

# Perioperative Myocardial Ischemia and Infarction

## Identification by Continuous 12-lead Electrocardiogram with Online ST-segment Monitoring

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**Background:** Perioperative myocardial ischemia is conventionally monitored using five electrocardiographic leads, with only one precordial lead placed at V<sub>5</sub>. This is based on studies from more than a decade ago. The authors reassessed this convention by analyzing data obtained from continuous on-line 12-lead electrocardiographic monitoring.

**Methods:** One hundred eighty-five consecutive patients undergoing vascular surgery were monitored by continuous 12-lead ST-trend analysis during and for 48–72 h after surgery. Cardiac troponin I was measured in the first 3 postoperative days, and cardiac outcome was prospectively recorded. Ischemia was defined as ST deviation, relative to the reference preanesthesia electrocardiogram, of 0.2 mV or more in one lead or 0.1 mV or more in two contiguous leads, lasting more than 10 min.

**Results:** During 11,132 patient-hours of monitoring, 38 patients (20.5%) had 66 transient ischemic events, with all but one denoted by ST-segment depression. Twelve patients (6.5%) sustained postoperative infarction (cardiac troponin I > 3.1 ng/ml). Among the 38 patients with ischemia, lead V<sub>3</sub> most frequently (86.8%) demonstrated ischemia, followed by V<sub>4</sub> (78.9%) and V<sub>5</sub> (65.8%). Among the 12 patients with infarction, V<sub>4</sub> was most sensitive to ischemia (83.3%), followed by V<sub>3</sub> and V<sub>5</sub> (75% each). Combining two precordial leads increased the sensitivity for detecting ischemia (97.4% for V<sub>3</sub> + V<sub>5</sub> and 92.1% for either V<sub>4</sub> + V<sub>5</sub> or V<sub>3</sub> + V<sub>4</sub>) and infarction (100% for V<sub>4</sub> + V<sub>5</sub> or V<sub>3</sub> + V<sub>5</sub> and 83.3% for V<sub>3</sub> + V<sub>4</sub>). On average, baseline preanesthesia ST was above isoelectric in V<sub>1</sub> through V<sub>3</sub> and below isoelectric in V<sub>5</sub> through V<sub>6</sub>. Lead V<sub>4</sub> was closest to the isoelectric level on the

baseline electrocardiogram, rendering it most suitable for ischemia monitoring.

**Conclusions:** As a single lead, V<sub>4</sub> is more sensitive and appropriate than V<sub>5</sub> for detecting prolonged postoperative ischemia and infarction. Two precordial leads or more are necessary so as to approach a sensitivity of greater than 95% for detection of perioperative ischemia and infarction.

PERIOPERATIVE myocardial ischemia is most commonly monitored using five electrocardiographic leads: four axial leads (right arm, left arm, right leg, and left leg), and one precordial lead placed at V<sub>5</sub>. This convention is based on previous observations in which the majority of ischemic episodes, up to 90% of those occurring during exercise testing and up to 75% of those observed intraoperatively, were detected by V<sub>5</sub> alone and that V<sub>5</sub> is the single most sensitive lead for ischemia.<sup>1,2</sup> However, the recent introduction of new technologies for accurate on-line ST-segment trend analysis, the realization that postoperative ischemia is more frequent and more important than intraoperative ischemia, and the understanding that prolonged rather than short episodes of ischemia are significantly associated with postoperative cardiac complications<sup>3,4</sup> justify the reexamination of previous concepts and convictions.

In the current investigation, we performed a detailed analysis of the 12-lead electrocardiographic data from our recently published study about perioperative ischemia and myocardial infarction after major vascular surgery.<sup>5</sup> Our objective was to determine the value of each one of the 12 electrocardiographic leads in detecting postoperative ischemia and myocardial infarction.

### Materials and Methods

After obtaining approval from the Institutional Review Board and informed consent, 185 consecutive patients undergoing major vascular surgery (84 undergoing carotid endarterectomy, 28 undergoing abdominal aortic surgery, and 73 undergoing lower-extremity arterial bypass procedure) at the Hadassah University Hospital (Jerusalem, Israel) were studied. Patients with unstable angina or myocardial infarction within the preceding 3 months were excluded. Monitoring included continuous intraarterial blood pressure and pulse oximetry measurement. Seven patients had regional (epidural or continuous spinal) anesthesia, 65 patients had combined

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**Table 1. Preoperative Electrocardiographic Data, Visual Interpretation**

	All Patients (n = 185)	Patients without Ischemia or Infarction (n = 147)	Patients with Myocardial Ischemia (n = 38)	Patients with Myocardial Infarction (n = 12)	P Value	
Pathological Q waves	61 (33.3%)	41 (27.9%)	20 (52.6%)	4 (33.3%)	*0.006	†NS
ST depression (>0.5 mm)	41 (22.2%)	30 (20.4%)	10 (26.3%)	5 (41.7%)	*NS	†NS
T wave Inversion	71 (38.4%)	55 (37.4%)	16 (42.1%)	7 (58.3%)	*NS	†NS
LVH (voltage criteria)	30 (16.2%)	19 (12.9%)	11 (28.9%)	5 (41.7%)	*0.024	†0.028

\* P values for comparison between patients with and without myocardial ischemia; † P values for comparison between patients with and without myocardial infarction.

LVH = left ventricular hypertrophy by voltage criteria on electrocardiogram.

general and epidural anesthesia, and 113 patients had general anesthesia only. After completion of surgery, patients were observed in the recovery room or the intensive care unit for at least 1 day after surgery. All preoperative medications were resumed postoperatively as soon as the patients were able to take fluids by mouth. All cardiac signs and symptoms during the hospital stay were recorded, and a 12-lead electrocardiogram was obtained before discharge from the hospital. The preoperative 12-lead electrocardiogram was analyzed based on the Sokolow-Lyon criteria for left ventricular hypertrophy (LVH), as previously described.<sup>6</sup>

Cardiac troponin I and creatine kinase MB were measured in all patients immediately after surgery, daily for the first 3 postoperative days, and later if clinically indicated. Postoperative myocardial infarction was defined as an increase in cardiac troponin I greater than 3.1 ng/ml,<sup>7,8</sup> accompanied by at least one of the following: typical ischemic symptoms, electrocardiographic changes indicative of ischemia (ST-segment depression or elevation), or new pathologic Q waves.<sup>9</sup>

*Continuous 12-Lead Electrocardiographic Recording*

Before induction of anesthesia, patients were connected to a continuous 12-lead electrocardiographic monitor (Solar 7000; Marquette Electronics, Milwaukee, WI), wired through a network to a Cardiac Review Station (ST-Guard, Marquette Electronics). Each minute, the ST-Guard stored all 12-lead electrocardiographic complexes, measured the ST-segment deviation in all leads as compared with the reference preanesthesia electrocardiogram, and displayed the ST trends. The ST segment was measured 60 ms after the J point. An episode of ischemia was defined as ST depression (in a non-Q-wave lead) or elevation, relative to the reference preop-

erative electrocardiogram, of 0.2 mV or more in one lead or 0.1 mV or more in two contiguous leads, lasting more than 10 min. Each episode of ST-segment deviation was automatically detected and marked by the ST-Guard. Monitoring was continued for 72 h, except in carotid endarterectomy patients, who usually ambulated after 48 h. The 12-lead ST-segment trends were reviewed by the study investigators, and artifacts were deleted. Periods marked by the ST-Guard as ST-segment deviations were inspected visually for accuracy, and those reflecting artifacts or pure up-sloping ST-segment depression were not considered to be ischemic.

*Analysis of Electrocardiographic Leads with ST Deviation*

In all patients with ischemia, the longest ischemic event was carefully analyzed, and the following parameters were recorded from each one of the 12-lead trends: (1) the ST level of the reference preanesthesia electrocardiogram; (2) the ST level at the beginning of ischemia (when first noted by the ST-Guard); and (3) the ST level at peak ischemia (maximal ST deviation recorded on one of the leads).

*Statistical Analysis*

Means ± SD of ST deviations were calculated, and the paired t test was used to compare the differences in ST deviation between the electrocardiographic leads. The sensitivity of the different leads in detecting ischemia and infarction was calculated. However, because our assumption was that all significant ST-segment events complying with our definition for ischemia were true positive ischemia, there were no false positives, and therefore, it was irrelevant to quantify the specificity of the different leads in detecting myocardial ischemia.

**Table 2. Leads with ST or T-wave Changes on Baseline Preoperative Electrocardiogram**

	L <sub>1</sub>	L <sub>2</sub>	L <sub>3</sub>	aVL	aVF	V <sub>1</sub>	V <sub>2</sub>	V <sub>3</sub>	V <sub>4</sub>	V <sub>5</sub>	V <sub>6</sub>
ST depression >0.5 mm	8.1%	5.4%	3.2%	4.8%	5.4%	0.5%	0.5%	0.5%	3.8%	10.3%	14.6%
T-wave Inversion	15.1%	8.1%	11.3%	20.5%	11.3%	3.8%	5.9%	6.5%	10.8%	20.0%	21.6%

Data from all 185 patients.

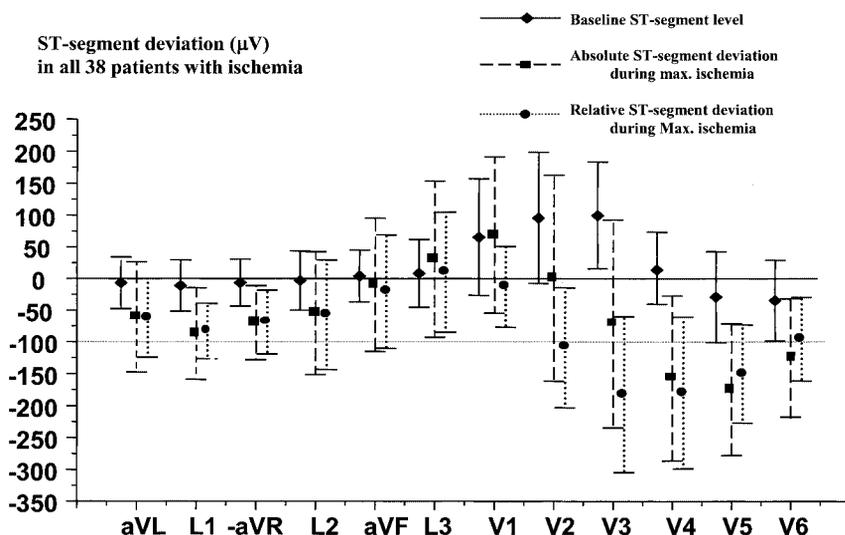


Fig. 1. Shows the ST-segment level at baseline (mean ± SD), the reference electrocardiogram (obtained before induction of anesthesia), the absolute ST deviation from isoelectric level at peak ischemia, and ST at peak ischemia relative to the reference electrocardiogram in all 38 patients with ischemia.

**Results**

During 11,132 patient-hours of monitoring (60.7 ± 11.9 h per patient), 38 patients (20.5%) had 66 ischemic episodes (1.7 ± 1.4 episodes per patient; range, 1-8), with all but one denoted by ST-segment depression. One patient had an episode of ST-segment elevation in leads L<sub>2</sub>, L<sub>3</sub> and aVF, associated with ST-segment depression in V<sub>1</sub> through V<sub>3</sub> and aVL, which lasted 24 min and was not accompanied by an elevation of cardiac markers. The duration of all patients' longest ischemic event was 96 ± 127 min (median, 46 min; shortest, 11 min; longest, 625 min). Twelve patients (6.5%) sustained a myocardial infarction defined as cardiac troponin I of 3.1 ng/ml or more (21.1 ± 26.5 ng/ml; range, 3.3-100.2); all of them were non-Q type and were detected either during (two patients) or within 18 h from a prolonged, transient ST-segment depression. One of the patients with postoperative infarction died.

Tables 1 and 2 show the preoperative electrocardiographic findings of the patients based on the visual

inspection of the preoperative 12-lead electrocardiogram. It shows a relatively high incidence of pathologic Q waves, baseline ST-segment depression (> 0.5 mm), T-wave inversion, and LVH by voltage criteria. Preoperative pathologic Q waves correlated with the occurrence of ischemia (P = 0.006), and LVH correlated with both postoperative ischemia and infarction (P = 0.02 and 0.03, respectively).

*Absolute versus Relative ST-segment Depression*

Figures 1 and 2 show for each electrocardiographic lead the differences between the preanesthesia ST-segment level (reference) and both the absolute ST deviation (from the isoelectric P-R interval) and the relative ST deviation (from the reference preanesthesia electrocardiogram) during peak ischemia in the 38 patients with ischemia (fig. 1) and the 12 patients with infarction (fig. 2). These data show a marked disparity in baseline ST-segment level between the anteroseptal and anterolateral chest leads, with leads V<sub>1</sub>, V<sub>2</sub>, and V<sub>3</sub> on average

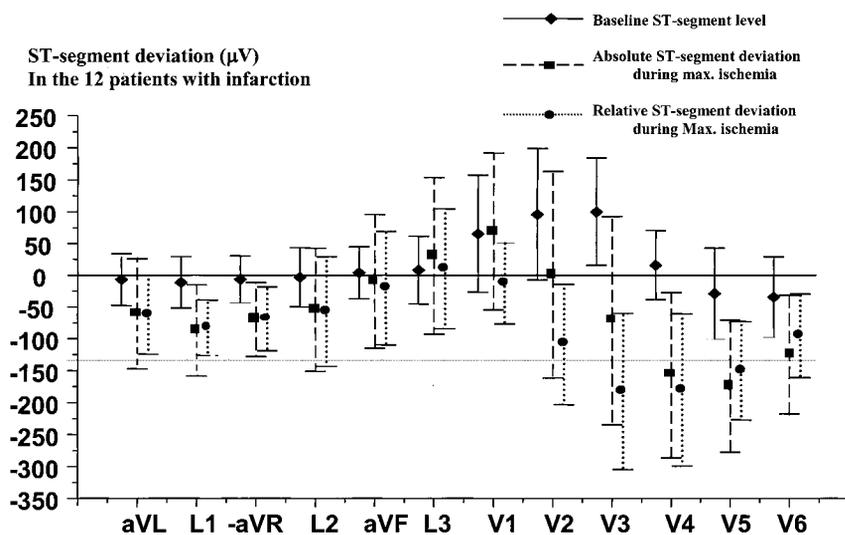
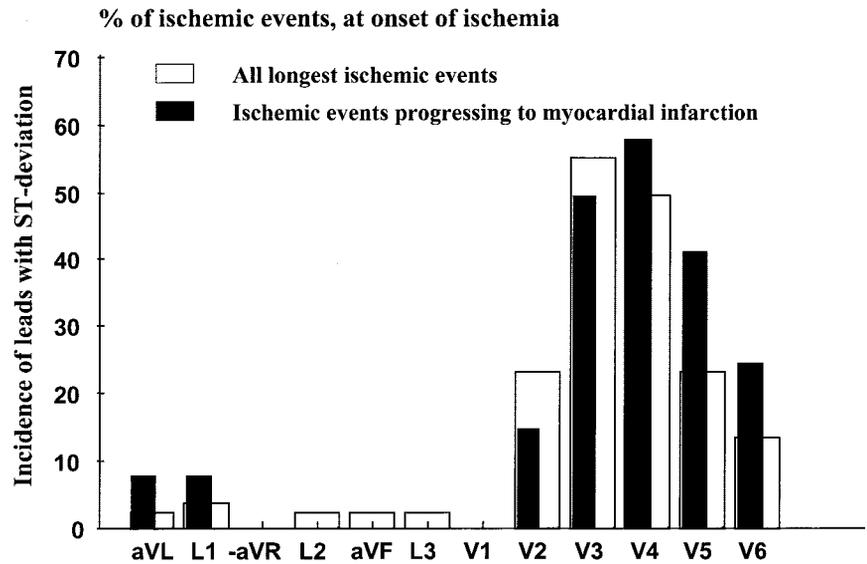


Fig. 2. Shows the ST-segment level at baseline (mean ± SD), the reference electrocardiogram (obtained before induction of anesthesia), the absolute ST deviation from the isoelectric line at peak ischemia, and ST at peak ischemia relative to the reference electrocardiogram in the 12 patients with myocardial infarction.

Fig. 3. Histogram showing the incidence in which prolonged ischemia was first noted by each lead at the onset of ischemia in all 38 longest ischemic events and in the 12 ischemic events that progressed to myocardial infarction.



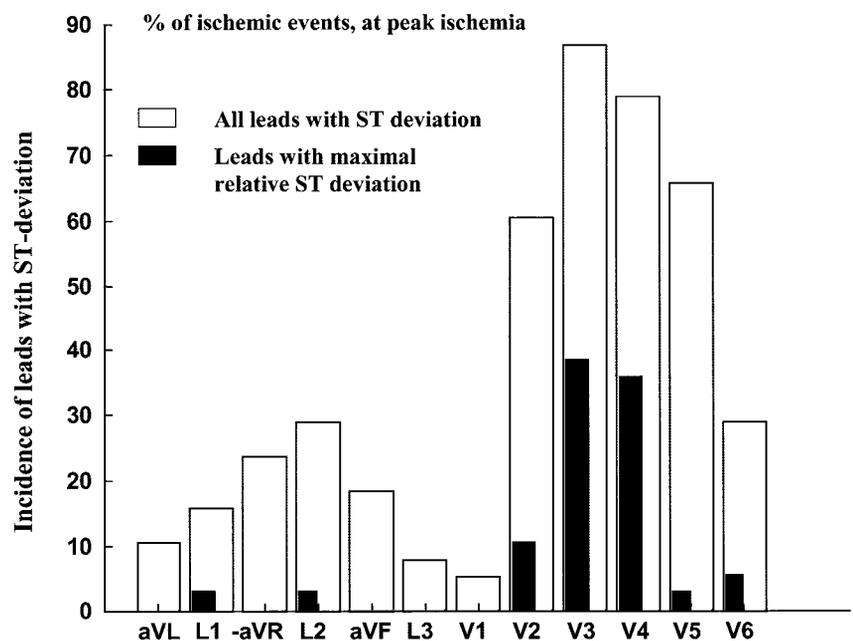
showing baseline ST-segment elevation, whereas leads V<sub>5</sub> and V<sub>6</sub> showed ST-segment depression on the preoperative electrocardiogram. Lead V<sub>4</sub> was closest to the isoelectric ST level on the reference preanesthesia electrocardiogram. These differences in reference ST level significantly affected the relations between absolute and relative ST-segment deviations during ischemia so that absolute ST depression was greater than relative ST depression in leads V<sub>5</sub> through V<sub>6</sub>, whereas the opposite occurred in V<sub>1</sub> through V<sub>3</sub> (figs. 1 and 2).

*Twelve-lead Sensitivity*

The sensitivity of each one of the 12 electrocardiographic leads in detecting ischemia at the beginning (when first noted on the ST-Guard) and at peak ischemia in patients with ischemia and in those with infarction is

shown in figures 3-5. Among all 38 patients with ischemia, V<sub>3</sub> was most frequently the first lead with ST deviation [21 patients (55.3%)], followed by V<sub>4</sub> (50%), V<sub>5</sub> and V<sub>2</sub> (23.7% each), and V<sub>6</sub> (13.1%) (fig. 3;  $P = 0.5$  for V<sub>3</sub> vs. V<sub>4</sub>,  $P < 0.0001$  for V<sub>3</sub> vs. V<sub>5</sub>, and  $P = 0.00013$  for V<sub>4</sub> vs. V<sub>5</sub>). Among the 12 patients who subsequently had myocardial infarction, ischemia was first noted on lead V<sub>4</sub> in seven patients (58.3%), followed by V<sub>3</sub> (50%), V<sub>5</sub> (41.7%), V<sub>6</sub> (25%), and V<sub>2</sub> (16.7%) (fig. 3;  $P > 0.2$  for all comparisons among V<sub>3</sub>, V<sub>4</sub>, and V<sub>5</sub>). At peak ischemia, lead V<sub>3</sub> most frequently (86.8%) demonstrated significant ST depression relative to the reference electrocardiogram, followed by V<sub>4</sub> (78.9%), V<sub>5</sub> (65.8%), and V<sub>2</sub> (60.5%) (fig. 4;  $P = 0.23$  for V<sub>3</sub> vs. V<sub>4</sub>,  $P = 0.08$  for V<sub>4</sub> vs. V<sub>5</sub>, and  $P = 0.006$  for V<sub>3</sub> vs. V<sub>5</sub>). Among the 12 patients with myocardial infarction, V<sub>4</sub> was the lead that most

Fig. 4. Histogram showing the incidence of all electrocardiographic leads demonstrating greater than 1 mm relative ST deviation during peak ischemia and the electrocardiographic lead with maximal ST deviation in all 38 patients with ischemia.



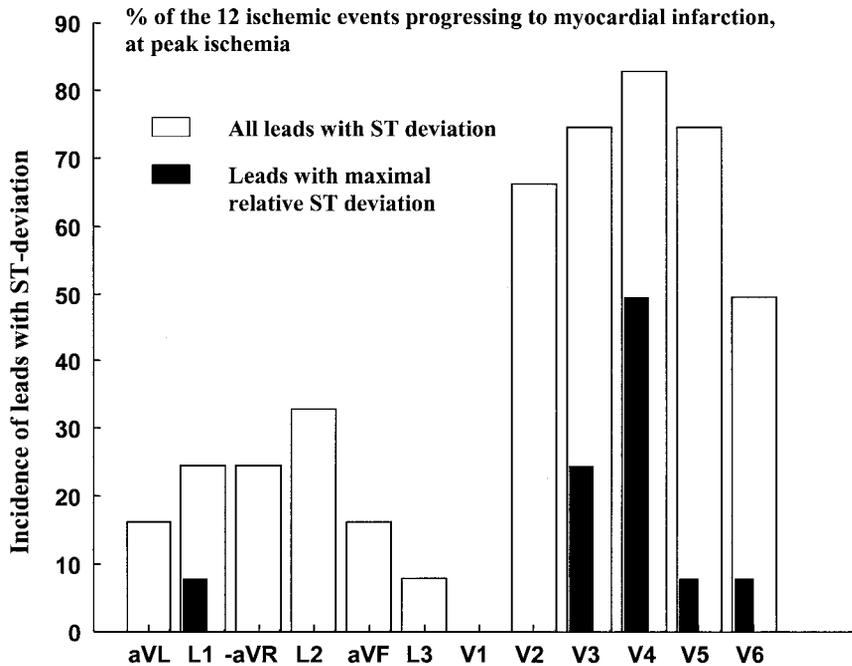


Fig. 5. Histogram showing the incidence of all electrocardiographic leads demonstrating greater than 1 mm relative ST deviation during peak ischemia and the electrocardiographic lead with maximal ST deviation in the 12 patients with myocardial infarction.

frequently demonstrated significant ST deviation (83.3%), followed by V<sub>3</sub> and V<sub>5</sub> (75% each), V<sub>2</sub> (66.7%), and V<sub>6</sub> (50%) (fig. 5;  $P \geq 0.1$  for all comparisons among V<sub>3</sub>, V<sub>4</sub>, and V<sub>5</sub>). Combining leads V<sub>3</sub> and V<sub>5</sub> had a sensitivity of 97.4% for detection of ischemia compared with 92.1% when combining either V<sub>4</sub> with V<sub>5</sub> or V<sub>3</sub> with V<sub>4</sub>. Among the patients in whom myocardial infarction developed, combining leads V<sub>4</sub> and V<sub>5</sub> or leads V<sub>3</sub> and V<sub>5</sub> had a sensitivity of 100%. The combination of V<sub>3</sub> with V<sub>4</sub> was 83.3% sensitive. The sensitivity for detection of ischemia was 94.7% when combining either V<sub>4</sub> or V<sub>3</sub> with all six axial leads and was only 76.3% when combining V<sub>5</sub> with the axial leads. Similarly, the sensitivity for detection of myocardial infarction was 91.7% if either V<sub>3</sub> or V<sub>4</sub> were combined with all axial leads and only 83.3% if V<sub>5</sub> and the axial leads were combined.

#### Correlations and Differences between Leads

Table 3 shows the strong positive correlation among the chest leads and between the chest and the inferior as well as the lateral leads in ST-segment depression during ischemia. Negative correlation in ST deviation occurred between the inferior (L<sub>2</sub>, L<sub>3</sub>, and aVF) and lateral (aVL and L<sub>1</sub>) leads (table 3), probably reflecting reciprocal ST changes. Using the paired *t* test, lead V<sub>4</sub> had significantly greater ST depression than either lead V<sub>5</sub> (by  $-43.5 \pm 74.7 \mu\text{V}$ ,  $P = 0.008$ ) or lead V<sub>6</sub> (by  $-84.3 \pm 98.3 \mu\text{V}$ ,  $P = 0.000$ ). Lead V<sub>5</sub> had deeper ST depression than V<sub>6</sub> (by  $-50.7 \pm 37.0 \mu\text{V}$ ,  $P = 0.000$ ). The ST depressions in leads V<sub>3</sub> and V<sub>4</sub> were not significantly different.

#### Discussion

We have recently shown that prolonged, stress-induced ischemia detected by ST-segment depression on

continuous 12-lead ST monitoring progresses to myocardial infarction, as indicated by an increase in serum troponin concentrations, and is the major cause of cardiac morbidity after major vascular surgery.<sup>5</sup> Moreover, early detection and treatment of silent ischemia on continuous ST-trend monitoring may improve the outcome of these high-risk cardiac patients.<sup>10</sup> Because in current practice perioperative myocardial ischemia is monitored by a limited number of electrocardiographic leads, the choice of the precordial lead has important implications on the detection of perioperative myocardial ischemia and on treatment. The current study differs with and expands on previous studies, in particular the milestone publication by London *et al.*,<sup>2</sup> in the following ways. (1) The current study used continuous on-line 12-lead ST-trend monitoring during both the intraoperative and postoperative periods. (2) The ST-trend analysis and the identification of ischemia were based on the ST-segment deviation from a reference preanesthesia electrocardiogram, not on the absolute ST deviation from the isoelectric P-R level, as was done in most previous studies. This method of ST measurement, with a resolution of  $1 \mu\text{V}$ , is more appropriate for identifying ischemia in patients with preexisting ST-segment and T-wave changes on their resting electrocardiogram.<sup>11</sup> (3) By design, we ignored all ST-segment episodes shorter than 10 min, based on our previous observations that such short-term events ( $< 10$  min) do not correlate with postoperative infarction and cardiac complication. Ten minutes of ST depression was arbitrarily chosen as a cut-off because it is long enough to avoid artifacts and spurious ischemia, but it is short enough not to culminate in myocardial infarction.<sup>4,5</sup> Thus, ignoring short events of ST deviation may have lowered the sensitivity of our ischemia detec-

**Table 3. Correlations and Differences Between Pairs of Electrocardiography Leads\***

	Paired Samples	Correlations		Differences by Paired <i>t</i> Test		
		R (Pearson's)	<i>P</i>	mean ± SD	<i>t</i>	<i>P</i>
Positive Correlation	aVL and L1	0.756	0.000	20.6 ± 40.8	2.579	0.016
	L1 and -aVR	0.434	0.027	-14.0 ± 50.2	-1.424	0.167
	L1 and V5	0.448	0.025	71.1 ± 69.0	5.151	0.000
	L2 and aVF	0.970	0.000	-36.8 ± 21.7	-8.643	0.000
	L2 and L3	0.843	0.000	-67.1 ± 51.2	-6.673	0.000
	L2 and V4	0.648	0.000	122.6 ± 91.1	6.864	0.000
	L2 and V5	0.678	0.000	85.2 ± 62.6	6.808	0.000
	L2 and V6	0.608	0.001	38.3 ± 69.7	2.800	0.010
	aVF and L3	0.937	0.000	-30.3 ± 33.0	-4.682	0.000
	aVF and V4	0.636	0.000	159.5 ± 92.9	8.750	0.000
	aVF and V5	0.584	0.002	120.0 ± 70.1	8.552	0.000
	aVF and V6	0.537	0.005	75.1 ± 77.6	4.938	0.000
	L3 and V4	0.568	0.002	189.8 ± 101.7	9.518	0.000
	L3 and V5	0.436	0.030	148.0 ± 80.4	9.196	0.000
	L3 and V6	0.439	0.025	105.4 ± 88.4	6.080	0.000
	V1 and V2	0.551	0.004	95.5 ± 79.6	6.122	0.000
	V1 and V3	0.418	0.033	169.5 ± 111.8	7.725	0.000
	V2 and V3	0.687	0.000	73.9 ± 89.5	4.210	0.000
	V3 and V4	0.783	0.000	-2.7 ± 79.3	-1.175	0.863
	V4 and V5	0.663	0.000	-43.5 ± 74.7	-2.910	0.008
V4 and V6	0.564	0.003	-84.3 ± 98.3	-4.375	0.000	
V5 and V6	0.879	0.000	-50.7 ± 37.0	-6.851	0.000	
Negative Correlation	aVL and L2	-0.571	0.002	-5.1 ± 132.0	-1.198	0.845
	aVL and aVF	-0.737	0.000	-41.9 ± 141.7	-1.509	0.144
	aVL and L3	-0.858	0.000	-72.2 ± 151.4	-2.432	0.022
	aVL and V4	-0.456	0.019	117.5 ± 157.4	3.808	0.001
	L1 and L3	-0.493	0.011	-92.8 ± 122.3	-3.872	0.001

\* Included in the table are only pairs with statistically significant correlation (either positive or negative).

tion, but it increased the specificity for detecting clinically significant myocardial ischemia. (4) This study for the first time analyzes the sensitivity of each of the 12 electrocardiographic leads for detecting prolonged ischemia associated with postoperative myocardial infarction.

Using multiple methods of analysis, we have repeatedly shown that V<sub>4</sub> rather than V<sub>5</sub> is the most sensitive and appropriate precordial lead for detection of postoperative ischemia and infarction. Lead V<sub>5</sub> is more likely than V<sub>4</sub> to have baseline ST depression, T-wave inversion, or both on the preoperative, resting electrocardiogram and may therefore exhibit deeper absolute ST-segment depression during ischemia. This deeper absolute ST depression in lead V<sub>5</sub> may seem more significant than other leads when examined visually as done by previous investigations. However, by examining the ST-segment trend composed of continuously measured ST-segment deviation from the reference electrocardiogram, leads V<sub>4</sub> and V<sub>3</sub> detected myocardial ischemia earlier, more frequently, and with greater relative ST depression than lead V<sub>5</sub>. This was true also for the subgroup of patients with prolonged ischemia progressing to myocardial infarction.

Previous studies have pointed out the importance of lead V<sub>4</sub> in the detection of stress-induced ischemia. Approximately 75–80% of the diagnostic information on exercise-induced ST-segment depression is contained in

leads V<sub>4</sub> to V<sub>6</sub>.<sup>12</sup> In one study about patients with positive exercise stress testing and perfusion defects on thallium-201 scanning, 86% of diagnostic ST-segment changes occurred in lead V<sub>5</sub>, 84% occurred in V<sub>4</sub>, and 100% occurred in either V<sub>5</sub> or V<sub>4</sub>, regardless of the site of perfusion defects detected by the thallium scanning.<sup>13</sup> London *et al.*<sup>2</sup> showed that lead V<sub>4</sub> was the second most sensitive lead for intraoperative ischemia (61%) after V<sub>5</sub> (75%) and that the combination of V<sub>4</sub> and V<sub>5</sub> provided a sensitivity of 90%. In the current study, using relative ST depression as the measure for ischemia, lead V<sub>4</sub> detected ischemia with a sensitivity of 78.9%, compared with 65.8% for lead V<sub>5</sub>, and V<sub>4</sub> had a sensitivity of 83.3% for detection of prolonged ischemia progressing to myocardial infarction, compared with a sensitivity of 75% for V<sub>5</sub>.

An interesting and important implication of these and previous data are that unlike in ST-elevation-type ischemia, in stress-induced ST-depression-type ischemia, it is impossible to identify the location of ischemia in terms of culprit coronary artery from the leads with ST depression. Li *et al.*<sup>14</sup> have shown that partial occlusion of either the left anterior descending or the circumflex coronary arteries with pacing in a sheep model caused subendocardial ischemia with similar ST-segment depressions on the free wall of the left ventricle as measured by epicardial electrocardiographic mapping. Moreover, ST-depression-type ischemia precipitated by tachycardia and stress is likely to occur in multivessel

coronary artery disease and poor collateral circulation, and it may affect a large portion of the subendocardial area, unlike transmural ischemia caused by an occlusion of a specific coronary artery, which is therefore rather localized. This explains the extensive congruity among the electrocardiographic leads in ST-segment depression during ischemia (table 3). Mainly the axial lateral leads, L<sub>1</sub> and aVL, correlated negatively to the inferior leads, L<sub>2</sub>, L<sub>3</sub>, and aVF, probably representing reciprocal ST changes (table 3).

London *et al.*<sup>2</sup> reported an incidence of 12% of ST-segment elevation, mainly in leads V<sub>2</sub> and L<sub>3</sub>. In our experience, true ST elevation was much less frequent. Some ST-segment elevation was occasionally measured in leads V<sub>1</sub> through V<sub>3</sub> secondary to shortening of the ST interval with high take-off of the T wave during tachycardia. Such up-sloping ST elevation measured on the T wave was usually mild, was not considered as ischemia in the current study, and did not correlate with infarction. Although all myocardial infarctions and the majority of ischemic events in this study were ST-depression type, this does not exclude the possibility of true postoperative ST-elevation-type ischemia and infarction.

Formal exercise stress testing is based on 12-lead electrocardiographic recording, whereas perioperative ischemia is conventionally monitored by only one chest lead (V<sub>5</sub>). Moreover, the majority of electrocardiographic monitors currently in use in the perioperative setting detect and activate their alarm based on the absolute ST deviation from the isoelectric level, not on the relative ST deviation from the reference resting electrocardiogram. The accuracy of such ischemia detection is particularly not optimal in leads V<sub>5</sub> and V<sub>6</sub> with baseline ST depression (figs. 1 and 2 and table 2). The current study corroborates previous studies implying that more than one precordial lead is necessary to achieve a high sensitivity in detecting stress-induced ischemia. Probably, most prudent is to choose among the three precordial leads: V<sub>3</sub>, V<sub>4</sub>, and V<sub>5</sub>, the two leads closest to the isoelectric ST-segment level at the baseline electrocardiogram. In the majority of cases, this is lead V<sub>4</sub> plus either V<sub>3</sub> or V<sub>5</sub>.

We conclude that as a single lead, V<sub>4</sub> discloses ischemia earlier, more frequently, and with a greater relative

ST depression than the conventional V<sub>5</sub>. Therefore, lead V<sub>4</sub> is more sensitive and appropriate than V<sub>5</sub> for the detection of prolonged postoperative ischemia and infarction. In addition, more than one precordial lead is necessary so as to approach a sensitivity greater than 95% in detecting postoperative ischemia and infarction. If only one precordial lead is available, as is the current situation in most places, the electrocardiographic lead with the most isoelectric ST level out of leads V<sub>3</sub>, V<sub>4</sub>, and V<sub>5</sub> on the preoperative electrocardiogram is recommended for monitoring of ischemia. However, more studies may be needed to determine the optimal intraoperative and postoperative leads for a given preoperative electrocardiographic pattern.

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