Transesophageal echocardiographic monitoring of myocardial ischemia during vascular surgery

Bruce L. Gewertz, M.D., Paul C. Kremser, M.D., Christopher K. Zarins, M.D., John S. Smith, M.D., John E. Ellis, M.D., Steven B. Feinstein, M.D., and Michael F. Roizen, M.D., Chicago, Ill.

Transesophageal echocardiography (TEE) was used to detect segmental ventricular wall motion abnormalities (SWMAs) associated with ischemia in 49 high-risk patients who had 50 major vascular procedures, including 23 infrarenal aortic, five suprarenal aortic, 14 carotid, seven distal, and one axillofemoral reconstructions. A modified gastroscope tipped with an echocardiographic transducer was inserted into the esophagus and positioned behind the heart to obtain a reproducible cross-sectional view of the left ventricle at the level of the papillary muscles. Twelve patients (24%) had SWMA at baseline, probably representing areas of old infarction. Fourteen patients (28%) had new intraoperative SWMAs. Ten of 14 patients were successfully treated and wall motion was normalized. One of the four patients with persistent SWMA suffered a nonfatal subendocardial infarct; another patient suffered intraoperative cardiac arrest and died. No infarcts were documented in the 10 patients successfully treated. The mortality rate in the entire high-risk group was 6%. Alterations in ventricular wall motion were noted in almost 50% of high-risk patients undergoing major vascular surgery. Seventy-one percent of acute SWMAs were reversed without any evidence of myocardial infarction. TEE allowed early recognition of evolving myocardial ischemia and facilitated immediate and specific fluid and pharmacologic interventions. Continued application of this technique may reduce the incidence and morbidity of perioperative cardiac complications. (J VASC SURG 1987;5:607-13.)

Most patients undergoing major arterial reconstructions have concomitant coronary artery disease, even in the absence of angina or electrocardiographic (ECG) abnormalities.1-3 In nearly all large clinical series, perioperative death is primarily related to myocardial ischemia.4,5 Although early detection and appropriate treatment of intraoperative myocardial ischemia would predictably reduce cardiac morbidity, standard monitoring with ECG and pulmonary artery pressures has been shown to be insensitive.6 Often ischemia has progressed to infarction before treatment can be started. Furthermore, it has been difficult to quantitate the benefits of fluid and pharmacologic therapy in this dynamic setting without some reliable measurement of ischemia and/or cardiac function.

In experimental models7,8 and selected patients9,10, myocardial ischemia has been highly correlated with acute changes in left ventricular regional wall motion. This has stimulated interest in the use of intraoperative echocardiography as a means to diagnose the segmental wall motion abnormalities (SWMAs) associated with developing ischemia. Previous experience with intraoperative two-dimensional tranesophageal echocardiography (2D TEE) has shown it to be a safe and effective means of assessing intraoperative myocardial performance and volume status.5

The current study was designed to define the incidence of chronic and acute perioperative changes in segmental wall motion in 49 selected high-risk vascular surgery patients. We used echocardiographic changes as a guide to specific intraoperative fluid and drug therapy and correlated outcome and cardiac morbidity with this indicator of myocardial ischemia.
Table I. Incidence of segmental wall motion abnormalities (50 procedures)

<table>
<thead>
<tr>
<th>No. abnormalities</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No abnormalities</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td>&quot;Baseline&quot; SWMA</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>New intraoperative SWMA</td>
<td>14*</td>
<td>28</td>
</tr>
</tbody>
</table>

NOTE: Forty-four percent of patients demonstrated chronic and/or acute perioperative SWMA. *Includes four patients with "baseline" SWMA.

Table II. Incidence of segmental wall motion abnormalities related to surgical procedure

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Baseline SWMA</th>
<th>Intraoperative SWMA</th>
<th>Myocardial infarction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suprarenal aortic (n = 5)</td>
<td>2 (40%)</td>
<td>5 (100%)</td>
<td>0*</td>
</tr>
<tr>
<td>Infrarenal aortic (n = 23)</td>
<td>8 (35%)</td>
<td>7 (30%)</td>
<td>2</td>
</tr>
<tr>
<td>Carotid endarterectomy (n = 14)</td>
<td>2 (14%)</td>
<td>1 (7%)</td>
<td>0</td>
</tr>
<tr>
<td>Distal or axillofemoral (n = 8)</td>
<td>0 (0%)</td>
<td>1 (13%)</td>
<td>0</td>
</tr>
</tbody>
</table>

*One intraoperative cardiac arrest.

MATERIAL AND METHODS

Between September 1985 and April 1986, TEE monitoring was performed in 49 high-risk patients undergoing 50 vascular procedures, including 23 infrarenal aortic, five suprarenal aortic, 14 carotid, seven distal, and one axillofemoral reconstructions. This group represented approximately 25% of all patients undergoing arterial reconstructions during this 8-month period. In general, patients were selected for TEE if the planned operative procedure required suprarenal or thoracic aortic clamping, or if a history of coronary artery occlusive disease or myocardial dysfunction was elicited. Overall, 12 patients (28%) had previous myocardial infarctions; seven (14%) were treated for heart failure, 32 (64%) were treated for hypertension, and three (6%) had overt evidence of renal dysfunction (serum creatinine greater than 2.0 mg/dl).

After endotracheal intubation, a modified gastroscopy with a 3.5 MHz two-dimensional echocardiographic transducer (Diasonic, Milpitas, Calif.) was inserted into the esophagus. The transducer was positioned behind the heart to obtain a reproducible cross-sectional view of the left ventricle at the level of the papillary muscles. The echocardiograms were evaluated continuously after intubation and throughout the procedure. Periods of interest (e.g., preclamp, postclamp, or after vasodilator infusion) and SWMAs were recorded on videotape for later detailed analysis. In selected patients, the transducer was intermittently repositioned to focus on the mitral valve area. Doppler flow patterns across the valve were obtained to assess left ventricular diastolic compliance and performance. Nearly all patients were also monitored with radial artery catheters for measurement of systemic blood pressure, Swan-Ganz catheters for cardiac output and pulmonary artery wedge pressure measurements, and conventional electrocardiograms. Changes in the level of anesthesia and the administration of fluids and vasoactive agents were based on alterations in systemic hemodynamics, cardiac function, and the development of SWMAs. Patients were monitored in an intensive care unit setting for at least 12 hours postoperatively and underwent postoperative ECG.

In one patient, a No. 5 French angiographic catheter was inserted into the right brachial artery via a percutaneous approach and advanced to the aortic root. Sterile diatrizoate meglumine and diatrizoate sodium (Renografin-76) solution (4 ml) containing sonication-generated microbubbles (mean diameter 4.5 ± 2.8 μm by laser) was injected immediately before and 3 minutes after infrarenal cross-clamping. The 2D TEE images were recorded onto 0.5 inch videotape. Short-axis cross sections were digitized with the use of an image-processing computer (Quantic 1200, B. Franklin, Inc., Bellevue, Wash.) with a real-time video digitizer. A 64 x 64 pixel resolution and 16 shades of gray were used for data acquisition. The computer program divided myocardial outlines into 32 myocardial segments; time-activity curves were constructed for each region.

RESULTS

After anesthesia was induced and before surgery, "baseline" SWMAs were detected in 12 patients (24%) (Table I). Abnormalities were seen predominantly in the septal and inferior ventricular wall. In 11 patients, these likely represented areas of previous infarction. In fact, a history of myocardial infarction was noted preoperatively in five of these patients. A single patient suffering an acute aortic occlusion, with no prior history of myocardial infarction, demonstrated "baseline" SWMA when taken to the operating room. This abnormality did not improve during operation and postoperative cardiac enzyme elevations confirmed an acute myocardial infarction. It is most probable that the infarct and SWMA occurred preoperatively coincident with the aortic thrombosis.

Fourteen patients (28%) had new intraoperative SWMAs involving the septum or inferior wall; in
Fig. 1. Static images of end-diastolic (A) and end-systolic (B) ventricular cross-sections before and after suprarenal aortic clamping in patient treated with nitroglycerin. Cardiac function was poor before clamping as demonstrated by poor ventricular wall motion and decreased ejection fraction (note large residual ventricular volume at end-systole, preclamp). Cardiac function is actually improved after aortic clamping as nitroglycerin infusion is begun, decreasing preload. Note improved contractility of ventricular wall, decreased end-diastolic volume, and increased ejection fraction (smaller residual ventricular volume at end-systole, postclamp).

Four of these patients, changes in wall motion involved worsening of “baseline” SWMA. Abnormalities usually occurred at times of cardiovascular stress; changes developed in 12 patients at the time of aortic clamping (eight) or undclamping (four). In particular, all five patients undergoing supraceliac or thoracic aortic clamping experienced SWMA. Only one patient undergoing carotid endarterectomy demonstrated a new SWMA during operation, although two endarterectomy patients had “baseline” SWMA after being given anesthetics (Table II).

In 10 of the 14 patients, changes were transient resolving before the surgical procedure was completed (four patients) or were successfully treated with intravenous nitroglycerin or nitroprusside (six patients) and wall motion was normalized (Fig. 1).

None of these 10 patients suffered a perioperative myocardial infarction. One of the four patients with persistent SWMA (still present at the completion of surgery and unresponsive to therapy) suffered a non-fatal, subendocardial infarction documented with ECGs and cardiac enzyme elevations. Another patient with persistent SWMA and preoperative hypotension had global myocardial ischemia and suffered a fatal intraoperative cardiac arrest. The other two patients whose SWMA persisted throughout surgery had neither enzyme nor ECG evidence of myocardial infarction.

The overall mortality rate was 6% (3 of 49 patients). Causes of death included acute aortic dissection with coarctation repair (one), colonic infarction after aortobifemoral bypass (one), and intraoperative
hemorrhage and myocardial failure during attempted repair of a contained rupture of a 12 cm suprarenal aortic aneurysm in a patient with renal failure.

In the single patient imaged during aortic root injection of “microbubbles,” we were able to document uniform myocardial perfusion before and after infrarenal aortic occlusion (Figs. 2 and 3). Consistent with the absence of regional hypoperfusion, no SWMAs were demonstrated and no myocardial ischemia was evident on the postoperative ECG.

DISCUSSION

Because of the high incidence of coexistent coronary artery disease in patients undergoing peripheral vascular procedures, it is not surprising that 50% to 100% of perioperative deaths are due to cardiac complications. In the past, attempts to reduce morbidity by optimizing cardiac function have been hindered by the lack of intraoperative monitoring devices that reliably diagnose myocardial ischemia. Conventional ECG monitoring often fails to detect ongoing myocardial ischemia, especially if the insult is nontransmural in nature. Data derived from hemodynamic measurements including pulmonary artery catheters do not distinguish between early ischemia and those changes in ventricular function and compliance associated with alterations in preload or afterload. Recent studies that have used both intraoperative nuclear ventriculography and 2D TEE have demonstrated that pulmonary capillary wedge pressure measurements are particularly inaccurate in dy-namic situations, such as aortic cross-clamping and clamp release.

In diverse experimental models, progressive coronary artery constriction invariably leads to regional wall motion abnormalities occurring before actual infarction. Therefore, it is reasonable to assume that a monitoring system that allows early detection of these changes might facilitate treatment and improve outcome. Two-dimensional echocardiography has been performed in awake humans suffering myocardial infarctions, undergoing angioplasty, and during exercise. Comparisons with nuclear ventriculography have shown it to be a reliable indicator of regional wall motion abnormalities as well as ventricular volume changes. In patients undergoing peripheral vascular procedures or coronary artery bypass surgery, the detection of new SWMAs by TEE more closely correlated with perioperative myocardial infarction than did intraoperative ECG changes. In this early experience no patient suffered an intraoperative ECG change without a concomitant wall motion change; often the SWMA was detected before the ECG change. In fact, ECG evidence of ischemia was noted in only 25% of patients with SWMA.

TEE has also been used to determine more sophisticated indicators of myocardial contractility, such as end-systolic wall stress and rate-corrected velocity of fiber shortening. In a series of patients undergoing carotid endarterectomy, those patients with higher wall stress and lower shortening fractions after aortounilateral bypass (one), and intraoperative...
had a greater incidence of new SWMAs despite "normal" hemodynamic parameters.\textsuperscript{21}

The present study confirms the prevalence of coronary artery disease among patients undergoing peripheral vascular reconstruction. Chronic or acute SWMAs were noted in nearly 50% of our patients. Suprarenal or thoracic aortic cross-clamping was uniformly associated with new SWMAs. Although no wall motion abnormalities were observed in a previous group of patients studied during infrarenal aortic cross-clamping,\textsuperscript{5} new SWMAs were observed in nearly 33% of the infrarenal aortic operations (7 of 23) in the current series (Table II). This observation is consistent with the ventricular compliance changes detected by nuclear ventriculography during aortic procedures and demonstrates the sensitivity of 2D TEE.\textsuperscript{15}

Most of the new SWMAs that resolved without treatment were those that occurred with aortic declamping. It is likely that these changes represented transient myocardial ischemia from relative hypovolemia and hypoperfusion of coronary arteries, which predictably resolved with correction of volume deficits and diastolic blood pressure. SWMAs occurring with aortic cross-clamping were more persistent and probably reflected progressive myocardial ischemia related to increased afterload and wall stress. Treatment with nitroglycerin or nitroprusside was successful in normalizing wall motion in six patients and none of these suffered myocardial infarcts. Two perioperative myocardial infarcts were noted in this series; one in a patient with a new SWMA who did not respond to treatment and another in a patient whose "baseline" SWMA was probably an acute preoperative event after sudden aortic thrombosis. Although the numbers are small, the absence of cardiac morbidity in patients with successfully treated SWMA suggests that intraoperative 2D TEE can both reliably detect myocardial ischemia and indicate the outcome of therapeutic maneuvers.

In 1982 two separate laboratories demonstrated that echo contrast agents, microbubbles, could be used to delineate myocardial blood flow in the canine model.\textsuperscript{22,24} Subsequently, it was reported that ultrasonic cavitation produces uniformly small echogenic microbubbles.\textsuperscript{25} These bubbles have been shown to be reproducible and have been confirmed to be smaller than red blood cells by light microscopy, laser particle counters, and Coulter counter analysis.\textsuperscript{26} Their size enables them to flow through the microvasculature at physiologic transient times without occlusion.\textsuperscript{27,28} Red blood cell flow and microbubble flow have been compared in the heart and kidney and have been found to be similar.\textsuperscript{29,30} These bubbles do not affect contractility, coronary blood flow, heart rate, or blood pressure.\textsuperscript{51}

The single patient in our report tolerated microbubble injection without complications. Uniform perfusion was demonstrated before and after aortic occlusion. No wall motion abnormalities developed and no areas of hypoperfusion were noted. On the basis of a large experience at our institution with echocardiographic contrast studies performed at the time of coronary transluminal angioplasty, decreases in regional myocardial blood flow are reliably detected with this methodology. Thus, continuing intraoperative studies with microbubbles may provide final confirmation that SWMAs are anatomically cor-
related with regional myocardial hypoperfusion. It is, of course, inappropriate to speculate further on the applicability of this particular technique without further clinical experience. In subsequent studies we hope to delineate relative endocardial and epicardial flow ratios. At the present time such analysis is time-consuming and must be done “off line,” thereby limiting application in the operating room.

We obtained Doppler flow patterns of left ventricular inflow to assess ventricular compliance in selected patients. Changes in compliance often account for the unreliability of pulmonary capillary wedge pressure in determining preload and the presence of myocardial ischemia.22 In patients with peripheral vascular disease, compliance may be abnormal in the resting state because of hypertension and left ventricular hypertrophy or chronic ischemia; hence, relatively high filling pressures may be necessary for adequate preload and ventricular performance.23 Preload is proportional to end-diastolic pressure and radius and inversely proportional to wall thickness. 2D TEE gives information on these last two factors that is unavailable from pulmonary artery catheters.

With a decrease in diastolic compliance, the pattern of blood flow through the mitral valve may change.24 Normally, filling of the left ventricle occurs predominantly in early diastole, in a passive manner; the latter contribution of atrial systole is secondary. However, in a “stiff” ventricle, late filling is crucial and atrial contraction becomes more important. Unfortunately, no patient studied with this particular technique suffered myocardial ischemia and we are unable to critically evaluate Doppler flow patterns as a measure of intraoperative changes in compliance. In patients who tolerated infrarenal cross-clamping without changes in hemodynamics, ECG, or wall motion, Doppler patterns were unchanged.

In summary, TEE is a safe and sensitive indicator of myocardial dysfunction and ischemia, which provides a rational basis for intraoperative management of high-risk patients. Indeed, in our series, TEE both indicated the need for and reliably assessed the results of intraoperative anesthetic, fluid, and drug therapy. Although a larger experience will be required, it appears that continued application and further refinement of related techniques may reduce the incidence and morbidity of perioperative cardiac complications.

REFERENCES


