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The Concordance of Intraoperative Left Ventricular Wall-motion Abnormalities and Electrocardiographic S-T Segment Changes

Association with Outcome after Coronary Revascularization

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Background: **Transesophageal echocardiography (TEE) and Holter electrocardiography (ECG) are used to detect intraoperative ischemia during coronary artery bypass graft surgery (CABG). Concordance of these modalities and sensitivity as indicators of adverse perioperative cardiac outcomes are poorly defined. The authors tried to determine whether routine use of Holter ECG and TEE in patients with CABGs has clinical value in identifying those patients in whom myocardial infarction (MI) is likely to develop.**

Methods: **A total of 351 patients with CABG and both ECG- and TEE-evaluable data were examined for the occurrence of ischemia and infarction. The TEE and five-lead Holter ECGs were performed continuously during cardiac surgery. The incidence of MI (creatine kinase-MB ≥100 ng/ml) within 12 h of arrival in the intensive care [ICU] unit, new ECG Q wave on ICU admission or on the morning of postoperative day 1, or both, were recorded.**

Results: **Electrocardiographic or TEE evidence of intraoperative ischemia was present in 126 (36%) patients. The concordance between modalities was poor (positive concordance = 17%; Kappa statistic = 0.13). Myocardial infarction occurred in 62 (17%) patients, and 32 (52%) of them had previous intraoperative ischemia. Of these, 28 (88%) were identified by TEE, whereas 13 (41%) were identified by ECG. Prediction of MI was greater for TEE compared with ECG.**

Conclusions: **Wall-motion abnormalities detected by TEE are more common than S-T segment changes detected by ECG, and concordance between the two modalities is low. One half of patients with MI had preceding ECG or TEE ischemia. Logistic regression revealed that TEE is twice as predictive as ECG in identifying patients who have MI. (Key words: Adverse cardiac outcome; coronary artery bypass surgery; heart surgery; myocardial infarction; myocardial ischemia; transesophageal echocardiography.)**

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CORONARY artery bypass graft (CABG) surgery is performed on >600,000 patients annually throughout the world.[1] To identify patients at high risk for myocardial infarction after CABG surgery, intraoperative monitoring for myocardial ischemia is used widely.[2-6] The standard tool is multiple-lead electrocardiography (ECG); a defined deviation of the S-T segment is assessed as a measure of myocardial ischemia. However, published estimates of the incidence of myocardial ischemia detected by ECG vary widely, due to differences among studies in both the type of electrocardiography performed and the method of analysis used,[3,5,7,8] and because ECG is often uninterpretable in the setting of CABG surgery.

Due in part to these limitations of ECG, there has been a trend toward the use of more sophisticated, expensive techniques, notably transesophageal echocardiography (TEE). Experimentally induced ischemic wall-motion abnormalities, which can be detected by TEE, appear earlier than ischemia-induced ECG abnormalities,[6,7] suggesting that TEE may be an earlier marker of ischemia than ECG monitoring. Few studies of CABG surgery, however, have assessed these technologies rigorously. The overall sensitivity and concordance between ECG and TEE has not been established and remains controversial.[9,10] Furthermore, and perhaps most importantly, the comparative predictive value of ECG *versus* TEE for myocardial infarction is unknown, with studies to date limited principally by small sample size.[7,10]

The goals of the present study were (1) to examine the concordance of wall-motion abnormalities assessed by TEE monitoring and S-T segment changes assessed by multiple-lead ECG monitoring, and (2) to determine whether ischemic episodes detected by one or both monitoring modalities during the intraoperative period identify patients at risk for myocardial infarction. We hypothesized that TEE and ECG would have a high positive concordance for detecting myocardial ischemia, and that the use of TEE, when added to ECG monitoring, would provide independent information to predict which patients were at risk for developing myocardial infarction.

Methods

General Methods

This study used a population of patients from a double-blinded clinical trial of acadesine, an adenosine regulating agent, in patients undergoing CABG surgery.[11] Acadesine did not reduce the incidence of myocardial infarction in this previous study. After obtaining institutional approval and informed consent, a total of 633 patients were enrolled from 20 academic centers within the United States. Patients scheduled for either emergent or nonemergent CABG surgery between July 1991 and April 1992 were randomly allocated to receive treatment with either placebo or one of two acadesine doses. Patients excluded from the study were those undergoing concurrent valve surgery or who had significant valvular disease, recent (within 1 week) or evolving myocardial infarction, cardiogenic shock, uric acid nephropathy, renal insufficiency, hepatic dysfunction, or significant esophageal disease. Of the 633 patients enrolled, 394 (62%) had TEE monitoring performed during operation (at 11 of 20 participating centers). Of patients who had TEE monitoring, 351 (89%) patients had ECG and TEE concurrently evaluable data either before or after bypass (or at both times) and were included in the analysis.[10]

Data Collection Methods

Before Operation. Data collection methods have been described in detail elsewhere.[11] Briefly, demographic and clinical data included a history of previous myocardial infarction, hypertension, diabetes, hypercholesterolemia, smoking; the presence of stable or unstable angina; and the use of cardiac medications within 24 h before surgery. Left ventricular ejection fraction and the number of significant coronary artery stenoses were recorded from data obtained at the preoperative cardiac catheterization. All cardiovascular medications, including nitrates, β-adrenergic blockers, and calcium-channel blockers, were continued until the time of operation.

General Clinical Care. Routine clinical monitors included a five-lead ECG and radial artery and pulmonary artery pressure measurements. The study drug, acadesine, or placebo was administered intravenously, starting approximately 15 min before induction of anesthesia and continuing for a total of 7 h. Anesthesia was induced using fentanyl (up to 50 μg/kg), midazolam (up to 0.2 mg/kg), and sodium thiopental (up to 7 mg/kg). Anesthesia was maintained using a continuous intravenous infusion of fentanyl (up to 0.25 $\mu g \cdot kg^{-1} \cdot min^{-1}$) and midazolam (up to 0.5 $\mu g \cdot kg^{-1} \cdot min^{-1}$). Vecuronium was used for muscle relaxation. No other anesthetic agents were used. Throughout the prebypass period, systolic blood pressure and heart rate were to be maintained within 20% of the preoperative baseline values, using prescribed anesthetic changes and administration of prescribed cardiovascular agents. Prophylactic use of cardiovascular agents with potential anti-ischemic properties (nitrates and calcium-channel blockers) was specifically excluded because this might have confounded the interpretation of the results. During bypass, blood pressure was to be maintained between 40 and 80 mmHg, using prescribed anesthetic and cardiovascular medications.

After Bypass. Systolic blood pressure was maintained between 90–130 mmHg and heart rate at <110 beat/min using prescribed cardiovascular medications. The use of inotropes and vasodilators was not controlled. Treatment of ischemia detected by intraoperative ECG monitoring or by TEE was not prescribed.

Holter Electrocardiography Ischemia. Patients were monitored with continuous three-channel Holter ECG (Marquette 8500 series; Marquette Electronics, Milwaukee, WI), placed for a minimum of 8 h before surgery (baseline) and from the time of anesthetic induction, continuously throughout the intraoperative period, and until 48 h after anesthetic induction. Holter data from the baseline and intraoperative period were used to determine the presence of myocardial ischemia. Frequency cutoff limits of 0.05 and 80 Hz were used to continuously record modified bipolar leads CM_5, CC_5, and ML.[12] Holter monitor information was not available to operating room investigators.

The Holter tapes were screened using a Marquette SXP Laser Holter scanner (Marquette Electronics) to determine S-T deviation episodes indicative of ischemia. An ECG ischemic episode, "ECG ischemia," was defined as reversible S-T depression of 0.1 mV or more from baseline at J + 60 ms, or more than 0.2 mV S-T elevation at the J point lasting for at least 1 min.[7,13] Only those episodes in which the new peak S-T deviation was at least 1 mm and lasted at least 1 min were considered to be positive. To diagnose a new episode of ischemia, its onset must have been at least 1 min after the end of the previous episode. For each of the perioperative periods, the incidence of ischemia, (*i.e.*, the percentage of patients with at least one ischemic episode starting in that period) was determined. Possible episodes of ischemia were reviewed and verified by two investigators who were blinded to patient identity, treatment group, and outcome.

Transesophageal Echocardiography Ischemia. Transesophageal echocardiography was recorded continuously from anesthetic induction until skin closure. The transducer was positioned and maintained at the level of the midpapillary muscle to obtain a short axis view of the left ventricle. Real-time TEE data were available to the investigator performing the protocol. Investigators were not instructed to manage TEE wall-motion abnormalities but were free to do so. Samples lasting 60 s were analyzed at the beginning of, 4 min before, and 1 and 6 min after each of the following surgical events: skin incision, sternotomy, pericardotomy, aortic cannulation, and right atrial cannulation. During the postbypass period, 60-s samples were obtained every 5 min until the TEE probe was removed after skin closure. Using the papillary muscles as landmarks, TEE images were divided into four segments: posterior, septum, anterior, and lateral. Wall motion in each segment was graded as follows: normal, mildly hypokinetic, severely hypokinetic, akinetic, or dyskinetic.[11] An episode of TEE wall-motion abnormality was defined as the worsening of wall-motion score in any segment by two or more grades relative to baseline (*e.g.*, mildly hypokinetic changing to akinetic) and lasting for at least 1 min.[5,10,11] A stricter definition of an ischemic episode (a change of three or more grades in wall-motion score) was also used to avoid potential confounding by wall-motion abnormalities because of technical manipulation during surgery.

Outcome Measurements

All outcomes were ascertained and validated by investigators at the coordinating center who were blinded to patient identity and group assignment. Our primary outcome measure was the diagnosis of myocardial infarction defined as creatine kinase-MB (CK-MB) level ≥100 ng/ml within 12 h after operation or new Q waves by ECG on arrival in the intensive care unit or on the morning of the first postoperative day.

The presence of new Q waves on postoperative 12-lead ECG was assessed using Minnesota Code criteria[14] as modified by Chaitman.[15] Twelve-lead ECGs were obtained at the time of screening, on arrival in the intensive care unit, and on the morning of postoperative day 1. Two investigators evaluated the set of ECGs to validate the coding and to make a final diagnosis to determine the presence of a new Q wave. Disagreements were resolved by a third investigator.

Four serum samples for CK-MB were obtained 1–12 h after aortic cross-clamp removal. Determinations of CK-MB concentration were performed centrally by Smith-Kline Beecham Clinical Laboratories (Van Nuys, CA) using an immunoenzymetric assay (Hybritech Tandem E CK-MB II, San Diego, CA). Because of interinstitutional variability in defining the extent of enzyme leak to diagnose myocardial infarction after CABG, we chose a uniform cutoff level of 100 ng/ml because most clinicians would agree that this constitutes significant myocardial necrosis.

Data and Statistical Analysis

All data were analyzed at the Ischemia Research and Education Foundation, San Francisco, California. Analyses were performed using SAS software (SAS Institute, Cary, NC) by investigators blinded to patient identification, risk group, study drug, and clinical care.

Incidence of Ischemia. "ECG ischemia" was considered present during the prebypass or postbypass period if a patient had one or more S-T segment changes during that period. Similarly, "TEE ischemia" was considered present if a patient had one or more episodes of segmental wall-motion score changes of 2 or more. The TEE data were also analyzed using a wall-motion score change of 3 or more as TEE ischemia.

Concordance between Electrocardiography and Transesophageal Echocardiography. To evaluate the concordance to detect ischemia by ECG and TEE, we compared the number of patients with and without ischemia by ECG in the prebypass period, in the postbypass period, or in either period to those with and without ischemia by TEE in the same time period. Detection of ischemia was said to be "positively concordant" when identified by both modalities. "Positive concordance" was defined as the number of patients having both TEE and ECG ischemia divided by the total number having ischemia by either modality. Detection of ischemia was said to be "negatively concordant" when ischemia was not detected by either modality. "Negative concordance" was defined as the number of patients without ischemia according to both TEE and ECG divided by the number without ischemia by either modality. Detection of ischemia was said to be "simultaneously concordant" when ischemic episodes were detected by both TEE and ECG at exactly the same time or within the same 5-min period. "Simultaneous concordance" was defined as the number of patients identified as having evidence of ischemia by TEE and ECG within the same 5-min period, divided by the total number identified as having ischemia by either modality during the pre- or postbypass period.

The Kappa statistic was used to determine the degree of agreement between the two monitoring modalities.[16] The value of Kappa can range from −1 (total disagreement) to +1 (perfect agreement), with 0 representing the chance expected agreement. Its associated probability value indicates whether the observed value of Kappa differs statistically from 0.

Association of Electrocardiographic S-T Segment Change or Transesophageal Echocardiographic Wall-motion Abnormality and Adverse Cardiac Outcome. We determined the relation of ischemia detected by each modality with our primary outcome, myocardial infarction. Relative risks of Q wave presence or peak CK-MB value equal to or greater than 100 ng/ml with corresponding 95% confidence intervals were calculated by comparing patients with ECG or TEE ischemia, or both, with patients without ischemia. Logistic regression models were performed to evaluate the independent effect of both modalities on myocardial infarction. In addition, because demographic or other preoperative characteristics (sex, age >70 yr, previous CABG surgery, history of myocardial infarction, diabetes, unstable angina, and low ejection fraction) may have predicted adverse outcome, we constructed models to determine whether the use of TEE and ECG added information to these preoperative characteristics in predicting myocardial infarction in our sample. Finally, sensitivity, specificity, and predictive values to identify patients who sustained a myocardial infarction were calculated for both ECG and TEE ischemia in the prebypass and postbypass periods.

Table 1. Demographic and Preoperative Characteristics of Patients (N = 351)

	N (%)
Age (mean ± SD) (yr)	62 ± 9
Female gender	59 (17)
History of smoking	253 (72)
Stable angina	98 (28)
Unstable angina	140 (40)
Valvular disease	33 (9)
Hypertension	200 (57)
History of myocardial infarction	182 (52)
History of congestive heart failure	43 (12)
History of arrhythmia	54 (15)
Prior CABG	38 (11)
Ejection fraction (mean ± SD)	56 ± 14
Left main stenosis ≥50%	70 (20)
No. of vessels with stenosis ≥70%	
1	25 (7)
2	137 (39)
3	183 (52)
Preoperative nitrates	227 (65)
Preoperative antithrombotics	107 (31)
Preoperative β blockers	209 (60)

CABG = coronary artery bypass graft.

Results

Of the 351 evaluable patients, Holter tapes were at least 70% evaluable in 98% of patients in the prebypass period and in 80% of patients in the postbypass period. The TEE tapes were at least 70% evaluable in 73% of patients in the prebypass period and in 81% of patients in the postbypass period. Table 1 shows the demo-

Table 2. Number (%) of Patients and Concordance of Ischemia as Detected by ECG and TEE in the Prebypass Period, the Postbypass Period, or Both Periods

	Prebypass or Postbypass	Prebypass	Postbypass
ECG−, TEE−	224 (63.8)	280 (79.8)	251 (71.5)
ECG+, TEE−	22 (6.3)	10 (2.9)	19 (5.4)
ECG−, TEE+	84 (23.9)	53 (15.1)	71 (20.1)
ECG+, TEE+	21§ (6.0)	8 (2.3)	10 (2.9)
Positive concordance*	21§/127 (16.5)	8/71 (11.3)	10/100 (10.0)
Negative concordance†	224/330 (67.9)	280/343 (81.6)	251/341 (73.6)
Simultaneous concordance‡	12/21 (57.1)	4/8 (50.0)	8/10 (80.0)

* No. of patients positive by both modalities/no. of patients positive by either modality.

† No. of patients negative by both modalities/no. of patients negative by either modality.

‡ No. of patients positive by both modalities within 5 min/no. of patients positive by both modalities.

§ Some patients had ischemia by one modality during one period and also had ischemia by the alternate modality during another period (for example, TEE ischemia in the prebypass period and ECG ischemia in the postbypass period).

graphic and preoperative characteristics of the study sample.

Of the 351 patients, 126 (36%) were identified as having one or more episodes of intraoperative ischemia by ECG or TEE, 71 (20%) in the prebypass period, and 100 (29%) in the postbypass period (table 2). ECG identified 43 (12%) of patients with S-T segment changes, with 18 (5%) detected in the prebypass period and 29 (8%) detected in the postbypass period. TEE identified 105 (30%) of patients with wall-motion abnormalities of grade 2 or more, 61 (17%) before bypass and 81 (23%) after bypass. Limiting the wall-motion abnormality scores to those of a grade 3 change or more, the incidence of ischemia detected by TEE decreased slightly, to 40 (11%) in the prebypass period and 57 (16%) in the postbypass period. This did not influence interpretation of concordance with Holter ECG or its relation to myocardial infarction.

Overall concordance between TEE (grade 2 wall-motion change) and ECG was poor (Kappa = 0.13; 95% CI = 0.03–0.23; *i.e.*, the observed value of Kappa was not significantly different from the chance expected agreement). Although neither modality detected ischemia in most patients, negative concordance was low, reaching only 68% overall (table 2). Positive concordance rates were lower (17% overall) due to the low probability of positive detection by both modalities (6% overall). Among positive patients, however, simultaneous concordance was relatively high, particularly in the postbypass period (80%). Of the 12 instances of simultaneous ischemic episodes (ECG and TEE episodes occurring within the same 5 min), the ECG S-T segment change preceded the TEE wall-motion abnormality in seven, onset was simultaneous in one, and wall-motion abnormalities preceded the ECG S-T segment changes in four.

Six patients had incomplete CK-MB information. One patient had incomplete ECG data. Sixty-two patients (18%) had a myocardial infarction diagnosed by either CK-MB or ECG. Forty three (12%) patients had a myocardial infarction diagnosed by CK-MB criteria alone; 27 patients (8%) had a myocardial infarction diagnosed by ECG alone. Eight patients had myocardial infarctions diagnosed by both modalities.

Intraoperative ischemia identified by either modality was associated with myocardial infarction (table 3). Myocardial infarction was twice as likely to develop in patients with ECG S-T segment changes compared with in patients without S-T segment changes (relative risk = 1.90; 95% CI = 1.13–3.20). This relation was also true for patients with segmental wall-motion abnormalities by TEE (relative risk = 1.93; 95% CI = 1.24–3.01).

Of the 62 patients with myocardial infarction, 32 (52%) were identified by either ECG or TEE. Transesophageal echocardiography identified 28 (45%) as having TEE wall-motion abnormalities; ECG identified 13 (21%) as having S-T segment changes; a total of 9 (15%) were identified by both modalities (table 4). The addition of TEE to ECG allowed us to detect adverse outcomes in 19 additional patients, whereas the addi-

Table 3. Relative Risk (RR) with Associated 95% Confidence Intervals (CI) of Myocardial Infarction (CK > 100 or Q Wave) in Patients with (+) and without (−) Ischemia by ECG and/or TEE

	Patients with MI (n)	%	RR	95% CI
ECG+	13	30.2	1.90	1.13–3.20
ECG−	49	15.9	1.00	
TEE+	28	26.7	1.93	1.24–3.01
TEE−	34	13.8	1.00	
ECG+, TEE+	9	42.9	3.20	1.76–5.81
ECG−, TEE+	19	22.6	1.69	1.01–2.83
ECG+, TEE−	4	18.2	1.36	0.53–3.50
ECG−, TEE−	30	13.4	1.00	

Table 4. In Patients with Postoperative MI (n = 62), the Number (%) with Intraoperative Ischemia as Detected by ECG, TEE, or Both Modalities

	By ECG Only	By TEE Only	By TEE and ECG
All patients	4 (6)	19 (31)	9 (15)
All patients pre-CPB monitoring only	4 (6)	12 (19)	1 (2)
All patients post-CPB monitoring only	3 (5)	17 (27)	6 (10)

CPB = cardiopulmonary bypass.

tion of ECG to TEE helped us to detect adverse outcomes in only 4 additional patients.

Similarly, of the 32 ischemic patients with myocardial infarction, 28 (88%) were identified by TEE and 13 (41%) by ECG. Nineteen (59%) were identified by TEE alone, compared with 4 (13%) by ECG alone. Results were similar for the prebypass and postbypass periods, with TEE identifying 13 of 17 (70%) ischemic patients in the prebypass period and 24 of 26 (92%) ischemic patients in the postbypass period who had myocardial infarctions.

Using multivariate modeling, which included preoperative patient characteristics in addition to ischemia, only the presence of wall-motion abnormality detected by TEE was an independent predictor of myocardial infarction (odds ratio = 2.35; 95% CI = 1.30–4.20). Although sensitivity for both modalities was low, TEE was more than twice as sensitive at identifying patients with myocardial infarction compared with ECG (table 5).

Discussion

This multicenter study compared the effectiveness of TEE with that of continuous ECG to detect intraoperative myocardial ischemia and to identify patients in whom postoperative myocardial infarction would develop. We found that (1) although wall-motion abnormalities that developed in 30% of patients were detected by TEE and S-T segment changes that developed in 12% were detected by ECG, the positive concordance of these two modalities is poor (17%); (2) patients identified as ischemic by either modality were twice as likely as nonischemic patients to have a myocardial infarction; (3) the presence of wall-motion abnormalities detected by TEE was an independent predictor of myocardial infarction; and (4) although the sensitivity of ECG and TEE to identify patients in whom a myocardial infarction developed was low, TEE was twice as sensitive as ECG (table 5).

The overall incidence of S-T segment change detected by continuous electrocardiographic monitoring in our multicenter study is comparable to that of other multiple-center and single-center studies using similar methods, where the incidence ranges from 18–55%.[2,3,5,7,17] Similarly, considering the prebypass period only, our 5% incidence of S-T segment change detected by continuous ECG monitoring is within the range observed in previous studies.[5,8,18] In the same way, the incidence of wall-motion abnormalities observed in this multiple-center study (17%) is similar to that previously identified in single-center studies that used similar methods.[5,8,17]

The low concordance to detect ischemia by ECG and TEE found in this study confirms the findings of other investigators.[9,10,19,20] In noncardiac surgery, Eisenberg *et al.*[10] examined the concordance of TEE, 12-lead ECG, and two-lead ECG in 285 patients with or at high risk for coronary artery disease. Agreement between the monitoring modalities in detecting nonischemic patients was high, but positive concordance was poor (16%). Similarly, Ellis *et al.*[20] identified a 17% positive concordance between five-lead ECG and TEE in detecting ischemia in 44 patients with or at risk for coronary artery disease. London *et al.*[19] identified a positive concordance of 16% between continuous 12-lead ECG and TEE to detect ischemia in 156 patients having high-risk noncardiac surgery; temporary overlap between modalities occurred in only five patients. In cardiac surgery, Smith *et al.*[9] detected intraoperative TEE wall-motion changes four times as frequently as S-T segment changes on five-lead ECG in 50 patients with or at risk for coronary artery disease.

Poor positive concordance between intraoperative TEE and ECG ischemia may be due to the limitations of each monitoring modality. The sensitivity of each

Table 5. Sensitivity (SENS), Specificity (SPEC), and Predictive Value (PV) of Ischemia by ECG or TEE in Identifying Patients Who Sustained Myocardial Infarction (MI)

Ischemia	MI Yes	MI No	SENS	SPEC	PV+	PV−
	62	289				
ECG	13	30	21.0	89.6	30.2	84.1
TEE	28	77	45.2	73.4	26.7	86.2
ECG or TEE	32	95	51.6	67.1	25.2	86.6

modality to detect an ischemic event is low. The five-lead three-channel Holter ECG monitor with the modified leads that we used in this study may be less sensitive than other multiple-lead ECG modalities[21–23] and may fail to identify ischemic changes in unmonitored leads. In addition, the effect on lead placement of chest wall distortion (sternotomy) during cardiac surgery may be significant. Changes in S-T segment may occur in the absence of myocardial ischemia due to variations in serum electrolyte concentrations, ventilation, changes in patient position, drug administration, or pericardial inflammation.[24] Wall-motion abnormalities may also occur in unmonitored areas and as a result of changes in preload and afterload.[25,26] Shah *et al.*[27] have shown that in addition to TEE monitoring of the short-axis view, monitoring the long-axis cross section of the left ventricle (using biplane or omniplane techniques) will increase detection of ischemia by approximately 40%. It is likely that the use of multiple views of the left ventricle during TEE monitoring would result in increased detection of segmental wall-motion abnormalities, possibly increasing the sensitivity of TEE in predicting postoperative myocardial infarction.[28]

Current definitions of ECG and TEE ischemic episodes may be inappropriate in the setting of anesthesia and surgery.[12] Guidelines for the diagnosis of ECG ischemia during anesthesia and surgery are adapted from those published by the American Heart Association[29] and are derived from data documenting ischemia in awake patients exercising on a treadmill, relating S-T changes to long-term events. Similarly, definitions of TEE ischemia are derived from studies performed in unanesthetized patients. During treadmill testing, ischemia has been shown to be due primarily to increases in oxygen demand,[30] whereas during anesthesia, ischemia may be due to a reduction in myocardial oxygen supply.[31,32]

Evidence exists to suggest that both S-T segment changes and systolic wall-motion abnormalities will develop in patients who experience from 45–90 s of complete coronary occlusion.[33,34] The low positive concordance that we observed may indicate that sudden complete coronary occlusion occurs rarely in patients after CABG procedures. Studies that examine the effect of nonoccluding coronary stenosis on ECG and wall motion in the nonsurgical setting suggest that during mild intraluminal constriction, systolic wall-motion abnormalities may occur without ECG changes.[35] When more severe intraluminal narrowing occurs, systolic wall-motion abnormalities may precede ECG changes by several minutes. Perhaps the most common cause of perioperative ischemia, however, is related to reductions in coronary blood flow secondary to changes in epicardial and microvascular tone, platelet and particulate emboli, and reperfusion injury mediated by leukocytes.[36–39] Independent of the mechanism(s), we observed no trend in the order of ischemia detection (*i.e.*, wall-motion abnormalities before ECG changes, or the reverse) in patients who had simultaneous concordant ischemic episodes, although the number of these patients was small (n = 12).

Few investigators have identified a correlation between ischemic episodes and adverse cardiac outcome in cardiac surgery. In 50 patients having elective CABG, Leung *et al.*[5] found an association between postbypass wall-motion abnormalities and postoperative myocardial infarction (defined as the presence of new Q waves on 12-lead ECG and CK-MB levels equal to or greater than 50 U/l). Thirty-three percent of patients with postbypass TEE ischemia had a myocardial infarction compared with none of the patients without ischemia. The present study of 351 patients showed that a myocardial infarction was five times more likely to develop in patients manifesting ischemia by ECG and TEE compared with patients without ischemia.

In this study, five-lead Holter intraoperative ECG monitoring was not as useful as TEE to identify patients in whom myocardial infarction developed. Even patient characteristics traditionally assumed to identify those at high risk, such as female sex, older age, previous CABG surgery, a history of myocardial infarction, diabetes, unstable angina, or low ejection fraction were not associated with myocardial infarction.

Our study is strengthened by its large sample size of patients with known coronary disease and for its use of prescribed protocols for hemodynamic control. Previous studies used smaller sample sizes[5] or included vascular patients who had or "were at risk for" coronary disease.[10,19,20] An advantage of our study is our use of strictly defined outcome measures, with outcome validation performed by blinded, independent investigators. Of particular note, the independent *post hoc* review of all TEE and Holter ECG data was performed by at least two experienced readers at a central analysis facility, minimizing interference from the operating room environment and improving consistency of interpretation.

Limitations of our study include the use of patients from a clinical trial for analysis. The administration of acadesine to some patients, although it did not alter the incidence of ischemia,[11] may have moderated its magnitude, thereby allowing detection by one modality and not the other. Importantly, S-T segment changes detected by ECG in the preoperative and early postoperative periods may be predictive of adverse cardiac outcome; our analysis chose only to investigate the intraoperative period, in which TEE and ECG monitoring were concurrent. Finally, the standard of care administered to patients participating in a clinical trial may be different than that given to the average patient. Data collection was not blinded to the clinical staff, and thus ischemic changes observed with standard monitoring on TEE or with clinical judgment could have produced a bias in our results by provoking a clinical intervention.

The utility of TEE for formulating a surgical plan, assessing immediate intraoperative results, and identifying patients with unsatisfactory results during and after valve and congenital heart surgery is well established.[40-44] In addition to detecting wall-motion abnormalities, intraoperative TEE monitoring during routine CABG surgery may be beneficial in providing information on left ventricular volume status and for assessing left ventricular function when unexplained hypotension occurs.[45] To justify its routine use, however, the use of expensive technology such as TEE for ischemia monitoring during CABG surgery should provide a clear and significant advantage, such as reduction in rates of perioperative complications or death. We have shown that TEE is a more sensitive ischemia monitoring modality compared with ECG for predicting myocardial infarction. Ultimately, the utility of TEE as an ischemia monitor in CABG surgery will depend on (1) whether future prospective trials prove that treatment of detected ischemic events actually changes outcome, and (2) whether the added cost of such technology will be justified using cost-benefit analysis.

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