG) and monitoring of the Endoclamp™ (three MVR and one ASD). In the CABG case fluoroscopy revealed a mild “kinking” of the abdominal aorta which was not detectable by echo. It led to difficulties in advancing the guide wire. Further advancement was performed under fluoroscopic control. In the other four cases increasing aortic root pressure indicated possible dislocation of the Endoclamp™. At this time echocardiographic imaging was poor but fluoroscopy revealed proper positioning of the balloon. Further inflation of the balloon resulted in reduction of aortic root pressure to baseline.

Both the administration of cardioplegic solution and aortic venting were visualized by the color-flow Doppler detecting a turbulent signal between the balloon, the coronary ostia and aortic valve (see Figure 5).

In seven patients (13.7%) with known minor aortic valve incompetence, persistent ECG signals indicated insufficient cardioplegic delivery. TEE control revealed transvalvular flow and additional cardioplegic solution was given.

In 49 patients the Endoclamp™ position was stable during initiation of cardioplegic delivery. However, in 39 patients we observed a slight migration of the Endoclamp™ toward the aortic arch. In one case, the balloon migrated toward the aortic arch during cardioplegic delivery. Consecutive decrease of right radial arterial pressure indicated occlusion of the brachiocephalic artery. Immediate switch from administration of cardioplegia to aortic venting resulted in adequate re-positioning of the Endoclamp™ under TEE guidance.

Vice versa, the balloon tended to move toward the aortic valve during aortic root venting. This happened within

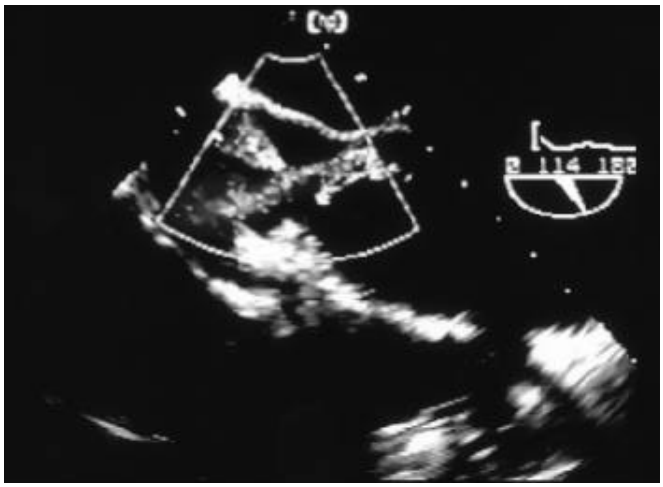

Figure 5. Transesophageal echocardiographic image in color-flow doppler mode shows cardioplegic delivery to the left (red) and right (blue) ostium coronary artery via the aortic Endoclamp™ catheter.

a range of 1.5 to 2 cm and was successfully detected. Correction was guided by echocardiographic imaging. At one point we observed a sudden and quick movement of the Endoclamp™ due to an unexpected increase in intraluminal pressure, finally resulting in a dislocation into the LV. The balloon was immediately deflated, withdrawn, repositioned and again inflated under TEE control.

Introduction and correct positioning of the VC was successfully guided under TEE control in all patients. Additional fluoroscopy was not necessary. In four cases inadequate venous drainage was observed by lack of chamber size reduction and persisting central venous pressure at baseline. The VC was withdrawn to the junction of the IVC and RA under TEE guidance which resulted in adequate venous drainage.

TEE-guided placement of the PVC in the main PA was successful in all patients. Additional continuous pressure measurements did not reveal significant discrepancy between echocardiographic imaging and pressure curve measurements.

We observed considerable air bubble formation in 15 patients immediately after closure of the LA. In most patients air formations were significantly reduced by continuous aortic root and direct aortic needle venting under TEE control.

Monitoring of left and right ventricular function was performed by TEE control in all patients. Preoperative LV function (EF = 56.8% + 10.8%) decreased significantly after declamping but reached baseline at the end of weaning from CPB in 42 (82.3%) patients.

After weaning from CPB echocardiographic examination of the aortic valve revealed no balloon mediated injury. No intimal lesions or significant changes in aortic diameter were observed. Sufficient function of the mitral valve after repair was confirmed by Doppler-flow measurement in all patients (17 without regurgitation, eight with insufficiency less than grade II). There was no evidence of perivalvular leak after mitral valve repacement. Mean and maximum transvalvular pressure gradients and calculated opening areas are shown in Table 1.

Table 1. Echocardiographic (CW/PW-Doppler) mean and maximum transvalvular pressure (p) gradients and calculated opening areas after mitral valve repairs (n=25).

	mean p (mmHg)	max p (mmHg)	Opening area (cm^2)
Mitral valve repair	2.00 ± 1.09	3.94 ± 1.85	2.84 ± 0.28

DISCUSSION

Perioperative transesophageal echocardiographic monitoring gains increasing importance during cardiac surgical procedures. The present data demonstrates that in addition to assessment of cardiac function TEE is a safe and feasible tool for guiding and controlling the catheter-based Port-Access™ CPB system. This is of importance considering the limited access to the heart. The avoidance of x-ray exposure is not only beneficial to the patient but also to the staff, especially when considering the increasing number of Port-Access™ procedures. Furthermore, interruptions of the surgical procedure due to intermittent fluoroscopic imaging is time-consuming and costly.

However, some recommendations as well as limitations have to be discussed when using TEE as the leading monitoring device during PAS. Before we started using TEE alone, we carefully compared visualization of the CPB system in the above described planes with fluoroscopic images for training of the observers. This is of particular importance when the quality of the echocardiographic image is decreased due to artifacts caused by air or instruments; this mainly occurs when the left atrium is opened (e.g., for MVR). Repositioning of the echo-probe may improve visualization but may not be sufficient in all situations. Invasive blood pressure measurements may also be very useful during periods of insufficient echocardiographic visibility. One additional obstacle with TEE-monitoring may be the lack of echocardiographic visualization of the inferior vena cava and the abdominal aorta.

Retrograde advancement of the guide wires and cannulas may cause aortic dissection as described previously [Reitz 1997, Mohr 1998]. Therefore TEE may not sufficiently control the potential risk of aortic dissection. Although preoperative assessment by abdominal Doppler sonography provides valuable information, immediate additional fluoroscopic imaging is mandatory when intraoperative difficulties (e.g., increased resistance) occur.

Concern has been raised about preexisting morphological peculiarities [Siegel 1997, Reichenspurner 1998] as well as possible changes of the functional state (elastic properties) of the ascending aorta during endoluminal clamping [Falk 1996]. Although we observed mild to moderate atheromatous plaque formations in about 17%, there was no evidence of plaque rupture, intimal damage or significant change in aortic caliber. Furthermore Falk and coworkers [Falk 1996] demonstrated preserved aortic distensibility

by calculating the elastic module in 24 patients that underwent PAS. Whether or not these elastic properties remain unchanged has to be elucidated through long-term follow-up studies.

To demonstrate effectiveness of de-airing during PAS, we detected considerable amounts of air-bubbles in some patients before venting. None of these patients however showed persisting neurologic deficits, as detected by simple clinical examination, due to accurate de-airing. Our findings are consistent with previous investigations by Tingleff et al and van der Linden et al who did not find a significant association between the amount of remaining air-inclusions detected by TEE or the occurrence of bursts detected by transcranial Doppler ultrasound, and the appearance of neurologic signs [van der Linden 1991, Tingleff 1995]. However, none of this studies used specific neurocognitive tests. Since it is known that open heart surgery is associated with high incidence of impaired neurological function [Martin 1982, Slogoff 1982] these findings have to be taken with caution. Further longitudinal investigations focusing on PAS are necessary.

In conclusion, the present study shows that single intraoperative TEE monitoring is safe and effective in successfully guiding and controlling the catheter-based Port-Access™ system in about 90% of the procedures. The avoidance of fluoroscopic imaging simplifies the performance, reduces the risk due to x-ray exposure and is time saving. To avoid complications related to insufficient echocardiographic imaging, supportive pressure measurements are useful and intermittent fluoroscopy may be mandatory.

The value of intraoperative TEE monitoring exceeds all other mentioned devices due to its ability to monitor the CPB device and to provide reliable information about the functional status of the heart at the same time.

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