The utilization of automated ST segment analysis in the determination of myocardial ischemia

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Perioperative cardiac morbidity is a recognized complication of anesthesia and surgery. Morbidity includes myocardial infarction, new onset of unstable angina, congestive heart failure, and arrhythmias. Almost one third of all patients undergoing noncardiac surgery may be at increased risk of cardiac complications by virtue of age, coronary artery disease (CAD), or presence of two or more risk factors for CAD. Although postoperative ischemia has been identified as a significant risk factor for morbidity, automated ST segment analysis systems available with the new generation bedside monitors have not been used to identify ischemic episodes in patients recovering from anesthesia.

Twenty-eight patients, age 41 to 80 years, were monitored in the postanesthesia care unit for ST segment changes (mean monitoring period, 97 minutes). Four patients had ischemic episodes from 7 to 44 minutes, and two of these patients had subsequent postoperative morbidity. All episodes were clinically silent. Automated ST segment analysis is an easily used technology that shows promise as a means of early detection of clinically silent perioperative myocardial ischemia.

Key words: Electrocardiography, myocardial ischemia, physiologic monitoring.

Introduction
Recent research has implicated postoperative ischemia as a significant indicator for perioperative cardiac morbidity. Mangano et al found that in a group of 474 men (243 with coronary artery disease and 231 with at least two risk factors for coronary artery disease), 41% had ischemia during the postoperative period. The group with postoperative ischemia had the largest risk of morbidity, and this was the only factor that was independently associated with an adverse cardiac event. Of further concern to the anesthesia provider is the fact that many episodes of ischemia may be clinically silent, which is to say without the patient experiencing chest discomfort. Ouyang et al found the highest incidence of silent ischemia in the early postoperative period, and this ischemia was associated with adverse cardiac events. Perhaps not surprisingly, Landesberg et al found that silent ischemia that persisted more than 2 hours was associated with adverse cardiac events in patients undergoing peripheral vascular surgery. There was a 21-fold increase in the risk of perioperative cardiac morbidity in patients with postoperative ischemia of cumulative duration more than 2 hours. Similarly, Raby et al found a 16-fold increase in the risk of adverse cardiac outcome in the presence of postoperative ischemia. It has been hypothesized that increased sympathetic stimulation from pain or emergence from anesthesia could be a causal factor for postoperative ischemia, but this has yet to be proven.

Despite existing literature identifying postoperative ischemia as a problem, the question remains, "How does one translate this information
into clinical practice?" Hollenberg et al identified preoperative factors that were present in patients in whom postoperative myocardial ischemia developed, suggesting these factors could be used as predictors. However, this method of using an indicator to predict postoperative ischemia, which subsequently predicts perioperative morbidity, may be subject to amplified error from false-positive findings at each step. One potential solution to this problem is continuous monitoring of at-risk patients for postoperative ischemia using automated ST segment analysis software. This software may already be in place on many cardiac monitors, thus requiring no additional machinery. Clearly, the advantage of this technology is that it allows a real-time assessment of ST segment changes that can be easily assessed by the clinician. Moreover, it does not require additional lead placement. Krucoff et al found no significant difference in the degree of ST segment deviation noted between traditional limb lead placement and the more common torso placements used in clinical practice. Little work has been done in the perioperative area using this equipment; however, in coronary care units, it has been found to be a useful technology in detecting early reocclusion after percutaneous transluminal coronary angioplasty.

One problem with ST segment analysis software is the limited number of comparative studies with accepted ischemia standards. Ellis et al found that there were disparities between differing ST segment analysis systems, printed multilead electrocardiogram (ECG), and transesophageal echocardiography (TEE). Similarly, Slogoff et al reported differences between ST segment analysis systems and Holter monitoring, suggesting that this was due to filtering differences. This would cause Holter monitors to give a consistently lower degree of deviation than ST segment analyzers, which the authors found to be true in a small study of patients who had undergone coronary artery bypass surgery. Nevertheless, others found that TEE and 12-lead ECGs were predictive of perioperative cardiac morbidity, but did not improve the predictive value significantly over the 2-lead 3-electrode configuration along with preoperative clinical risk factors. Indeed, if the postoperative period is the most critical time for detecting ischemia, it would seem logical that TEE offers little advantage because it is confined to intraoperative use. There are currently no large scale outcome studies using ST segment analysis software.

This study was an initial attempt to assess the utility of ST segment technology in the early postoperative period for patients undergoing vascular, abdominal, or thoracic surgery. Patients undergoing nonemergent surgical procedures were studied to avoid including those with traumatic injuries associated with massive blood transfusions and fluid shifts.

**Materials and methods**

A one-group repeated measures design was used to assess the incidence of ST segment changes in a convenience sample of postoperative adult surgical patients between May and July 1995. Eligible patients were 40 years of age or older, had undergone nonemergent thoracic, abdominal, or vascular surgery, and a preoperative 12-lead ECG had been performed. Pregnant or immediate (less than 2 weeks) postpartum patients and those with ventricular pacemakers were excluded. Because patients undergoing vascular, thoracic, and abdominal surgery are considered at higher risk for cardiac morbidity, these patients were chosen to be studied. Because earlier work has not shown the type of anesthetic agent to have a significant effect on cardiac outcome, type of anesthesia was at the discretion of the provider.

All ST segment analysis was performed automatically by the bedside monitor (Marquette Tramscope 12C, Marquette Electronics Inc., Milwaukee, Wisconsin). The Marquette system uses 2 points in the measurement of ST deviation: the isoelectric (I) point is obtained from the PR segment, then deviation is measured at the J point + 60 milliseconds. For the purposes of this study, an ischemic event was defined as an ST segment change of 1 mm or greater lasting for at least 60 seconds.

With a 5-electrode configuration, 3-lead ST analysis is possible with the Marquette system at any one time. Lead I was chosen to detect ischemia of the anterior wall, and lead II to detect inferior wall ischemia. Only one precordial lead could be monitored with the configuration available, and V5 was chosen. Several researchers have found the anterior precordial leads V3 or V4 to be most effective in detecting ischemia due to coronary artery occlusion. However, in the surgical population, the more likely cause of ischemia is increased myocardial oxygen demand that exceeds supply, leading to subendocardial ischemia. London et al found V5 to be the best lead for detecting ischemia intraoperatively, which may reflect the position of his lead directly over the apex of the left ventricle.

A printout of a baseline QRS complex with ST segment analysis was obtained on arrival in the postanesthesia care unit (PACU) for all patients. Using a full disclosure monitor (Marquette Multi-parameter Arrhythmia Review Station [MARS],
Unity Monitor, Marquette Electronics Inc., a full review of each patient's ECG for the duration of their PACU stay was performed to verify the cardiac rhythm of the patient at the time that ST deviation was noted by the bedside monitor. Thus, it could be ascertained whether the ST segment deviation recorded by the bedside monitor was due to artifact, dysrhythmia, or baseline errors. The MARS Unity Monitor also allowed for validation of graphic printouts of the baseline ST segment that were not witnessed. However, no ST segment analysis was performed by the MARS monitor.

A convenience sample of 28 patients was enrolled after approval by the hospital and university institutional review boards. Nurses in the PACU were oriented to the study and taught how to place leads according to a standard protocol. While ST segment monitoring was part of the standard bedside monitoring capabilities, ordinarily it was not in use by the PACU staff.

Written informed consent was obtained from each subject in the study. Anesthetic technique was at the discretion of the provider, and the study period commenced when the patient arrived in the PACU. At this time, patients were monitored with a 5-electrode configuration ECG instead of the usual 3-electrode version for the duration of their stay in the PACU.

Lead placement was according to a standardized protocol. Upper extremity leads were placed at the level of the shoulder on each side; lower extremity leads were placed at the level of the iliac crest anteriorly on each side. The chest lead was placed in the V5 position (anterior axillary line, in a horizontal plane with lead V4).

During the time spent in the PACU, each patient had continuous heart rate, oximetry, and ST segment analysis monitoring. Nursing staff recorded vital signs at usual intervals on the nursing record, but this charted information was not used for the study. Instead, on discharge from the PACU, a graphic printout of heart rate, oximetry, and ST segment deviation for leads I, II, and V5 throughout the PACU stay was obtained from the bedside monitor and placed in a box for later review. The presence of chest pain, postoperative pain, or both and the treatment for pain were recorded by nursing staff according to usual charting protocols. At the close of the study, each chart was reviewed for postoperative morbidity, preoperative cardiac disease, risk factors (diabetes mellitus, hypertension, smoking, or hypercholesterolemia), and the presence of pain while the patient was in the PACU.

Results

Twenty-eight subjects were included in the study, with an age range of 41 to 80 years (mean ± standard deviation, 57.8 ± 10.7 years). The research took place at a county hospital facility with a predominantly Hispanic but mixed ethnic population, and the sample characteristics reflected this (Table I).

Most patients (24) received a general anesthetic for their surgery, three patients received a subarachnoid block, and the remaining patient received an epidural anesthetic. Three patients were previously given the diagnosis of CAD, and three further patients had two or more risk factors for CAD. Two patients had known cardiac disease although not necessarily CAD. One had been admitted with supraventricular tachycardia that required cardioversion and was currently receiving digoxin. The other had renal disease with a history of congestive heart failure.

The total amount of monitored time for all patients was 2,727 minutes (mean ± standard deviation, 97 ± 33.9 minutes), and four patients exhibited ischemic events (ST segment changes of more than 1 mm from baseline (Table II)). Ischemic events ranged in length from 7 to 44 minutes. Three of the four patients with ischemic changes revealed them in only one lead (two in lead V5, one in lead II). The other subject had changes in two leads (II and V5). There was an equal incidence of depression and elevation.

Three of the four patients who had ST changes

| Table I |
| Sample characteristics |
| Gender | Female 20 | Male 8 |
| Age (years) | 57.8 ± 10.7 |
| Ethnicity | Hispanic 17 | African-American 5 | Caucasian 2 | Asian 2 | Not recorded* 2 |
| Risk factors for morbidity | Documented coronary artery disease (CAD) or cardiac disease 5 | Two or more risk factors for CAD 3 | Less than two risk factors for CAD 20 |
| Type of surgery | Abdominal 22 | Vascular 5 | Thoracic 1 |

*Data obtained from chart review; some charts incomplete.
had cardiac disorders, and the other was a smoker with a history of peripheral vascular disease. An association between preoperative cardiac disease, or predisposition to CAD, and ischemic events postoperatively was observed but it was not statistically significant (Table III).

All episodes of ST change were silent; that is, patients did not report chest pain. One patient (TP) experienced pain, but it was incisional pain from the surgical site (Figure 1 shows the ECG changes seen in this patient). There was an average heart rate increase of 10 beats per minute observed from the pre-ischemic to the intra-ischemic period (Table IV). The difference approached statistical significance ($P = .113$). There was no significant difference in pulse oximetry readings before, during, and after ischemic events.

During the study, the nurses could see the ST segment deviation data displayed on the monitor and were free to use these data if they chose. However, no patient received any treatment as a result of witnessed ST segment changes.

There were two episodes of cardiac morbidity in the sample, and both patients had experienced ischemic events in the immediate postoperative period. In one case (patient JA, see Table II), the patient experienced chest pain on the second postoperative day, which resolved with administration of nitroglycerin and oxygen. Another patient (TP, see Table II) had mild congestive heart failure, evidenced by rales bilaterally, that resolved with conservative treatment (fluid restriction). Samples for cardiac enzymes were not drawn postoperatively from either patient.

| Table III |
| Association between ischemic events and cardiac history |

<table>
<thead>
<tr>
<th>Cardiac history/ risk factors</th>
<th>No ischemic changes</th>
<th>Ischemic changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cardiac disease and less than 2 risk factors</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Cardiac disease or 2 or more risk factors</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Fishers exact test, 2 tail, $P = .058$.

Discussion

Results from this exploratory study suggest that patients with cardiac disease or two or more risk factors for CAD show an increased incidence of ST changes during the immediate postoperative period. This confirms earlier work in predominantly male populations that has shown a high incidence of ST changes during the postoperative period in patients at risk. Furthermore, the incidence seen in this small study (38%) is comparable to that seen in a much larger group in which a 41% incidence of postoperative ischemia was found in patients at risk. Other research has also found an

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incidence of 30% to 63% of postoperative ischemia.\(^5\) Although it cannot be ascertained that the 1-mm change seen on the automated ST segment analysis system is equivalent to "gold standard" ischemia monitoring such as Holter or 12-lead monitoring used in other studies, the occurrence and similar incidence in this high-risk population, as well as two episodes of cardiac morbidity, suggest the change has some validity. Unfortunately, because cardiac isoenzymes or serial ECGs were not performed postoperatively for any of the patients, the true incidence of subendocardial or silent infarction in this study cannot be assessed and may be higher than that identified by chart review.

The apparent change in heart rate from before to during an ischemic event is also of interest, although it was not found to be statistically significant. (This may be a reflection of the small sample.) A 10-beat change in heart rate could be enough to cause a clinically significant increase in myocardial oxygen consumption that cannot be compensated for. However, the unchanged postischemic heart rate suggests that this alone may not be the cause of ischemia. Further work is needed to elucidate the relationship between heart rate and ischemia during the postoperative period.

One potential problem concerns placement of the precordial lead. Because all PACU nurses were involved in the study, there is the potential for variability between nurses' practices that could contribute to error in the degree of ST segment deviation seen. (To control for this potential threat, all nurses were taught how to place the V5 lead prior to commencement of the study.) In addition, patient movement from supine to lateral could cause
alterations in the degree of ST segment deviation. However, informal observation suggests that most patients remained supine during the immediate recovery period. In addition, data from the MARS monitor did not show large amounts of artifact that might be associated with patient movement.

It should also be remembered that because a 12-lead study has not been performed in the postoperative period, it is possible that V5 is not the most sensitive lead for ST segment analysis. However, the predominant presence of changes in V5 compared with leads I and II suggests that it is a useful lead for this population. In future research, a definitive 12-lead ECG study is required to confirm the usefulness of this particular precordial lead.

The major significance of this study is that these changes were identified with automated ST segment analysis technology that has not been used previously for this population. Furthermore, all of these changes were silent and would not have been detected by nursing staff in the absence of ST segment analysis. The absence of chest pain or other cardiac symptoms such as dysrhythmias suggests that automated ST segment analysis may be able to serve as an early warning of myocardial ischemia. While other methods may be used to detect these changes, the potential advantages of this technology over Holter or continuous 12-lead ECG monitoring are numerous, owing to its ease of application by PACU personnel, straightforward interpretation, and minimal capital costs because it is present on many current bedside monitoring systems. If automated ST segment analysis systems could be used to identify patients at high risk of morbidity, this information could be used to help define which patients should be followed up more closely postoperatively or treated pharmacologically to prevent morbidity and mortality.

Whether treatment of patients proven to be susceptible to perioperative cardiac morbidity would be efficacious in preventing the occurrence of postoperative morbidity remains to be seen. Further long-term and larger studies are required in this area to ascertain the incidence of ST changes, the nature or extent of change that should be considered significant, and the effectiveness of treatment in preventing morbidity for these patients.

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AUTHORS
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