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# *Does Perioperative Myocardial Ischemia Lead to Postoperative Myocardial Infarction?*

*Stephen Slogoff, M.D.,* and Arthur S. Keats, M.D.†*

**To determine if a relationship exists between perioperative myocardial ischemia (ST segment depression ≥ 0.1 mV) and postoperative myocardial infarction (PMI), nonparticipating observers recorded all ECG, hemodynamic, and other events between arrival of patients in the operating room and onset of cardiopulmonary bypass during 1,023 elective coronary artery bypass operations (CABG). The roles of preoperative patient characteristics, quality of the operation limited by disease as rated by the surgeon and duration of ischemic cardiac arrest as risk factors for PMI also were quantified. ECG ischemia occurred in 36.9% of all patients, with almost half the episodes occurring before induction of anesthesia. PMI was almost three times as frequent in patients with ischemia (6.9% *vs.* 2.5%) and was independent of when ischemia occurred. Ischemia was related significantly to tachycardia but not hypertension nor hypotension and was frequent in the absence of any hemodynamic abnormalities. The anesthesiologist whose patients had the highest rate of tachycardia and ischemia had the highest rate of PMI. Although neither single nor multiple preoperative patient characteristics related to PMI, suboptimal quality of operation and prolonged ischemic cardiac arrest increased the likelihood of PMI independent of the occurrence of myocardial ischemia. The authors conclude that perioperative myocardial ischemia is common in patients undergoing CABG, occurs randomly as well as in response to hemodynamic abnormalities, and is one of three independent risk factors the authors identified as related to PMI. PMI is unrelated to preoperative patient characteristics such as ejection fraction and left main coronary artery disease, and its frequency will relate primarily to perioperative management rather than patient selection. (Key words: Anesthesia: cardiovascular. Heart: ischemia; Myocardial infarction. Surgery: cardiac.)**

POSTOPERATIVE MYOCARDIAL INFARCTION accounts for up to 40% of the deaths following coronary artery bypass operations.[1,2] In designing anesthetic techniques for these operations, major emphasis has been directed toward prevention of intraoperative myocardial ischemia by control of determinants of myocardial oxygen supply and demand, based on the assumption that intraoperative ischemia leads to postoperative myocardial infarction. Despite this widely held assumption, no relationship has been demonstrated between intraoperative myocardial ischemia by electrocardiography and any unfavorable outcome. The major purpose of this study was to examine the relationship of myocardial ischemia appearing at any time before cardiopulmonary bypass (CPB) during coronary artery bypass operations (CABG) to postoperative myocardial infarction (PMI). In addition to new episodes of myocardial ischemia, preoperative and perioperative variables potentially contributing to the incidence of PMI also were recorded in order to quantify ischemia as a risk factor for PMI. A unique aspect of the study was the collection of data by observers who did not participate in any aspect of the operation.

## Methods

### Design of Study

All patients scheduled for CABG by surgeons who agreed to participate were eligible for study. Patients excluded from the study were those who had previous CABG, those scheduled for associated procedures such as ventricular aneurysm resection, those whose electrocardiograms prevented the diagnosis of ischemia, *e.g.*, LBBB, and those operated on when an observer was unavailable. Between June 1, 1981, and May 30, 1982, data relating to the perioperative experiences of 1,023 patients were collected, representing approximately 75% of all eligible patients during this period.

Nine attending anesthesiologists participated in the study as part of their regular clinical duties. Operating room assignment was based on a regular rotation among all operating rooms. Assignment to a patient included in this study was by chance alone. Each patient was interviewed by his or her attending anesthesiologist the night before operation and had the anesthetic-related procedures explained. Premedication was by the choice of the anesthesiologist and consisted of various combinations of diazepam, lorazepam, pentobarbital, promethazine, meperidine, morphine, and scopolamine. Chronically administered beta blockers and nitrates were continued until the morning of operation, unless specifically discontinued earlier by the attending cardiologist or not specifically ordered by the anesthesiologist. Choice of anesthetic agents and anesthetic management decisions were made by the anesthesiologist according to his usual practice. Anesthesia was induced in all patients by thiopental or diazepam followed by pancuronium for tracheal intubation. Anesthesia was maintained by halothane or enflurane supplemented with a narcotic (morphine 30–40 mg or fentanyl 1.0–1.25 mg) in 85% of patients,

* Clinical Associate Professor.

† Clinical Professor.

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Address reprint requests to Dr. Slogoff: Division of Cardiovascular Anesthesia, Texas Heart Institute, P. O. Box 20269, Houston, Texas 77025.

by nitrous oxide and narcotic only in 12% of patients and by inhalation agents only in 3%. Anesthesia during CPB was maintained by thiopental, diazepam, and fentanyl alone or in combination.

### Observers

All data were collected by observers who did not participate in any aspect of patient care. Two nurses and three premedical students were trained to extract discrete information from the patients' charts, to read oscilloscope tracings, obtain strip recordings, and record collateral information directly from participating surgeons and anesthesiologists.

### Preoperative Data

Data necessary to predict mortality based on the CASS criteria[3] were recorded. These included age, sex, left main coronary artery obstruction, left ventricular end-diastolic pressure, left ventricular score (a measure of regional function defined in the CASS Study),[3] and ejection fraction. A predicted mortality was calculated for each patient. In addition, chronic hypertension and diabetes mellitus when diagnosed preoperatively were noted. Drugs used for chronic cardiac therapy before operation and time of last dose were recorded.

### Intraoperative Data

On arrival of the patient in the operating room calibrated ECG tracings of leads II and $V_5$ were recorded and retained for comparison with the routine preoperative electrocardiogram. Tracings were obtained every two min until initiation of cardiopulmonary bypass. Heart rate and direct blood pressure were recorded with each tracing. For purposes of analysis, hypertension was considered present when systolic blood pressure was ≥180 mmHg, hypotension when systolic blood pressure was ≤90 mmHg, and tachycardia when heart rate was ≥100 beats/min when these changes persisted for at least 4 min. The data also were analyzed with the use of per cent change rather than absolute values for hemodynamic abnormalities. Conclusions drawn from both sets of analyses were the same, but, because of the large variation in control values, criteria based on absolute values were more physiologically meaningful and increased the specificity of the relationships examined. Time of anesthetic induction, tracheal intubation, skin incision, sternotomy, and cannulation of the atrium and aorta in preparation for cardiopulmonary bypass were noted, as were all drug administrations. Ischemia by electrocardiography was considered present when at least 0.1 mV new ST segment depression compared with the preoperative resting electrocardiogram occurred and was graded: none, 0.10–0.19 mV or ≥0.2 mV.

All operations were performed with a bubble oxygenator utilizing normothermia and hemodilution. Distal anastomoses of vein grafts to coronary arteries were performed first during continuous aortic cross-clamping (ischemic time) at the start of which a single dose of cold (6–10° C) cardioplegic solution (500 ml 5% dextrose in 0.45% sodium chloride plus potassium chloride 20.0 mM, magnesium chloride 7.5 mM, sodium bicarbonate 2.5 mM, and calcium chloride 1.0 mM) was injected into the root of the aorta. The heart also was bathed in cold saline until the conclusion of cardioplegia infusion. Before removing the aortic cross-clamp, the operating surgeon rated the quality of distal anastomosis and vein grafts according to the following: I—all good anastomotic sites and good quality vein; II—one bad anastomotic site related to presence of plaque, or poor quality vein; III—enough poor quality bypasses (artery or vein) to believe the patient would not be improved by operation; IV—the opinion that operation may be detrimental to the patient.

Proximal vein grafting to the aorta was performed during partial aortic occlusion. Hemodynamic and related data following bypass were not considered relevant to the purposes of this study, since major coronary occlusive disease was presumably no longer present.

### Postoperative Data

Ten hours after onset of cardiopulmonary bypass, blood was drawn for quantitative CPK analysis by a modification of the ultraviolet enzymatic determination (Abbott® ABA-100 Method). The MB fraction was determined by ultraviolet examination after isoenzyme separation by electrophoresis (Corning® Electrophoresis Method). While total CPK-MB released after infarction correlates well with infarct size, CPK-MB levels peak 6–16 h after cardiopulmonary bypass and peak levels correlate well with total spillage.[4–7] A 12-lead electrocardiogram was obtained on the morning of the first postoperative day. Transmural infarction was considered present when new Q waves of at least 0.04 s duration in adjacent leads appeared or when old Q waves extended to new adjacent leads, or when new persistent LBBB appeared *and* when CPK-MB was in excess of 80 U. Diagnosis of PMI required that both criteria were met. These criteria were selected because they are the most commonly used criteria and are more rigorous than CPK-MB alone, thereby decreasing false positives and increasing specificity when applied to the analyses of perioperative factors. All patients were followed to discharge. Fourteen patients originally included in the study subsequently were excluded because of postoperative bleeding requiring reexploration. None of these suffered PMI. Two patients suffered nonfatal infarctions,

one at 4 and one at 10 days after operation. These infarctions were not considered as being related to the events studied here.

### Deaths

Among the 1,023 patients, 14 (1.4%) died postoperatively, five of whom were considered to have died as a direct result of PMI. All five required vasopressor infusion, and four needed intraaortic balloon pump support to effect weaning from cardiopulmonary bypass. One, with obvious acute anterior wall infarction, did not survive long enough for CPK-MB analysis. The other four had ECG criteria of PMI and CPK-MB levels of 90–340 U.

Of the other nine patients who died, none had ECG evidence of new infarction, and CPK-MB ranged from 0 to 78 U/l. Seven died of central nervous system complications, one of a late postoperative ventricular fibrillation and one of prolonged circulatory failure without infarction. Among the seven central nervous system (CNS) deaths, three were secondary to prolonged low cardiac output postoperatively and one to prolonged hypotension during dysrhythmia in the prebypass period. The other three CNS deaths were probably secondary to cerebral emboli. In two of these, friable plaque was discovered in the aorta at the time of proximal graft insertion. The five patients who died of PMI were included in the group considered to have PMI; the other nine were included in the group without PMI.

### Data Analysis

All data were placed in a National Advanced System Computer® (AS/9000N) with an IBM® 3033 Operating System. The relationship of each preoperative characteristic and intraoperative variable to the incidence of PMI was tested by chi-square analysis, corrected for continuity when appropriate. In addition, all variables were subjected to stepwise discriminant analysis utilizing the minimum Wilks' lambda as a measure of group discrimination, with a maximum discriminant probability for inclusion of $P = 0.05$.[8] Factors that correlated highly with each other were considered first, and those found to be dependently related were adjusted to avoid destabilization of the analysis by multiple evaluation of the same determinant. The minimum Wilks' lambda analysis admits those factors that have the greatest predictive value (F number) and corrects for covariates containing redundant information at each step of the analysis. From the factors that remained significantly related after discriminant analysis, a model was created that utilized discriminant analysis coefficients to calculate the probability that any patient would or would not develop PMI as well as the predictive strength of these factors for the entire population.[8]

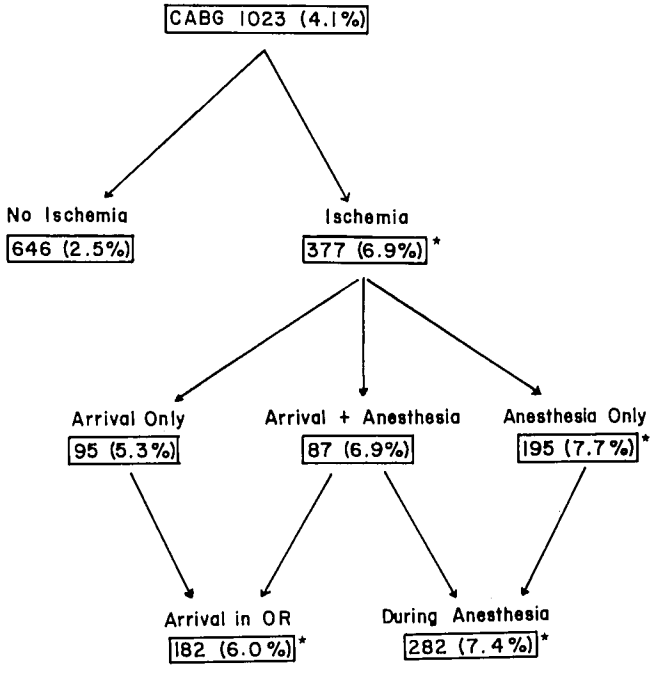


Fig. 1. Incidence of myocardial ischemia and PMI in 1,023 patients undergoing CABG. Numbers in boxes represent number of patients; numbers in parentheses represent per cent of subgroup who suffered PMI. (Note that numbers in the bottom row total more than 377 because of the inclusion of 87 patients in both arrival and during anesthesia groups). *Significantly different from "No Ischemia."

## Results

By the criteria described, 42 (4.1%) of the 1,023 patients studied suffered PMI, five of which were fatal (12%). Postoperative hospital mortality from all causes was 1.4% (14 patients), with PMI accounting for 36% of hospital mortality.

### Myocardial Ischemia

*Incidence:* More than one-third of all patients (36.9%) suffered at least one episode of perioperative ischemia. (fig. 1) Almost half the patients with new ischemic episodes arrived at the operating room with ST segment depression 0.1 mV or more, compared with their preoperative ECG. Eighty-seven of these had additional distinct episodes of ischemia following induction of anesthesia and before CPB. The risk of PMI was independent of the time at which ischemia appeared (fig. 1) and seemed related to the degree of ST segment depression (table 1). PMI occurred in 6.9% of all patients with new episodes of ischemia, compared with 2.5% in patients without ischemia ($P < 0.005$).

TABLE 1. Relationship between Degree of ST Segment Depression and Incidence of PMI

| | Perioperative ST Segment Depression | | |
|---|---|---|---|
| | None | 0.10–0.19 mV | ≥0.2 mV |
| Number of patients | 646 | 291 | 86 |
| Incidence of PMI (%)* | 2.5 | 6.2 | 9.3 |

* $P < 0.005$ by multiple chi-square.

*Relation to Hemodynamics:* Ischemia was significantly more common in patients who had hemodynamic abnormalities (hypertension, hypotension, or tachycardia) both before and during anesthesia (table 2). In 220 of the 241 patients arriving at the operating room with a hemodynamic abnormality, the abnormality was hypertension. Hemodynamic abnormalities were three times as frequent between induction of anesthesia and CPB. Although myocardial ischemia was more common in patients with hemodynamic abnormalities, ischemia was not rare in patients without hemodynamic abnormalities. In addition, more than half the ischemic episodes during anesthesia were not temporally related to the hemodynamic abnormality. Despite this, ischemia was significantly more frequent in patients who developed tachycardia but not hypertension or hypotension (table 3).

*Relation to Operative Events:* When ischemia occurred during anesthesia, it was associated with one of five discrete events in all but four of 282 patients (table 4). Ischemia was most likely to occur during intubation or surgical stimulation (skin incision or sternal splitting) with the same pattern in patients with and without hemodynamic abnormalities.

*Role of the Anesthesiologist:* The contribution of each of nine anesthesiologists in the overall incidence of hemodynamic abnormalities, myocardial ischemia and PMI was examined (table 5). Although the incidence of ischemia on arrival in the operating room was similar for all anesthesiologists, anesthesiologist 7 had the highest incidence of intraoperative tachycardia, myocardial ischemia, and postoperative myocardial infarction.

TABLE 2. Relationship between Hemodynamic Abnormalities and Incidence of Myocardial Ischemia

| | Hemodynamic Abnormalities | | | |
|---|---|---|---|---|
| | Arrival in OR | | During anesthesia | |
| | Absent | Present | Absent | Present |
| No. of patients | 782 | 241 | 249 | 774 |
| Myocardial ischemia (%) | 15.5 | 25.4* | 18.9 | 30.4* |

* Significantly different from "Absent" ($P < 0.0005$).

TABLE 3. Relation of Specific Hemodynamic Abnormalities during Anesthesia to Myocardial Ischemia

| | No Hemodynamic Change | Tachycardia | Hypotension* | Hypertension* |
|---|---|---|---|---|
| No. of Patients | 249 | 249 | 485 | 96 |
| Incidence of ST Segment Depression | 18.9% | 40.6%† | 25.6% | 26.0% |

* Fifty-six patients with both hypotension and hypertension were included in both groups. Ischemia occurred in 15 of these patients.
† Significantly different from "No Change" ($P < 0.0005$), "Hypotension" ($P < 0.0005$), and "Hypertension" ($P < 0.025$).

## FACTORS OTHER THAN MYOCARDIAL ISCHEMIA

*Preoperative Predictors:* Preoperative patient characteristics described in the CASS reports as predictors of mortality and PMI after CABG did not prove to be predictors of either outcome in these patients (table 6). Neither ejection fraction, left ventricular end-diastolic pressure, nor left main disease was significantly related to PMI (table 7). Neither the specific combination of any preanesthetic medications nor the preoperative use of beta-blockers or nitrates, their continuation, or duration of withdrawal correlated with ischemia on arrival to the operating room, intraoperative ischemia, or PMI.

*Surgical Rating:* The quality of the distal anastomoses as rated by the operating surgeon before removal of the aortic cross-clamp was considered a measure of the adequacy of operation as limited by small or diseased distal vessels or poor quality veins for grafting. Quality of anastomoses was rated optimal in 75.4% of the operations and not helpful or possibly harmful to 14 patients. These estimates of the technical limitations of operation before observation of their function correlated significantly with the incidence of PMI (table 8).

*Ischemic Time:* The usual ischemic time for CABG in this institution is less than 40 min. When more than 40 min of ischemic time was required, PMI increased from 2.6% of 840 operations to 10.9% of 183 operations ($P < 0.001$). Longer ischemic times were related to more difficult anastomoses. When surgical ratings were optimal, only 13.6% of operations exceeded 40 min of ischemic time. With less than optimal ratings, ischemic time exceeded 40 min in 30.9% of operations.

*CPK-MB Analysis:* Of the 981 patients without PMI, 25% had no measurable CPK-MB in their serum 10 h after cardiopulmonary bypass, while in only four patients did CPK-MB exceed 80 U. CPK-MB levels were not higher in patients with intraoperative ECG ischemia. Only ischemic time (fig. 2) and number of bypass grafts, which are interdependent, correlated with CPK-MB spillage in patients without PMI.

TABLE 4. Appearance of Intraoperative Myocardial Ischemia in Relation to Anesthetic and Surgical Events

| Hemodynamic Abnormalities | No. of Patients | Induction | Intubation | Surgical Stimulation | Cannulation | Start CPB |
|---|---|---|---|---|---|---|
| Absent | 47 | 11% | 32% | 47% | 9% | 2% |
| Present | 231 | 12.1% | 40.7% | 34.2% | 11.3% | 1.7% |
| All patients with ischemia* | 278 | 11.9% | 39.2% | 36.3% | 10.8% | 1.8% |

* Four patients with ischemia temporally unrelated to any event were excluded.

*Discriminant Analysis:* Before undertaking stepwise discriminant analysis of the relationship between perioperative factors and PMI, two significant univariate predictors were adjusted for interdependency. Anesthesiologist and ST segment depression during anesthesia were interrelated significantly (table 5). After adjustment of anesthesiologist for ischemia, anesthesiologist was no longer a predictor. For the same reason, ischemic time was corrected for surgical rating. Resulting discriminant analysis using a maximum $P$ value = 0.05 for inclusion found ischemic time, ST segment depression before cardiopulmonary bypass, and surgical rating the only significant independent factors in the development of PMI (table 7).

## Discussion

Perioperative myocardial ischemia from any cause in patients undergoing CABG always has been considered undesirable, and anesthesiologists have written extensively on its relation to hemodynamic variables, anesthetic agents, techniques, precipitating events, improved methods of diagnosis, prevention, and treatment. Despite this, no relationship is known to exist between perioperative ischemia and any unfavorable outcome, particularly PMI. Since PMI following CABG is a low-frequency event whose incidence currently ranges from 2.8%[9] to 13.7%[6] and reportedly is increased by some preoperative and intraoperative characteristics, study of a large group of patients was required to identify the role of perioperative ischemia in PMI. A major strength of this study was the accumulation of sufficient data in a short time in one institution to permit control of the myriad of variables present in multiclinic studies and to minimize changes in medical and surgical practices that occur with time. An additional strength was the collection of all data by unbiased nonparticipant observers who were not distracted by procedures or events. Although data for comparison are not available, our incidence of ischemia and hemodynamic abnormalities greatly exceeded our expectations and was probably attributable to the use of observers. Our data clearly demonstrate a strong relationship between PMI and new ischemic episodes appearing between the arrival of the patient to the operating room and the onset of CPB. This relationship was independent of preoperative patient characteristics, the quality of surgical repair, and the duration of myocardial ischemia. In addition to demonstrating this relationship, these data confirm and fail to confirm other preconceptions concerning perioperative myocardial ischemia.

TABLE 5. Role of Anesthesiologist in Perioperative Ischemia and PMI

| | | Incidence (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ischemia | | | During Anesthesia | | |
| Anesthesiologist | No. of Patients | On Arrival | During Anesthesia | PMI | Tachycardia | Hypertension | Hypotension |
| 1 | 139 | 19 | 29 | 2.9 | 19 | 9 | 57 |
| 2 | 131 | 14 | 22 | 4.6 | 21 | 5 | 48 |
| 3 | 104 | 15 | 26 | 3.8 | 23 | 11 | 46 |
| 4 | 118 | 22 | 38* | 5.1 | 27 | 14 | 49 |
| 5 | 138 | 13 | 18 | 5.1 | 20 | 8 | 45 |
| 6 | 129 | 16 | 22 | 3.1 | 23 | 4 | 46 |
| 7 | 64 | 20 | 45* | 12.5* | 48* | 17* | 38 |
| 8 | 105 | 26 | 32 | 1.9 | 28 | 16* | 46 |
| 9 | 95 | 17 | 26 | 1.1 | 24 | 5 | 45 |
| Total | 1,023 | 17.8 | 27.6 | 4.1 | 24.3 | 9.4 | 47.4 |
| Multiple chi-square | | NS | <0.0005 | <0.05 | <0.005 | <0.01 | NS |

* Significantly greater than group mean ($P < 0.05$).

TABLE 6. Actual Mortality and Mortality Predicted from Preoperative Characteristics Identified by Cass Study[3]

| | No. of Patients | Predicted | Actual |
|---|---|---|---|
| Total | 1023 | 2.5% | 1.4% |
| Survivors | 1009 | 2.5% | 0% |
| Nonsurvivors | 14 | 2.4% | 100% |
| PMI present | 42 | 2.2% | 12% |
| PMI absent | 981 | 2.5% | 0.9% |

TABLE 8. Incidence of PMI as Related to Surgical Rating of Quality of Operation

| Rating | Operations | PMI Rate* (%) |
|---|---|---|
| I | 771 | 3.4 |
| II | 238 | 5.9 |
| III & IV | 14 | 14.3 |

* $P < 0.05$ by multiple chi-square.

Since PMI accounts for almost half the mortality after CABG, we assumed intraoperative ischemia would constitute a risk factor for PMI in addition to those preoperative factors described by the CASS study for mortality[3] and by others for PMI.[1,9–12] We were surprised, therefore, to find that the risk factors for mortality identified by CASS were not predictors of either mortality or PMI for patients in this study (table 6). The failure of the CASS predictors confirms the Stanford experience that contrasted their results over the years 1971–1975 and 1977–1979.[9] In the early period, left main coronary disease, severity of CHF, chronic hypertension, and degree of mitral regurgitation were significant predictors of mortality, whereas only the presence of CHF predicted mortality in the more recent period. In neither group did the CASS predictors of sex, wall motion score, ejection fraction, age, or LVEDP relate to mortality. They found age and left main coronary disease to predict PMI in their early group but not in the recent group. Female gender and the performance of coronary endarterectomy predicted PMI in the recent group but not the earlier group. In a subsequent report by CASS, their mortality predictors were unable to predict PMI.[13] The failure of the CASS predictors that relate primarily to the preoperative patient characteristics forces a reappraisal of the role of patient selection in the outcome of CABG and of the validity of basing anesthetic management decisions on preoperative variables as ejection fraction, wall motion score, or presence of left main disease.

TABLE 7. Relationship of Preoperative and Perioperative Characteristics to PMI

| | Univariate Analysis *P* Value | Discriminant F | Analysis *P* Value* |
|---|---|---|---|
| Ischemia before cardiopulmonary bypass | <0.005 | 13.7 | 0.0002 |
| Ischemic time | <0.001 | 12.3† | 0.003 |
| Surgical rating | <0.05 | 9.0 | 0.017 |
| Anesthesiologists | <0.05 | 0.4‡ | 0.07 |
| Number of grafts | 0.84 | <1 | NS |
| Coronary endarterectomy | 0.25 | <1 | NS |
| Age | 0.42 | <1 | NS |
| Sex | 0.15 | <1 | NS |
| Left main disease | 0.54 | <1 | NS |
| LVEDP | 0.30 | <1 | NS |
| LV score | 0.50 | <1 | NS |
| Ejection fraction | 0.29 | <1 | NS |
| Diabetes | 0.38 | <1 | NS |
| Hypertension | 0.35 | <1 | NS |

* Maximum P to enter discriminant analysis = 0.05.
† Adjusted for surgical rating.
‡ Adjusted for frequency of pre-CPB ischemia.

We assumed that perioperative myocardial ischemia was associated primarily with events during and after induction of anesthesia. We therefore were surprised to observe that in almost half the patients with perioperative myocardial ischemia, ischemia was present on arrival in the operating room and that the prognostic significance of this ischemia for PMI was no different than ischemia occurring during anesthesia. Ischemia upon arrival in the operating room before operation was highly associated with hypertension and was only 10% less frequent in patients without any hemodynamic abnormality. Tachycardia was present in only 12 patients on arrival and was associated with ischemia in only three (25%). Neither hypertension nor ischemia during this period was related to the preoperative use of beta blockers and vasodilators or the duration of preoperative withdrawal.

In reviewing ischemic episodes occurring after induction of anesthesia, we were similarly surprised that ischemia occurred in 18.9% of patients without hemodynamic abnormality and was only 11% more common when abnormalities occurred (table 2). During anesthesia, ischemia was associated most frequently with tachycardia, not hypertension, and particularly not related to hypotension, the commonest hemodynamic abnormality by virtue of our preference for potent inhalation agents (table 3). This weak association between hemodynamic abnormality and ischemia contrasts with the strong relationship between ischemia, tachycardia, and hypertension for anesthesiologist 7 and with the strong temporal relationship between ischemia and anesthetic–surgical events known to produce intense sympathetic stimulation. Most (75.5%) ischemic episodes during anesthesia were associated with intubation and surgical stimulation (table 4).

It is difficult to reconcile these observations without postulating a certain randomness in the appearance of

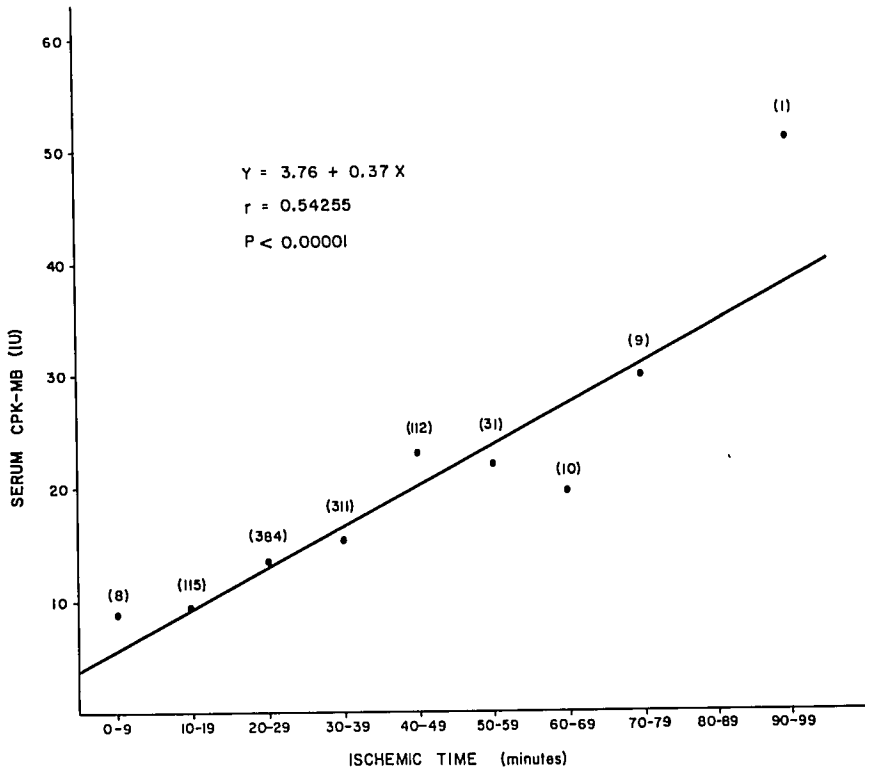


FIG. 2. Relationship between cardiac ischemic time and serum CPK-MB (U/l) 10 h after cardiopulmonary bypass in 981 patients without electrocardiographic evidence of PMI. Numbers in parentheses represent patients whose values provided the group means plotted.

myocardial ischemia on which is superimposed a direct relationship to anesthetic and surgical events producing sympathetic stimulation with or without hemodynamic abnormalities as we defined them. This randomness would be in accord with the natural history of coronary artery disease. Deanfield *et al.*[14] monitored ST segment depression during normal daily life in 30 ambulatory patients with stable angina. ST segment depression of 1–3 mm occurred more than four times each monitored day, was associated with angina in only 24% of the episodes, with a heart rate rise of more than 10 beats/min in only 23% of the episodes, and consistently was associated with regional myocardial ischemia by positron tomography, with or without angina. All this suggests that transient decreases in coronary supply are common during daily life in patients with chronic angina, whether the result of episodes of coronary spasm or other unidentified causes of redistribution of coronary flow. Clearly most were not related to increased myocardial demand. That this pattern of spontaneous decreases in myocardial supply exists in patients undergoing anesthesia for CABG is a reasonable assumption that would account for the high fequency of ischemia observed, particularly in the absence of hemodynamic abnormalities. Spontaneous random decreases in myocardial supply also would account for the lack of a strong association between hypotension and ischemia and not preclude the higher frequency of ischemia under circumstances of increased myocardial demand.

Although perioperative ischemia appeared in 37% of all our patients, only 42 (4.1%) developed PMI temporally related to events surrounding operation. Of these 42, 17 had no new ischemic episodes before or during operation. Obviously factors other than perioperative ischemia determined the incidence of PMI after CABG. We excluded preoperative patient characteristics, either singly or in combination, and identified two surgical factors, the quality of the operation as limited by the patient's disease process and ischemic time. In only one other report has a relationship between quality of anastomosis at the time of postoperative angiography and the development of PMI been demonstrated.[15] Several others found duration of cardiopulmonary bypass and ischemic time to be significant predictors of PMI and have assumed this to reflect increased complexity of disease.[10,12,16,17] In our study, ischemic time significantly related to PMI, even when adjusted for the technical difficulty of the operation. When discriminant function coefficients of these three independant factors (table 7) were used to score each patient's risk of PMI, we correctly predicted 52.4% of patients with PMI and 76.1% of patients without PMI, an overall correct prediction for 75.2% of patients. Obviously other unidentified factors operate as determinants of PMI and may relate to aspects of perfusion, surgical technique, or weaning from bypass.

The failure to identify preoperative patient characteristics that predict PMI and the clear identification of

perioperative events as predictors of PMI strongly suggests that physician selection plays a greater role than patient selection in PMI after CABG. The demonstration of a significant difference among nine anesthesiologists in their frequency of postinduction ischemia and subsequent PMI supports this view. We believe the varying rates of ischemia during anesthesia among anesthesiologists reflect their varying skills in managing patients for CABG operations and may represent an objective measure for assessing clinical skills. Now that a relationship between ischemia during anesthesia and PMI has been established, a high-frequency event (ischemia) can be substituted for a low-frequency event (PMI) facilitating such assessments. In addition, a high-frequency event predisposing to an unfavorable outcome can provide a basis for measuring improvement in preoperative preparation and anesthetic management of patients with coronary artery disease.

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