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Perioperative Myocardial Ischemia

Its Relation to Anatomic Pattern of Coronary Artery Stenosis

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Background: **Recently, the frequency of intraoperative myocardial ischemic episodes in patients with steal-prone coronary anatomy, compared with other groups of patients undergoing coronary artery surgery (CABG), has been characterized. Because the relationship between anatomic distribution of coronary stenosis and myocardial ischemic episodes over the entire perioperative period has not been well defined, the authors sought to examine this relationship in 100 adult patients undergoing CABG surgery.**

Methods: **Continuous electrocardiographic (ECG) monitoring was performed in the pre-, intra-, and postoperative periods, quantifying the frequency (episodes/hour of monitoring [epis/h]) and duration (minutes/hour of monitoring [min/h]) of ECG ischemic episodes defined as a reversible ST segment shift ≥ 1 mm at J + 60 ms of ≥ 1 min duration. Based on preoperative coronary angiography, patients were categorized into the following groups: group 1 (n = 40), steal-prone coronary anatomy (occluded major coronary artery and ≥ 50% stenosis of the artery supplying the collateral vessels); group 2 (n = 17), left main or equivalent coronary stenosis (≥ 50% stenosis of left main coronary artery or ≥ 70% proximal stenosis of the left anterior descending and circumflex coronary arteries); and group 3 (n = 43), coronary artery stenosis ≥ 70% not fitting the preceding categories.**

Results: **Compared with group 3, patients in group 1 had more frequent and longer ECG ischemic events preoperatively, and were nearly two times more likely (relative risk 1.82, 95% confidence interval 1.07–3.10) to develop an ischemic event during this period. There were no differences in the relative risk, frequency, or duration of an ischemic episode between groups 1 and 3 during the intraoperative and postoperative periods, or between groups 1 and 2 or groups 2 and 3 during any perioperative period. In group 2 patients, the frequency of ischemic epis/h was less intra- compared with preoperatively, while, in group 3, the ischemic epis/h decreased postoperatively compared with the intraoperative period. The duration of ischemic episodes (min/h) in group 3, however, increased postoperatively compared with the pre- and intraoperative periods, while, in group 2, the duration of ischemic episodes (min/h) was less intraoperatively compared with the preoperative period. Ninety-seven percent of preoperative ECG ischemic episodes occurred without symptoms. Postoperative myocardial infarction occurred in three patients in group 3, two in group 2, and one in group 1. There were no perioperative deaths.**

Conclusion: **These data indicate that, compared with patients with non-left main or equivalent coronary stenosis, those with steal-prone coronary anatomy have more frequent and longer ECG ischemic episodes preoperatively. The data also indicate that there are no other differences in the risk, frequency, or duration of ischemic episodes between groups perioperatively. Thus, different distributions of coronary artery stenosis may be associated with changes in the perioperative characteristics of ECG ischemic episodes. (Key words: Anesthesia: cardiac. Heart: coronary artery disease; myocardial ischemia. Monitoring: Holter electrocardiography. Surgery, cardiac: coronary artery bypass graft.)**

THE frequency, characteristics, and significance of electrocardiographic (ECG) evidence of perioperative myocardial ischemia in patients undergoing coronary artery bypass operations (CABG) have been reported by several investigators.[1–7] These investigations have shown, for example, a relationship between intraoperative myocardial ischemia and postoperative myocardial infarction (PMI) after CABG surgery.[1,2,4] Furthermore, the majority of intraoperative myocardial ischemic events have been shown to occur without increases in indices of myocardial oxygen demand and, therefore, are related to decreases in myocardial oxygen supply.[1–4,7] Additionally, Knight *et al.*[3] have shown that a pattern of myocardial ischemia detected preoperatively with continuous ECG (Holter) monitoring per-

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sists intra- and postoperatively. Slogoff and Keats[2,4] have postulated that most intraoperative myocardial ischemic episodes in CABG patients may represent the same pathophysiologic derangements as those causing preoperative asymptomatic (silent) myocardial ischemia. Therefore, it seems possible that some aspect of perioperative myocardial ischemia in CABG patients is, primarily, a characteristic of the underlying coronary artery disease. Several investigators have examined the relationship between steal-prone coronary anatomy and intraoperative myocardial ischemia.[8-10] The potential significance of different anatomic distributions of coronary arterial stenosis on the frequency or pattern of myocardial ischemia over the entire perioperative period in CABG patients has not been completely examined. In view of this, the current study was performed to examine the relationship between angiographically determined location of coronary artery stenosis and the frequency of myocardial ischemia using continuous ECG monitoring perioperatively in patients undergoing CABG surgery.

Materials and Methods

Patient Selection

With approval from the Human Studies Committee of Washington University School of Medicine and individual informed consent, 100 adult patients scheduled for CABG surgery were enrolled in this study. Patients receiving digoxin, those with left bundle branch block, and those with preexisting ST segment abnormalities that would hinder later ECG analysis were excluded from the study. Cardiac catheterization was performed according to institutional standard procedure with coronary angiograms reviewed by blinded cardiologists. Left ventriculograms were also performed, and left ventricular function was graded as normal or mildly, moderately, or severely reduced. Patients were categorized, after enrollment, into three groups on the basis of anatomic location of coronary stenotic lesions, as determined by coronary angiography. Group 1 consisted of 40 patients with steal-prone coronary anatomy, defined as a complete occlusion of a major coronary artery with coronary blood flow to the myocardium distal to the occlusion supplied by collateral vessels originating from another major coronary artery with a ≥ 50% stenosis.[11] Group 2 included 17 patients with either left main coronary artery stenosis (≥ 50%) or left main equivalent stenosis, defined as ≥ 70% proximal stenosis of left anterior descending and circumflex coronary arteries. Nine patients meeting criteria for both groups 1 and 2 were placed in the steal-prone anatomy group. Group 3 consisted of 43 patients with significant stenosis (≥ 70%) in 2 or more major coronary arteries not fitting one of the preceding anatomic categories.

Electrocardiographic Monitoring

Two-channel continuous ECG (Holter) monitoring was performed throughout the perioperative period with either a solid-state recorder (Monitor One Touch TC100, Qmed, Clark, NJ) or an AM Holter monitor (series 8500, Marquette Electronic, Milwaukee, WI). No patient received monitoring with both systems. Silver/silver chloride electrodes were used for bipolar monitoring of modified leads V5 and II. The preoperative monitoring period consisted of the interval from monitor attachment to induction of general anesthesia. During this monitoring period, patients were instructed to record any symptomatic anginal episodes, such as chest pain or chest pressure, shortness of breath, nausea and vomiting, lightheadedness, or diaphoresis. The intraoperative monitoring period included the interval from induction of anesthesia until cardiopulmonary bypass (CPB). The postoperative monitoring period consisted of the period after CPB until monitor detachment in the ICU (usually 24 h later).

The solid-state recording system used in this study digitizes incoming ECG signals and passes the signals to a microprocessor, where a proprietary, extensively validated algorithm meeting American Heart Association specifications for ST segment monitoring recognizes the QRS complex and distinguishes between normal and ectopic complexes.[12,‖] The digitized ECG signal is compared with an internal reference for calibration. The degree of ST segment deviation from baseline to be considered as an ischemic episode is set before monitor attachment in 1-mm increments. After the classification of QRS complexes as normal, the ST segment is analyzed (60 ms after the J point) in comparison with the isoelectric segment. On detection of an ST segment deviation meeting the predetermined definition of a significant change from baseline in either

‖ Levin RI, Cohen D, Frisbie W, Selwyn AP, Berry J, Dearfield JE, Keller B, Campbell DQ: Potential for real-time processing of the continuously monitored electrocardiogram in the detection, quantification, and interventions of silent myocardial ischemia. Card Clin 4:735–745, 1986.

channel, the algorithm considers the possible onset of an ischemic episode. Data describing the number and duration of ischemic episodes identified is stored in a volatile random access memory.

Cassette tapes obtained from AM Holter recorders were analyzed on a Marquette series 8000 ECG analysis system using standard techniques. Briefly, all QRS complexes are correctly classified as normal, ectopic, paced, or artifact. A computerized analysis of the ST segment is then performed at J + 60 ms on normally classified beats generating a high-resolution ST segment trend from both leads for the entire tape. When J + 60 ms occurred within the T wave, the ST segment analysis sample was adjusted to proceed the T wave, but was always > J + 40 ms. Episodes of ST segment deviation from the baseline identified from the high-resolution trend analysis were then reviewed, and hard copy of representative ECG samples was obtained for later analysis.

At the end of a monitoring period, stored data from the solid-state monitoring system were transferred from the monitor device to a module (Buffer Interface Module, Qmed) designed to receive, store, and transfer a report. The report was then automatically transmitted to a dot-matrix printer to obtain hard copy of episodes identified as ST segment deviation. Episodes of ST segment deviation considered for analysis were generated from the solid-state monitoring system's algorithm, and not from hard copy of complete ECG disclosure. To limit the effects of drift in the baseline ECG with the solid-state monitor that could potentially result in false-positive ischemic episodes, hard copy tracings of the ischemic ECG episodes identified by the algorithm were compared with representative hard copy ECG tracings obtained by the recorder at 4-h intervals. All ECG tracings identified from both monitoring systems were independently reviewed by two investigators blinded to anatomic groups. Myocardial ischemic ECG episodes (ischemic episodes) were defined as reversible ST segment depressions or elevations of ≥ 1 mm (0.1 mV) from the baseline lasting at least 1 min. Return of the ST segment to baseline for ≥ 1 min was required for episodes to be considered as separate. Shifts in the ST segment from baseline were not considered as ischemic episodes when occurring with intraventricular conduction delays ≥ 0.12 ms. Ischemic ST segment episodes were included for analysis on acceptance by both reviewers. The number of ischemic episodes occurring at heart rates ≤ 90 beats/min was recorded.

Perioperative Management

Patients continued receiving all cardiac medication until the time of surgery, including nitroglycerin, β-adrenergic, and calcium channel-blocking drugs. Premedication was with lorazepam, morphine, and scopolamine. The primary anesthetic technique consisted of high-dose synthetic opioid (fentanyl or sufentanil) supplemented by volatile anesthetics (enflurane or isoflurane) and neuromuscular relaxants (vecuronium, metocurine, and pancuronium). Cardiopulmonary bypass used centrifugal pumps and membrane oxygenators, along with hypothermia and hemodilution. Intermittent cold potassium cardioplegia and aortic cross-clamping were used, in addition to topical myocardial cooling.

Twelve-lead ECGs were obtained in the immediate postoperative period, and daily while the patients remained in the ICU. Serum creatinine kinase MB (CK-MB) isoenzymes were obtained daily for the first 2 postoperative days. The diagnosis of a myocardial infarction required both the presence of new Q waves of > 0.04 ms duration and CK-MB ≥ 50 IU.

Statistical Analysis

Statistical analysis was performed on a personal computer using SAS version 6 software (SAS Institute, Cary, NC). The probability of detecting myocardial ischemic episodes in susceptible individuals is increased in proportion to the duration of Holter monitoring.[3,5] Therefore, ischemic episodes were normalized to hours of continuous ECG monitoring as episodes per hour (epis/h) for the pre-, intra-, and postoperative periods. Quantifying the severity of myocardial ischemia as epis/h of ST segment deviation overestimates frequent ischemic episodes of potentially brief duration, while underestimating episodes of longer duration. Therefore, the duration of ischemic ECG episodes were also normalized to hours of continuous ECG monitoring and expressed as minutes per hour (min/h). Because not all patients experienced an ECG ischemic event, the data were categorized for analysis. Ischemic episodes were categorized as either present or absent, and duration of ischemic episodes were categorized as 0, 0 but less than 20 min, and > 20 min. Fisher's exact test was used to evaluate these categorical data as to the relationship of the above anatomic groups with frequency and duration of perioperative ECG evidence of myocardial ischemia during each perioperative period and between monitoring systems. When testing differences between groups, the following planned com-

parisons were performed each at a value of $P = 0.05$: groups 1 *versus* 2, 1 *versus* 3, and 2 *versus* 3. Wilcoxon signed-rank test was used to test ischemic epis/h and duration (min/h) of ischemic events across perioperative periods within groups using the following planned comparisons at values of $P = 0.05$: pre- *versus* intraoperative, pre- *versus* postoperative, and intra- *versus* postoperative. To assess the risk of developing a myocardial ischemic episode between anatomic groups and between perioperative periods, relative risk ratio with 95% confidence interval was calculated using a logistic model. Values are expressed as mean ± SD unless otherwise specified. Significance was considered for values of $P < 0.05$.

Results

Continuous ECG monitoring was performed in each patient for 18.3 ± 3.6 h in the preoperative period, 4.3 ± 0.8 h intraoperatively, and 30.2 ± 12 h during the postoperative period. Demographic information and other patient characteristics are listed in table 1. The solid-state ECG monitor was used in 60 patients (21 patients in group 1, 12 patients in group 2, and 27 patients in group 3) and the AM Holter recorder in 40 patients (19 patients in group 1, 5 patients in group 2, and 16 patients in group 3). The frequency and duration of ischemic ECG episodes between the two monitoring systems are shown in table 2. There were no differences in the frequency (epis/h) of perioperative ischemic ECG events between monitoring systems when considering all patients, irrespective of anatomic group. The duration of ischemic episodes (min/h), however, was significantly longer with the AM Holter recorder compared with the solid-state monitor during the pre- and postoperative periods. There was no difference in the frequency of ischemic epis/h within an anatomic group between the two monitoring systems for any perioperative period. A significantly greater proportion of patients in group 1, however, had ischemic episodes of longer duration (min/h) in the pre- and postoperative period observed with the AM Holter recorder compared with the solid-state recorder. There were no differences in duration of ischemic episodes between monitoring systems in groups 2 and 3 perioperatively or in group 1 intraoperatively.

A total of 335 ECG ischemic episodes were identified in 59 of 100 patients studied. Ninety-seven percent of preoperative ischemic episodes were not accompanied

Table 1. Demographics and Other Perioperative Patient Characteristics

	Group 1 (n = 40)	Group 2 (n = 17)	Group 3 (n = 43)
Age (mean ± SD, yr)	62.10 ± 9.43	64.8 ± 11.0	58.9 ± 9.9
History of prior MI (n)			
<3 mo before surgery	12	5	15
>3 mo before surgery	12	4	10
Hypertension	28	11	28
Diabetes mellitus	10	5	11
Prior CABG	2	0	2
History of CHF	6	3	6
Severe left ventricular dysfunction*	3	3	5
Moderate left ventricular dysfunction*	17	3	10
Antianginal medication			
Nitrates	28	14	29
Calcium channel blockers	29	9	26
β-Adrenergic blockers	18	8	20
No. of bypass grafts (mean ± SD)	4.03 ± 0.95	3.9 ± 0.9	3.3 ± 1.4
Internal mammary artery	39	15	39
CABG/valve	5	2	5
CABG/carotid endarterectomy	1	1	1
CPB time (mean ± SD, min)	123.5 ± 43.3	133.8 ± 48.2	127.3 ± 53.2
Aortic cross clamp (mean ± SD, min)	57.2 ± 22.5	60 ± 30.3	58.2 ± 31.6
Inotropic drugs after CPB	16	8	11

MI = myocardial infarction; CABG = coronary artery bypass graft; CHF = congestive heart failure; CPB = cardiopulmonary bypass.

* Determined by left ventriculogram at cardiac catheterization.

Table 2. Number (episodes/h) and Duration (min/h) of Electrocardiographic Ischemic Episodes Per Hour of Monitoring Detected by Different Holter Systems

	Preoperative		Intraoperative		Postoperative	
	Episodes	Duration	Episodes	Duration	Episodes	Duration
Solid-state monitor	0.12 ± 0.35	1.80 ± 2.95	0.09 ± 0.29	4.12 ± 5.16	0.04 ± 0.05	1.14 ± 1.30
AM Holter monitor	0.10 ± 0.18	4.61 ± 5.60*	0.15 ± 0.51	7.36 ± 8.80	0.07 ± 0.12	10.6 ± 13.46*

Values are mean ± SD.

* $P \leq 0.05$ between monitors.

by clinical symptoms. Forty-one patients experienced at least one ischemic ECG episode in the preoperative period, and 12 experienced an intraoperative, and 44 experienced a postoperative, ischemic episode. Nine of the 12 patients with an intraoperative ischemic ECG episode also experienced a preoperative ischemic event. Twenty-seven of 44 patients with a postoperative ischemic ECG episode had prior ischemia in either the pre- or intraoperative periods. Although there was a trend for preoperative ischemic episodes to be associated with an increased relative risk of intraoperative ischemia (relative risks 2.88, 95% CI 0.93–8.93), this trend did not reach significance ($P = 0.054$). Ischemic ECG episodes in the pre- or intraoperative period did not confer an increased relative risk of an ischemic episode in the postoperative periods.

Intergroup Ischemia Characteristics

The frequency and other characteristics of ischemic ECG episodes for each group during the three perioperative periods is shown in table 3. Twenty-nine of the 40 patients in group 1 developed perioperative ischemic episodes, as did 9 of 17 patients in group 2 and 21 of 43 patients in group 3. The frequency of ischemic epis/h in group 1 in the preoperative period was significantly greater than that observed in group 3. There was no difference in the frequency of preoperative ischemic ECG epis/h between groups 1 and 2 or 2 and 3. Intraoperatively, there was no difference in frequency of ischemic epis/h between groups, nor were there intergroup differences in ischemic epis/h in the postoperative period. The number of patients, as categorized for analysis of ischemic episode duration, is shown in table 4. In parenthesis is the number of patients experiencing ischemic events in each category in whom the events were observed with the AM Holter recorder. A significantly greater proportion of group 1 patients experienced ischemic ECG episodes of longer duration (min/h) preoperatively compared with group 3. However, there were no additional differences in duration of ischemic episodes between groups perioperatively. The relative risk of developing a myocardial ischemic episode during the perioperative period between anatomic groups is shown in table 5. Patients in group 1 (steal prone) had nearly a twofold greater probability (relative risk 1.82, 95% CI 1.07–3.10) of developing an ischemic episode during the preoperative period compared with group 3. However, there was no difference in the relative risk of an ischemic episode between groups 1 and 3 during the intra- or postoperative periods, nor were there differences between groups 1 and 2 or groups 2 and 3 for any of the perioperative periods.

When comparing the distribution of pre-, intra-, and postoperative ischemic epis/h within a group (table 3), there was a decrease in ischemic epis/h from the pre- to intraoperative period in group 2, and a significant decrease in the ischemic epis/h between the intra- and postoperative periods in group 3. Although only a single intraoperative ischemic episode was observed in group 2, nonparametric statistical analysis included individuals without intraoperative ischemic episodes, accounting for the SD noted for group 2 in table 3. In group 2, there was a decrease in duration of ischemic episodes intra- compared with preoperatively. In group 3, the decrease in ischemic epis/h postoperatively was accompanied by an increase in duration of episodes compared with the pre- and intraoperative periods. There were no other differences in the duration of ischemic episodes within an anatomic group compared with other perioperative periods.

Seventy-six percent of preoperative ischemic ECG episodes in group 1 (n = 83) occurred at a heart rate ≤ 90 beats/min, as did 88% in group 2 (n = 22) and 87% in group 3 (n = 27). Intraoperatively, 92% and 86% of ischemic ECG episodes in groups 1 (n = 23)

Table 3. Characteristics of Perioperative Electrocardiographic (ECG) Ischemic Events by Anatomic Group (Group 1, n = 40; Group 2, n = 17; Group 3, n = 43)

	Preoperative			Intraoperative			Postoperative		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Total ECG ischemic episodes	109	25	31	25	1	7	67	14	56
Patients with ischemic ECG episodes	22	6	13	8	1	3	18	5	21
Duration (h) of Holter monitoring	18.3 ± 3.1	18.3 ± 4.3	18.2 ± 3.7	4.25 ± 0.7	4.3 ± 0.7	4.41 ± 0.1	30.6 ± 13.4	30.5 ± 12.4	29.8 ± 11.6
Ischemic ECG episodes per hour of monitoring (mean ± SD) (median; range)	0.17 ± 0.33* (0.06; 0–1.67)	0.14 ± 0.44 (0.0; 0–1.84)	0.05 ± 0.14 (0.0; 0–0.84)	0.20 ± 0.54 (0; 0–2.77)	0.02 ± 0.07† (0; 0–0.30)	0.06 ± 0.26 (0; 0–1.45)	0.07 ± 0.11 (0; 0–0.37)	0.03 ± 0.05 (0; 0–0.16)	0.05 ± 0.07‡ (0; 0–0.36)
Duration of ischemic ECG episodes per hour of monitoring (mean ± SD) (median; range)	2.50 ± 4.61§ (0.29; 0–24.17)	0.74 ± 2.11 (0; 0–8.7)	0.27 ± 0.70 (0; 0–3.78)	1.44 ± 4.39 (0; 0–23.7)	0.30 ± 1.25¶ (0; 0–5.16)	0.54 ± 2.47 (0; 0–14.90)	2.62 ± 5.96 (0; 0–29.94)	0.21 ± 0.46 (0; 0–1.71)	2.40 ± 8.42** (0; 0–52.9)
Number of ischemic ECG episodes occurring at heart rate ≤90 (%)	83	22	27	23	1	6	10	7	7
Patients with ischemic ECG episodes isolated to one perioperative period	10	3	4	1	0	2	5	3	9

* $P \leq 0.03$ frequency of ischemic episodes/h: Group 1 *versus* Group 3.

† $P \leq 0.03$ distribution of ischemic episodes/h: Group 2 intraoperative *versus* preoperative.

‡ $P \leq 0.04$ distribution of ischemic episodes/h: Group 3 postoperative *versus* intraoperative.

§ $P \leq 0.02$ duration of ischemic episodes (min/h): Group 1 *versus* Group 3.

¶ $P \leq 0.03$ duration of ischemic episodes (min/h): Group 2 intraoperative *versus* preoperative.

** $P \leq 0.04$ duration of ischemic episodes (min/h): Group 3 postoperative *versus* preoperative and intraoperative.

Table 4. Categorization of Ischemic Episode Duration (min) by Anatomic Group and Perioperative Period

Duration	0 min	1–20 min	>20 min
Preoperative			
Group 1	18 (8)	8 (1)	14 (10)
Group 2	11 (4)	3 (0)	3 (1)
Group 3	30 (10)	10 (3)	3 (3)
Intraoperative			
Group 1	32 (16)	5 (1)	3 (2)
Group 2	16 (5)	1 (0)	0
Group 3	40 (14)	1 (1)	2 (1)
Postoperative			
Group 1	22 (10)	7 (0)	11 (9)
Group 2	12 (5)	3 (0)	2 (0)
Group 3	22 (8)	9 (2)	12 (6)

Values represent total number of patients in category, with number in parentheses representing patients examined with an AM Holter recorder.

and 3 (n = 6), respectively, occurred at heart rates ≤ 90 beats/min, while the single intraoperative ischemic episodes in group 2 occurred at a heart rate ≤ 90 beats/min. Postoperatively, 15 and 13% of ischemic episodes occurred at heart rates ≤ 90 beats/min in groups 1 (n = 10) and 3 (n = 7), respectively, and 50% of postoperative ischemic episodes in group 2 (n = 7) occurred at a heart rate of ≤ 90. Intraoperatively, 35 of 40 patients in group 1 received supplemental isoflurane. Eight of these group 1 patients who developed ECG evidence of myocardial ischemia received isoflurane, and 27 other group 1 patients received isoflurane without evidence of intraoperative ischemia events.

Patient Outcome

Perioperative myocardial infarctions (PMI) occurred in three patients in group 3, two patients in group 2, and one patient in group 1. Two patients from group 3 with a PMI experienced no perioperative ECG ischemic episodes. The patient in group 1 with a PMI experienced three preoperative ischemic episodes. Of the patients in group 2 with PMI, perioperative ischemic episodes occurred in one patient preoperatively and one patient postoperatively. There were no perioperative deaths.

Discussion

The current investigation has expanded on previous studies of perioperative myocardial ischemia in CABG patients by examining the relationship between the anatomic distribution of coronary artery stenosis and ECG evidence of myocardial ischemia over the entire perioperative period. The major new findings of this study in patients undergoing CABG surgery are that individuals with steal-prone coronary artery disease have more frequent and longer ECG ischemic episodes preoperatively when compared with patients with nonleft main or left main equivalent coronary artery stenosis. In the current study, the presence of angiographically determined steal-prone coronary anatomy confers a nearly twofold increased relative risk of a preoperative ischemic ECG episodes compared with the latter anatomic group. The data indicate, however, that there is no increased risk for intra- or postoperative ECG ischemic episodes between these two anatomic groups. Anatomic distribution of coronary artery stenosis, in the current study, was also associated with changes in the pattern of ECG ischemic episodes observed in subsequent perioperative periods.

We have chosen to examine the frequency of perioperative myocardial ischemic events in patients with two variants of coronary artery stenosis: steal-prone coronary anatomy and left main coronary artery stenosis. In patients with steal-prone anatomy, blood flow from collateral vessels to myocardium distal to an occluded major supplying artery approximates a functional 90% stenosis and, therefore, may be limited in situations of altered myocardial oxygen supply and de-

Table 5. Relative Risk of an Ischemic Electrocardiographic Episode between Groups during Each Perioperative Period

	Preoperative		Intraoperative		Postoperative	
	Relative Risk Ratio	95% Confidence Interval	Relative Risk Ratio	95% Confidence Interval	Relative Risk Ratio	95% Confidence Interval
Group 1 *vs.* Group 3	1.82*	1.07–3.10	2.87	0.82–10.06	0.92	0.58–1.46
Group 1 *vs.* Group 2	1.56	0.77–3.14	3.40	0.46–25.12	1.53	0.68–3.45
Group 2 *vs.* Group 3	1.17	0.53–2.57	0.84	0.09–7.55	0.60	0.27–1.34

* $P \leq 0.05$.

mand.[13-19] With reduced vasodilating reserve blood supply to steal-prone myocardium is pressure dependent.[13-19] Therefore, myocardial ischemia may result if coronary arteriolar vasodilation in myocardial regions with normal vasodilatory reserve were to divert, or "steal," blood flow away from this collateral-dependent myocardium. When they reviewed over 16,000 individuals in the CASS Registry, Buffington *et al.*[11] found that 23% of patients had the angiographic requirements for coronary steal-prone anatomy. Because of strict entrance criteria that excluded patients with unstable angina, coexisting valvular heart disease, and left ventricular ejection fractions less than 35%, data from the CASS registry may not necessarily be applicable to all patient populations.[20] Steal-prone coronary anatomy was found in 34% of 955 patients by Slogoff *et al.*[9] and 33% of 186 patients by Leung *et al.*[10] Patients in the current study were not consecutively enrolled; thus, the frequency of coronary steal-prone coronary anatomy that we observed (40% of patients) probably does not represent a true prevalence of this form of coronary artery disease. Regardless, the high frequency of this variant of coronary artery disease has enhanced clinical interest in steal-prone coronary anatomy, especially in light of multiple conflicting animal and human reports relating the use of the volatile anesthetic isoflurane to the development of myocardial ischemia in this setting.[8-11,17-19] Prior investigations of the frequency of myocardial ischemia in patients, specifically with steal-prone coronary artery disease, however, have been primarily limited to the intraoperative period.[8-10] These reports have shown that, compared with patients with other variants of coronary artery disease, the frequency of intraoperative myocardial ischemia is no different in patients with steal-prone coronary anatomy, supporting the findings of the current study.[9,10] Our results, however, show that the risk of ECG ischemic episodes is higher, preoperatively, in patients with steal-prone anatomy compared with patients with nonleft main or equivalent coronary stenosis. After the induction of anesthesia, the previously elevated risk of myocardial ischemia in the steal-prone group (group 1) compared with this latter anatomic group (group 3) was no longer observed.

We also examined the relationship between perioperative ischemic events and the presence of left main or left main equivalent coronary artery stenosis. The presence of coronary arterial obstruction to either the left main coronary artery or to the proximal two branches, the left anterior descending and circumflex arteries, has the potential for compromising blood flow to a large portion of myocardium. Left main coronary artery stenosis has previously been linked to poor outcome after CABG surgery.[21] However, there are conflicting reports on the risk of PMI in CABG patients with left main coronary stenosis.[22,23] Seventeen percent of our patients had left main or equivalent coronary artery stenosis, but, because of the small number of patients in this group, the data from these patients must be interpreted with caution. Nonetheless, rather than incorporate patients from group 2 into the "other" anatomic group (group 3), we chose to keep this group separate. Our data indicate no difference in the relative risk, frequency, or duration of ECG ischemic episodes in patients in the left main coronary stenosis group compared with the other two anatomic groups for any perioperative period.

Anesthetic technique was not standardized in this study, but consisted of high-dose opioid with supplemental volatile anesthetics given at the discretion of the attending anesthesiologist. Patients in each anatomic group examined received similar anesthetics and perioperative care. All patients with steal-prone coronary disease (group 1) with intraoperative ischemic ECG episodes received supplemental isoflurane. In contrast, 27 other patients from group 1 also received isoflurane without experiencing an intraoperative ischemic episode. Several investigators have found no relationship between the frequency of myocardial ischemia and anesthetics administered during CABG surgery.[4,9] Furthermore, we have reported that the frequency of myocardial ischemia in patients with steal-prone coronary anatomy undergoing CABG surgery is unrelated to volatile anesthetics administered when heart rate and blood pressure are maintained within 10–15% of preinduction values.[8] The current study, however, was not designed to examine the tendency of isoflurane to cause myocardial ischemia by a coronary steal mechanism.

In a previous study of 50 patients undergoing CABG surgery, Knight *et al.*[3] demonstrated that a pattern of myocardial ischemia detected by continuous ECG monitoring for 2 preoperative days was no worse intra- or postoperatively. In the current study, we also examined the distribution and duration of ischemic ECG epis/h of Holter monitoring within groups during the three perioperative periods. Our results (table 3) indicate that anatomic distribution of coronary stenosis may influence the intragroup perioperative pattern of ECG ischemic episodes. A pattern of myocardial isch-

emic ECG changes could not be demonstrated in all patients, however, as 3 of 12 patients with intraoperative, and 17 of 44 patients with postoperative, ischemic episodes did not have ECG evidence of ischemia in prior perioperative periods. Our preoperative monitoring period (18 ± 3.6 h) was shorter than that employed by Knight *et al.*[3] (43 ± 12 h) and, perhaps, preoperative ischemic episodes could have been detected in more patients with a longer monitoring period. Knight *et al.*[3] have also demonstrated that intraoperative ischemic ECG episodes in CABG patient are more frequent in those with preoperative ischemic events, but the risk of postoperative ischemia was no different for those with or without pre- or intraoperative ischemic episodes. In the current study, there was a nonsignificant trend for preoperative ischemic episodes to be associated with an increased risk of intraoperative ischemic events. There was no difference in the relative risk of a postoperative ischemic episode for patients with ECG evidence of myocardial ischemia in prior perioperative periods.

Ninety-seven percent of preoperative ischemic ECG episodes in our population occurred in the absence of symptoms; this is similar to the 87% incidence of silent myocardial ischemia reported by other investigators.[3] This frequency of silent myocardial ischemia in preoperative CABG patients is greater than that reported for patients with both chronic stable and unstable angina (68–78%),[24–27] but similar to that reported to occur in high-risk postmyocardial infarction patients (93%).[28] Perhaps this high frequency of asymptomatic ischemic events in our population should not be surprising, considering the fact that 32% of our patients were operated on within 3 months of a prior myocardial infarction. Additional explanations for the high incidence of silent myocardial ischemic events in preoperative CABG patients may include an altered pain perception because of the preoperative use of sedative and opioid drugs, and other factors that have not yet been defined. This high prevalence of preoperative silent myocardial ischemia in this population of CABG patients indicates that even the most detailed preoperative history will not accurately quantify the magnitude of myocardial ischemia.

Although it provides a method to continuously monitor for perioperative myocardial ischemia, several limitations exist with the use of ECG monitoring. Several factors can affect the ST segment perioperatively, including, for example, alteration in serum electrolytes and myocardial temperatures. Ventricular cardiac pacing in the postoperative period can also interfere with interpretation of ST segment changes in some patients. In addition, baseline drift of the ST segment can occur with solid-state ECG recorders, resulting in false positive ischemic episodes. We attempted to limit the number of false positive results by comparing only hard copy tracings of identified ischemic episodes with interval ECG samples that were updated every 4 h. False negative results are also possible if the solid-state monitor is attached and the reference ST segment is determined during an ischemic episode. Positional induced changes in the ST segment were not examined, and could also, potentially, influence primarily preoperative ECG monitoring. Analysis of ST segment deviation identified from the solid-state monitor's algorithm, as opposed to that obtained from complete ECG disclosure, is also a limitation. In this study, two different ECG monitoring devices were employed. The potential for varying sensitivities of the monitors for the detection of myocardial ischemia exist. Whether the differences in ischemic episodes duration observed (table 2) was a manifestation of different sensitivities between the two monitoring systems or a representation of inadvertent selection of two patient populations with different myocardial ischemic characteristics is not known. More patients in group 1 had longer pre- and postoperative ischemic episodes observed with the AM Holter recorder compared with the solid-state monitor. This finding was not observed with the other anatomic groups or for group 1 intraoperatively. Thus, because the differences in duration of ischemic events between monitoring systems was not consistently observed, these results would indicate that the differences in ischemic episode duration observed during these periods in group 1 were related to differences in the characteristics of ischemic episodes within this group, and were not the result of different sensitivities of the continuous ECG monitors employed in this study. Furthermore, because both monitoring systems were used equally among anatomic groups, we are uncertain of what effect, if any, employment of these two monitoring systems had on our results.

Angiographic identification of collateral coronary vessels is an additional limitation of this study. Coronary angiography can only identify collateral blood vessels with diameters > 100 μm, and is not capable of identifying intramyocardial collateral vessels.[29] Moreover, it has been demonstrated that collateral blood vessels detected by contrast echocardiography may go unde-

tected by angiography.# Therefore, the prevalence of coronary steal-prone anatomy in our population may have been underestimated. In any case, the angiographic definitions employed in this study appeared to be suitable for identifying subsets of patients whose characteristics of perioperative myocardial ischemia appear to differ.

We conclude that patients undergoing CABG surgery have frequent ECG ischemic episodes that are usually silent in the preoperative period. The anatomic pattern of coronary artery stenosis may identify individuals whose characteristics of perioperative myocardial ischemia may differ. On the basis of our data, it would appear that individuals with steal-prone coronary artery anatomy are at increased risk for preoperative ischemia, but at no higher risk for intra- or postoperative ischemic episodes, compared with individuals with other anatomic distribution of coronary artery stenosis.

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