Incidence of Perioperative Myocardial Ischemia Detected by Different Electrocardiographic Systems

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To determine the extent to which different electrocardiographic systems account for differences in reported incidence of perioperative myocardial ischemia, the authors simultaneously recorded in 109 patients undergoing coronary artery bypass grafting (CABG) the V5 or modified CMS lead on five ECG systems by means of a specially constructed common V5 lead. The systems included a Spacelabs® Alpha 14 Model Series 3200 ECG Cardule at bandwidths of 0.05–125 Hz and 0.5–30 Hz (a typical operating room monitor), a Marquette® Electronics MAC II ECG at 0.05–40 Hz and 0.05–100 Hz (a standard ECG), and a Del Mar® Holter recorder at 0.1–100 Hz. Relative ST-segment position and incidence of new ischemia compared to the preoperative ECG were determined in 109 sets of prein-traction traces and 877 sets of intraoperative traces. ST-segment position on the three recording systems conformed with the American Heart Association (AHA) low-frequency response recommendations (0.05 Hz) were similar. Compared to the standard ECG, ST-segment position on the Spacelabs at 0.5–30 Hz was consistently more negative. Displacement on the Holter was consistently less negative and less positive. By the 0.1-mV displacement criterion for diagnosis of myocardial ischemia on any one ECG system, 16.5% of patients on arrival and 32.1% of patients intraoperatively suffered new myocardial ischemia. Based on the operating room monitor, arrival and intraoperative ischemia were present in 15.6 and 27.5% of patients, respectively. Ischemia at the same periods was less frequent by the standard ECG system (5.5 and 12.9%, respectively) and least frequent by the Holter recorder (4.6 and 8.3%, respectively). If the criterion for ischemia was reduced to the least measurable ST-segment displacement (0.025 mV), the incidence would have been approximately the same with all ECG systems. These data confirm the higher sensitivity of the operating room monitoring systems in diagnosing myocardial ischemia with no apparent loss of specificity. The authors suggest that the criterion of 0.1-mV displacement of the ST segment derived from exercise electrocardiography may be too stringent for perioperative patients with documented coronary artery disease. (Key words: Anesthesia; cardiac; Heart; ischemia; Monitoring; electrocardiography; Holter. Surgery; cardiac; coronary artery bypass grafting.)

IN RECENT STUDIES incorporating a total of 2,974 patients undergoing coronary artery bypass grafting operations (CABG), we observed new myocardial ischemia detected by ST-segment displacement on the ECG in 24.6% of patients on arrival to the operating room and in 32.1% of patients between induction of anesthesia and onset of cardiopulmonary bypass (CPB). Although these frequencies of ischemia were similar to those reported by others in small groups of at-risk patients undergoing CABG or major vascular operations using similar ECG recording systems, they were appreciably higher than in studies employing Holter off-line or systems with continuous on-line ST-segment analysis. Investigators reporting a low incidence of ischemia attributed our higher incidence to inadequate preoperative medication, inappropriate anesthetic management, or misuse of antianginal therapy. In addition, the sensitivity and specificity of our system for detection of ischemia were questioned editorially. We therefore undertook the next logical study by determining the extent to which differences in reported frequency of perioperative ischemia were related to different sensitivities of the systems used to detect ECG ischemia. We studied patients identical to those in our previous studies, except that the V5 ECG was acquired through a common lead that served as simultaneous input to a Spacelabs® (Redmond, WA) Cardule, the operating room monitor used in all our previous studies; a Marquette® (Milwaukee, WI) MAC II ECG recorder, the system used to obtain the standard preoperative 12-lead ECG used as the baseline from which new perioperative ischemia was diagnosed; and a Holter recorder that was used for continuous recording in some studies of perioperative ischemia.

Methods

With hospital Institutional Review Board approval and patient consent, 120 consecutive patients scheduled for elective first-time CABG without additional procedures were selected for study. Patients were excluded only when the preoperative ECG pattern did not permit ST-segment analysis because of dysrhythmia or bundle branch block or when an observer was unavailable. On arrival to the operating room, standard limb leads for a Spacelabs® Alpha 14 Model Series 3200 ECG Cardule and separate

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standard limb leads for a Marquette® Electronics MAC II ECG system were applied to each patient after skin preparation with alcohol. A lead was also placed in the right supraclavicular fossa to serve as the negative terminal for a modified CM5 lead for a Del Mar® (Cincinnati, OH) model 453-A Holter monitor. A specially constructed common lead was placed at the V5 position with output transmitted by three wires of equal impedance into each of the three ECG systems. In this manner, each system received the ECG V5 or modified CM5 signal simultaneously. Silver–silver chloride electrodes were used at all sites.

The Spacelabs® Alpha 14 Cardule has a frequency response bandwidth of 0.5–30 Hz in the “monitoring” mode (SL-MON) and 0.05–125 Hz in the “diagnostic” mode (SL-DIAG). The Marquette® MAC II ECG has a variable frequency response and was used both in the standard 0.05–100 Hz mode (ECG-100) and in the 0.05–40 Hz mode (ECG-40) to simulate the upper range of the Spacelabs® Cardule in the “monitor” mode. Frequency response of the Del Mar® Holter recorder (Holter) is 0.1–100 Hz. All Marquette® and Spacelabs® ECG traces were recorded on paper strips at 25 mm/s speed with a calibrated amplitude signal of 1 mV equal to 1 cm. Holter tapes were replayed through an Avionics® (Cincinnati, OH) processor and then transferred in real-time speed to an identically calibrated strip chart recorder at the same speed (25 mm/s). Each system was synchronized with integrated clocks, and electronic marks were made on the Holter recorder at 10-min intervals to verify the timing correlation of all simultaneous traces. The reliability of the specially constructed three-wire V5 lead in accurately transmitting an ECG signal in the absence of confounding patient variables was confirmed by simulator-generated signals at two different ST-segment positions (0.0 and −2.5 mm) and by heart rates of 60, 90, and 115 beats per min.

Just before induction of anesthesia, the initial ECG trace was recorded for 30 s in each mode, and Holter monitoring was initiated. Thereafter, the ECG was recorded every 5 min until onset of CPB. At each 5-min recording cycle, the two frequency modes of the Spacelabs® and Marquette® ECG were recorded alternately for 15 s each. Holter monitoring was continuous. Each strip was identified for patient, system, mode, and time.

After operation, a copy of the preoperative 12-lead ECG trace recorded the previous day on an identical Marquette® MAC II ECG in the standard mode (0.05–100 Hz bandwidth) was used as the baseline for comparison of V5 R-wave amplitude and ST-segment position with each of the five traces obtained in the operating room before anesthesia. Because of the uncertain relationship between R-wave enhancement and ST-segment displacement, the data of six patients were excluded because measured R-wave amplitude on the initial tracing of at least one system lay outside our preset 90–110% range of the R wave on the preoperative trace. Every strip from each system was then independently visually assessed by two trained technicians and one investigator (S.S.). ST-segment morphology and position in increments of 0.025 mV (0.25 mm) were noted from representative QRS complexes in each strip. Reader disagreements as to ST-segment position by more than 0.25 mm were rare and were always resolved by consensus review. The data of an additional five patients were excluded because of unreadable Holter tracings.

Ischemic episodes were characterized as “arrival” when present before induction of anesthesia and as “intraoperative” when occurring between induction and onset of CPB. Ischemia was diagnosed as ≥1 mm horizontal or down sloping ST-segment depression or ≥1 mm ST-segment elevation at 60 ms after the J point when compared to the position of the ST segment on the V5 lead of the preoperative 12-lead ECG. Intraoperative ischemia was diagnosed when at least 1.0-mm displacement of the ST segment occurred in the absence of arrival ischemia, when ST-segment displacement increased in the same direction by at least 1 mm more than its position on arrival, or when new 1.0-mm ST-segment displacement appeared after partial or complete recovery from arrival ischemia.

Continuous data are presented as mean ± 1 SD. Mean ST-segment displacements for each mode were compared by analysis of variance and paired t tests. Incidence of ischemia by each mode were compared to one another by chi-squared analysis corrected for continuity.

Results

Simulator Data

The three-lead cable used for acquiring the V5 and modified CM5 signals simultaneously transmitted R-wave amplitude accurately to the SL-MON, SL-DIAG, ECG-100, and ECG-40 systems. As expected of a bipolar system, Holter recorded an R wave 30% higher than the simulated wave.21 This R-wave enhancement, however, did not occur in patient recordings probably because of the more lateral displacement of the negative terminal of the unmodified CM5 lead system required by planned median sternotomy.22 At heart rates of 60, 90, and 115 beats per min, isoelectric ST segments were faithfully recorded by the SL-DIAG, ECG-100, and ECG-40. The SL-MON and Holter traces displayed up to 0.25 mm ST-segment depression at all heart rates. At a simulated horizontal ST-segment displacement of −2.5 mm, all systems recorded a horizontal displacement within 10–15% of the signal.
### Table 1. ST Segment Position Relative to Preoperative ECG on Each of Five Simultaneously Recorded ECGs

<table>
<thead>
<tr>
<th>System</th>
<th>ST Segment Position (mm)</th>
<th>ST Segment Position (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arrival (n = 109)</td>
<td>Intraoperative (n = 877)</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>ECG-100</td>
<td>+0.047 ± 0.47</td>
<td>+2.75 to -1.25</td>
</tr>
<tr>
<td>SL-MON</td>
<td>-0.156 ± 0.68*</td>
<td>+3.00 to -2.25</td>
</tr>
<tr>
<td>Holter</td>
<td>+0.005 ± 0.44</td>
<td>+1.75 to -1.75</td>
</tr>
<tr>
<td>SL-DIAG</td>
<td>+0.048 ± 0.55</td>
<td>+2.75 to -2.25</td>
</tr>
<tr>
<td>ECG-40</td>
<td>+0.042 ± 0.50</td>
<td>+2.75 to -1.50</td>
</tr>
</tbody>
</table>

1 mm = 0.1 mV.

* P < 0.05 compared to ECG-100.

## Comparison of Patient Data

Technically adequate simultaneous sets of tracings from all systems in which the R-wave amplitude criterion was met were obtained from 109 patients and provided 109 sets of arrival tracings and 877 sets of intraoperative tracings. Only 7 of 109 sets of arrival traces and 77 of 877 sets of intraoperative traces were identical to the baseline ECG trace on all five systems. In all other sets of traces, ST displacement of at least 0.25 mm occurred in at least one ECG system, and in 98% of these, displacement was in the same direction on all systems. When displacement in the opposite direction occurred within sets, the inconsistent displacement was never more than 0.25 mm. On arrival, mean ST-segment position of the ECG-100 relative to baseline obtained preoperatively by an identical system was +0.047 ± 0.47 mm. Mean ST-segment positions for the SL-DIAG and ECG-40 were similar, whereas ST-segment positions were more negative on the SL-MON and Holter recordings (table 1). In the 877 sets of intraoperative tracings, the same hierarchy appeared. Mean displacement on the SL-DIAG and ECG-40 systems were within 0.05 mm of the ECG-100, whereas traces of the SL-MON and Holter were significantly more negative (table 1). Since more than two-thirds of all displacements ranged from 0–0.25 mm, with the remainder ranging from ±0.5–±3.25 mm, standard deviations were mathematically large relative to their respective means that were close to zero.

To determine if differences among ECG systems were related to degree of ST-segment displacement, sets of traces were grouped according to displacement on the ECG-100 in 0.25-mm increments ranging from -2.0 to +1.0 mm. Corresponding mean displacements on the other four systems were calculated. As both positive and negative ST-segment displacement on the ECG-100 increased from zero, the SL-MON ST-segment position was consistently more negative independent of displacement direction, whereas the Holter was less negative for negative deflections and less positive for positive deflections (fig. 1). Displacements of the SL-DIAG and ECG-40 were so similar to ECG 100 that they were not included. Representative traces of large displacements are shown in figure 2.

## Diagnosis of Myocardial Ischemia

Using the 1-mm displacement criterion in any one of the five systems, 18 (16.5%) of 109 patients had myocardial ischemia on arrival and 34 (31.2%) patients had myocardial ischemia at some time during anesthesia. Repeated episodes of intraoperative ischemia in the same patient were considered a single ischemic event in calculating this incidence. Four of 18 patients with arrival ischemia and 8 of 34 with intraoperative ischemia had ST-segment elevation rather then depression. In all patients with ischemia, ST segments were displaced in the same direction on all five systems. In subsequent analysis of myocardial ischemia, the direction of ST-segment displacement was therefore ignored.

Myocardial ischemia was most frequently diagnosed by the SL-MON (table 2). In only 1 of 18 patients on arrival...
and 4 of 34 patients intraoperatively was myocardial ischemia not present on SL-MON when present on one other system. The 1 patient with arrival ischemia was diagnosed on all systems other than SL-MON and Holter. The 4 patients with intraoperative ischemia were diagnosed on the ECG-100 and Holter, SL-DIAG, ECG-40, and ECG-100 and SL-DIAG but not on the other systems. In 16 of 18 patients with arrival ischemia and 28 of 34 patients with intraoperative ischemia, all five systems displayed displacements greater than 0.25 mm at the time myocardial ischemia was present on one system. Conversely, in 2 of 18 patients on arrival and 6 of 34 intraoperatively, at least one system displayed no displacement at all when one other system diagnosed myocardial ischemia. Depending on the system used and requiring the ≥1 mm criterion, ischemia would have been diagnosed on arrival in 4.6–15.6% of patients and intraoperatively in 8.5–27.5% of patients (table 2). If displacement greater than 0.25 mm rather than 1 mm had been considered as the criterion for myocardial ischemia, this diagnosis would have been made with approximately equal frequency by all the ECG systems (table 2). The mean ST-segment displacement demonstrated by each system at the time myocardial ischemia was present on one system was calculated for arrival ischemia (fig. 3) and intraoperative ischemia (fig. 4). Both show a larger mean displacement by SL-MON; similar displacements by ECG-100, ECG-40, and SL-DIAG; and least displacement by the Holter monitor.

Discussion

CHARACTERISTICS OF ECG SYSTEMS

The American Heart Association (AHA) recommendations for ECG recording require a flat-frequency response at a bandwidth of 0.05–100 Hz.23 This high-frequency limit permits traces of sufficient fidelity to evaluate QRS morphology and accurately interpret rapid rhythms such as atrial flutter.24 The low-frequency limit permits accurate reproduction of slower events such as P- and T-wave morphology and ST-segment excursion.24 Frequency response limits and the filters of any ECG system are selectable. Systems used in operating rooms and intensive care units usually have a narrower bandwidth to provide interpretable traces in the noisier clinical setting by filtering out extraneous signals that might interfere with diagnosis. Attenuation of the high-frequency input reduces distortion from muscle movement, 60-Hz electrical current, and electromagnetic interference from other electrical equipment.24 Attenuation of the low-frequency input provides a more stable baseline by reducing respiratory and body movement artifacts and those from poor electrode contact.24 The low-frequency limit of an electrocardiographic system is therefore the characteristic that primarily affects ST-segment excursion.

Using patient-generated, processed ECG signals, Benson and Pipberger demonstrated that increasing low-frequency cutoff from 0.05–0.5 Hz at 6 dB per octave rolloff introduced at least 1 mm of erroneous ST-segment depression in 3 of 25 ECG systems at 60 ms beyond the
Table 2. ST Segment Displacement Recorded Simultaneously by Five ECG Systems in Patients with Perioperative Myocardial Ischemia

<table>
<thead>
<tr>
<th>Recording System</th>
<th>ECG-100</th>
<th>SL-MON</th>
<th>Holter</th>
<th>SL-DIAG</th>
<th>ECG-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival Ischemia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST segment displacement ≥1.0 mm</td>
<td>6</td>
<td>17*</td>
<td>5</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Patients with ischemia†</td>
<td>5.5%</td>
<td>15.6%</td>
<td>4.6%</td>
<td>10.1%</td>
<td>6.4%</td>
</tr>
<tr>
<td>ST segment displacement 0.25–0.75 mm</td>
<td>12</td>
<td>1*</td>
<td>12</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>All displacement</td>
<td>18</td>
<td>18</td>
<td>17</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Intraoperative Ischemia‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST segment displacement ≥1.0 mm</td>
<td>14</td>
<td>30*</td>
<td>9</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Patients with ischemia†</td>
<td>12.8%</td>
<td>27.5%</td>
<td>8.3%</td>
<td>13.8%</td>
<td>13.8%</td>
</tr>
<tr>
<td>ST segment displacement 0.25–0.75 mm</td>
<td>15</td>
<td>4*</td>
<td>19</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>All displacement</td>
<td>29</td>
<td>34</td>
<td>28</td>
<td>31</td>
<td>50</td>
</tr>
</tbody>
</table>

1 mm = 0.1 mV. Data are shown as number of patients. * P < 0.05 versus ECG-100. †≥1.0-mm ST horizontal or down-sloping segment shift from preoperative baseline 60 ms after the J point on at least one ECG system. ‡ Repeated episodes of intraoperative ischemia were considered a single ischemic event.

J point. They attributed these artifacts to the slower recovery of the ST-segment position in systems with greater low-frequency filtering, which magnified ST-segment depression closer to the J point. Berson and Piberger's data suggest that ST-segment reproduction by our 3 systems with the recommended 0.05-Hz cutoff would be similar regardless of their high-frequency filtering and that the Holter (0.1-Hz cutoff) and SL-MON (0.5-Hz cutoff) would produce more ST-segment depression. Bazaral et al. also suggest greater recorded ST-segment excursion with a bipolar system typically used with a Holter recorder as compared to a standard ECG unipolar system. The similar incidence of diagnosed ischemia by all three monitors with similar low-frequency filters was observed (table 2). In addition, simultaneous comparison of the Spacelabs Cardux at two different lower edge frequencies (0.5 and 0.05 Hz) revealed a 50–100% increase in diagnosed myocardial ischemia with increased low-frequency filtration. In our data, however, the Holter did not follow predictions and recorded even less ST-segment excursion than systems with 0.05-Hz cutoffs.

The unreliability of ambulatory recording systems has been described previously and has been attributed to phase shift. Since the complex ECG signal is actually the sum of many simpler signals (all sine waves of different frequencies), phase shift at lower frequencies will alter the temporal relationships of the component sine waves and generate an inaccurate ECG complex. When peaks and troughs of the low-frequency sine waves are added

Fig. 3. Mean ST segment excursion on each ECG system for 18 patients with new myocardial ischemia on arrival to the operating room and diagnosed by at least 1.0-mm ST segment displacement from preoperative ECG on at least one of the five ECG systems. Direction of displacement was ignored in calculating means.

Fig. 4. Mean ST segment excursion on each ECG system for 34 patients with new intraoperative myocardial ischemia diagnosed by at least 1.0-mm ST segment displacement from preoperative ECG on at least one of the five ECG systems. Direction of displacement was ignored in calculating means.
to the PQRST signal asynchronously, the position of the
ST segment will be altered accordingly.\textsuperscript{26} Phase shift is
reported with all ECG systems but is a particularly com-
mon problem in systems designed for ambulatory ECG
monitoring\textsuperscript{26} because of the two-fold risk of introducing
it during recording and again at playback.\textsuperscript{27} While not
interfering with dysrhythmia diagnosis, phase shift could
account for unpredictably altered sensitivity of the Holter
when used for ischemia detection.\textsuperscript{26,27}

Although the effects of low-frequency filtration and
phase shift can be reproducibly demonstrated in the lab-
atory with signals from a periodic wave generator,\textsuperscript{27} their
effect in the clinical perioperative setting is variable
and unpredictable. In the same recording system, an iso-
electric ST segment can be displaced in either direction
in the same patient at different times depending on factors
such as heart rate, patient movement or position, electrode
resistance, and other electronic equipment attached to
the patient, any of which may alter the frequency com-
oponents that make up the ECG signal.\textsuperscript{25-27} Shook \textit{et al.}\textsuperscript{28}
showed that the newer AM and FM ambulatory recorders
with lower edge flat-frequency responses at 0.05 Hz or
less will faithfully reproduce ST-segment excursion when
compared to a standard ECG during exercise testing. This
fidelity, however, has not been confirmed in the elec-
tronically noisy environment of the operating room. Rec-
ognizing all these problems, new recommendations for
continuous ECG monitoring systems in operating rooms
and other acute care settings have been proposed.\textsuperscript{29} The
proposers, however, also recognize that implementation
of all their proposals could make "the monitor useless in
many instances."\textsuperscript{29}

\textbf{Reported Incidence of Perioperative
Myocardial Ischemia}

In recent published studies of the incidence of myo-
cardial ischemia during operation in patients with ischemic
heart disease, ECG system bandwidths are almost never
reported. Nevertheless, if the frequency of ischemia
diagnosed by the prevailing ECG criteria are pooled by the
ECG system used, three groups can be characterized.
Based on our best estimate from the cited papers and in
the absence of reported bandwidths or recorder char-
eteristics, these groups include intraoperative recording
from (group 1) monitoring systems designed for operating
room use similar to our Spacelabs Cardule,\textsuperscript{5-10} (group 2)
a system similar to the standard ECG,\textsuperscript{50-52} and (group 3)
Holter-type monitors in which ST-segment excursion was
read visually off-line as done here,\textsuperscript{11-15} computer analyzed
off-line,\textsuperscript{14-17} and computer analyzed on-line in real
time.\textsuperscript{18}\$ There is a decreasing incidence of reported
intraoperative ischemia in each group: group 1, 51.4\% of
303 patients; group 2, 20.7\% of 184 patients; and group
3, 15.0\% of 800 patients. Group 3 clearly represents a
heterogeneous set of systems with regard to frequency
bandwidths, potential for phase shift, and method of ST
segment analysis. Not surprisingly, the range of reported
ischemia in this last group was wide (8.1\%-50\%).\textsuperscript{15} Addi-
tionally, the two studies using real-time automated ST-
segment analyzers reported widely different incidences
(8.1\% and 35\%).\textsuperscript{18} If these patients had been excluded
from group 5, the Holter-type ambulatory devices would
have recorded a 17.9\% incidence in 536 patients. These
pooled data reveal the same hierarchy of ischemia detec-
tion by ECG systems that appeared in our data (fig. 5).
Too few published data are available to permit a similar
comparison of arrival ischemia.

\textbf{Criterion for ECG Diagnosis
of Myocardial Ischemia}

Regardless of the ECG system, all reported studies of
perioperative ischemia used diagnostic criteria for isch-
emia that were essentially the same as we employed, \( \geq 1 \)
nm ST-segment displacement at 60 ms after the J point.
This criterion for myocardial ischemia originated from
the AHA standard for exercise electrocardiography that
requires \( \geq 0.1 \) mV ST-segment displacement with specific
morphology at near-maximal exercise for diagnosis of
ischemic heart disease. This standard was designed to en-
sure adequate specificity by maintaining false-positives at

![FIG. 5. Pooled published data on the frequency of intraoperative
myocardial ischemia in patients with ischemic heart disease\textsuperscript{5,8,9,10,11-13} grouped according to ECG system used for diagnosis. The incidence
of ischemia in 2,974 patients described in our previous reports\textsuperscript{14} using
SL-MON is represented by the horizontal hatched line at 32.1\%. Published
data and data from the 100 patients reported here (current
study) indicate lower frequencies of diagnosed ischemia with a standard
ECG apparatus and lowest frequencies with Holter or ST analyzer
less than 10%. Ascoop et al., however, demonstrated that reducing the diagnostic criterion for ischemic heart disease from 0.1–0.035 mV displacement during exercise electrocardiography doubles the sensitivity without decreasing specificity as confirmed by coronary angiography. The sensitivity and specificity of the 0.1-mV criterion for ischemia in perioperative CABG patients who are resting or anesthetized have not been investigated. Although ischemia in perioperative patients diagnosed by the exercise criterion varied according to the ECG system used, there was essentially complete agreement in incidence if ST-segment displacements of 0.025 mV or more were included among the “positives” (table 2).

Others have cautioned against using monitoring equipment with less than recommended frequency bandwidths for this purpose to prevent artifactual ischemia. Despite this, we found that the ECG changes described in our previous reports using the SL-MON system with its narrower bandwidth were not artifactual in that observed ischemia behaved exactly like myocardial ischemia diagnosed outside the operating room by systems using recommended bandwidths. Ischemia observed in our studies appeared in patients with ischemic heart disease with a frequency directly related to heart rate, improved by treatment with propranolol and nitroglycerin, and was a significant independent predictor of postoperative myocardial infarction. Most importantly, however, the magnitude of ST-segment depression was directly related to the frequency of postoperative infarction. To this extent, the ST-segment displacements we observed were highly specific and not artifactual in this highly selected population.

Compared to an ECG system with AHA recommended bandwidth and using the AHA exercise criteria for diagnosis, most operating room monitors probably overestimate and, at least, the older Holter types used in this and many other reports underestimate the incidence of perioperative ischemia. Regarding this incidence, it is relevant that investigators using wall motion abnormalities diagnosed by echocardiography and cardiokymography as the criterion for intraoperative myocardial ischemia have reported an incidence of 48–74% during vascular operations in patients with documented coronary artery disease (CAD). This incidence was two to four times higher than that diagnosed by ECG in these same patients. Although it is now no longer believed that all intraoperative wall motion abnormalities result from ischemia, these reported observations are the basis of the common belief that the ECG, while highly specific, is relatively insensitive for the diagnosis of ischemia. This insensitivity, however, may be largely attributable to the use of the 0.1-mV criterion. For example, in our data, if 0.025-mV rather than 0.1-mV displacement were used as the criterion, intraoperative myocardial ischemia would have been diagnosed in 66–87% of all 109 patients depending on the ECG recording system, an incidence in the same range as wall motion abnormalities once considered diagnostically of intraoperative ischemia. We speculate that ECG displacement greater than 0.025 mV but less than 0.1 mV as the minimal criterion might be just as sensitive as wall motion abnormalities in detecting myocardial ischemia in patients with known CAD. However, the specificity of such high-frequency events detected either by ECG or wall motion abnormalities is as yet undetermined and requires a correlation with other measures of ischemia and clinical outcome.

Conclusions

If the AHA criterion for diagnosis of ischemic heart disease by exercise electrocardiography is required for the diagnosis of perioperative ischemia, the Spacelabs’ Alpha 14 ECG Cardule in the “monitor” mode and possibly all similar monitoring systems probably overestimate, and some Holter-type systems underestimate, the incidence of ischemia compared to systems with AHA recommended lower frequency cutoffs. However, the increased incidence observed on operating room monitors is not artifactual since specificity of the observation remains high as demonstrated in our previous studies in patients with documented CAD. We therefore believe that if ischemia detection is important to patient care, ECG systems that make it more rather than less detectable are appropriate for patients with known CAD in the perioperative setting. Furthermore, because the specificity of this magnified incidence of ischemia remains high, the original rationale for increased filtering in the electrically noisy operating room environment continues to apply. These observations also imply that when ECG monitoring systems with greater than 0.05-Hz low-frequency filtration are used in populations not known to have ischemic heart disease, observations of ST-segment displacement of even 1 mm must be interpreted cautiously.

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