We have studied myocardial ischaemia, heart rate and arrhythmia in 82 patients undergoing elective thoracotomy. Myocardial ischaemia was detected using a microprocessor-based surveillance system programmed to record leads V2 and V5. Patients were monitored on the day before and for up to 72 h after surgery. The total monitoring time was 5158 h. The incidence of silent myocardial ischaemia before operation was 11% (nine of 82). This increased to 24% (20 of 82) after operation. Postoperative myocardial ischaemia was associated with preoperative myocardial ischaemia in six patients. Before operation, the mean duration of myocardial ischaemia was 0.31 min per hour of monitoring. After operation, this increased to 1.36 min per hour of monitoring (P<0.05). For the whole population, mean heart rate before operation was 74 beat min⁻¹ and increased to 84 beat min⁻¹ after operation (P<0.01). Patients with ischaemia had a mean heart rate of 92.8 beat min⁻¹ after operation compared with those with no ischaemia whose mean heart rate was unchanged at 81.8 beat min⁻¹ (P<0.05). The incidence of atrial tachyarrhythmia increased from one patient before operation to 12 patients after operation (P<0.01). Atrial tachyarrhythmia was not associated with postoperative myocardial ischaemia. Nine patients had an adverse operative outcome; two had non-fatal myocardial infarction and seven died. Postoperative myocardial ischaemia was associated with adverse outcomes (P<0.05).

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It is recognized that patients with decreased cardiac reserve are prone to more perioperative mortality and morbidity. One factor that can be monitored in the perioperative period is myocardial ischaemia. It has been shown that the presence of pre- and postoperative myocardial ischaemia in high-risk surgical populations is associated with an adverse cardiac outcome. It has been proposed that detection and treatment of perioperative ischaemia may reduce postoperative cardiac morbidity.

Studies of perioperative ischaemia have been performed in patient groups with a recognized high incidence of ischaemic heart disease, such as those undergoing vascular surgery or those with cardiac risk factors undergoing general surgery. In addition, patient populations undergoing transurethral resection of the prostate, hip arthroplasty and lower segment caesarean section have been studied.

Patients undergoing thoracic or upper abdominal surgery have a two- to four-fold increased risk of perioperative myocardial infarction compared with other operative sites. In addition, thoracic surgery is associated with arrhythmia and patients with arrhythmia have an increased mortality after pneumonectomy. In general surgical populations, heart rate is increased in the postoperative period and this is thought to be detrimental. Lending support to this theory, a study in general surgical patients showed that those who received beta blocking agents in the perioperative period had fewer postoperative deaths.

The aims of this observational study were to determine the incidence and severity of perioperative ischaemia, arrhythmia and tachycardia in patients undergoing thoracic or thoraco-abdominal surgery and to examine the relationship between these and adverse operative outcomes.

Patients and methods

The study was performed at the Northern General Hospital, Sheffield, UK, between June 1993 and July 1995. The study was approved by the Local Ethics Committee and written, informed consent was obtained from all patients.
Myocardial ischaemia, heart rate and arrhythmia after thoracotomy

Any patient undergoing thoracotomy for lung or oesophageal surgery was considered eligible for entry and a total of 100 patients were considered. Patients with the following conditions were excluded because ECG monitoring would be unreliable: digoxin therapy; left bundle branch block or left ventricular hypertrophy on the preoperative 12-lead ECG; a cardiac pacemaker. Patients were assessed for a history of cardiac disease (myocardial infarction or angina) and cardiac risk factors. Cardiac risk factors were as described by Mangano and co-workers:13 known ischaemic heart disease, (defined as previously diagnosed angina pectoris or myocardial infarction); hypertension; diabetes; age 65 yr or more; current smoker. A preoperative 12-lead ECG was recorded. Patients were withdrawn if they failed to complete both a period of pre- and postoperative monitoring. Of the patients considered, 18 were excluded or declined consent. This was an observational study and so the anaesthetic technique and postoperative analgesia regimen were not standardized.

Equipment and monitoring
Myocardial ischaemia, arrhythmia and heart rate were detected using the Compas computerized ambulatory ECG surveillance system (Cardiac Care Units Incorporated, 6279 Variel Avenue, Unit C, Woodland Hills, CA 91367, USA.). This is a microprocessor-based solid state system programmed with algorithms for accurate analysis of both ischaemia and arrhythmia. Leads V2 and V5 were monitored for ST segment changes. Significant myocardial ischaemia was defined as ST segment depression of 2 mm or more below, or elevation of at least 3 mm above baseline at 60 ms after the J point and persisting for more than 1 min. The following definitions for arrhythmia were used. Supraventricular arrhythmia was a heart rate greater than 140 beat min⁻¹ lasting for more than 10 min. Ventricular arrhythmia was either ventricular tachycardia, a run of 7 ventricular premature depolarizations at a rate greater than 120 beat min⁻¹, or the occurrence of greater than 30 ventricular premature depolarizations per hour.

There were two periods of patient monitoring: preoperative, within the 24 h before surgery, and after operation during the 72 h after surgery. Patients were not monitored in theatre because of the difficulties in interpreting ECG changes during open chest surgery.

The reports were analysed after all patients had completed the study. All recordings were analysed by one of the investigators (J. G.) blinded to outcome. Where there was uncertainty, another investigator was consulted and a consensus agreed. The presence and duration of myocardial ischaemia, presence of arrhythmia and mean heart rate were noted for each patient in each period of monitoring.

Adverse operative outcome was defined as death or myocardial infarction in hospital. A diagnosis of a postoperative myocardial infarction required the following triad: a clinical suspicion of myocardial infarction; change in the postoperative 12-lead ECG; and documented increase in cardiac enzyme concentrations (CPK > 150 iu litre⁻¹).

Statistical analysis
Statistical analysis was performed using SPSS for Windows version 6. A chi-square analysis was used to test the incidence and association between preoperative and postoperative myocardial ischaemia. The number of ischaemic events per hour was calculated from the sum of ischaemic events divided by the total number of hours monitored for each patient in each time period. The Wilcoxon signed rank test was used to test the changes between preoperative and postoperative ischaemic events per hour. Ischaemic minutes per hour of monitoring was calculated from the sum of ischaemic time divided by the total number of hours monitored for each patient in each time period. The Student’s t test was used to test changes between preoperative and postoperative ischaemic minutes per hour of monitoring and mean heart rates. Chi-square analysis was used to test changes between preoperative and postoperative arrhythmias and to test the association between myocardial ischaemia and arrhythmia, and myocardial ischaemia and adverse outcome.

Results
Patient characteristics are summarized in Table 1. Of the 13 patients with a history of angina pectoris, 11 also had a previous myocardial infarction. Fifty-two percent of patients had an abnormal preoperative 12-lead electrocardiogram. Of the 82 patients studied, six (7%) had no cardiac risk factors, 23 (28%) had one cardiac risk factor and 53 (65%) had two or more cardiac risk factors. Patients were monitored for an average of 15 h 26 min (range 30 min to 23 h 59 min) before surgery and 47 h 27 min (range 2 h 20 min to 70 h 18 min) after surgery. Total monitoring time was 5158 h.

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<table>
<thead>
<tr>
<th>Table 1 Patient characteristics (mean (range) or number (%))</th>
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<tbody>
<tr>
<td><strong>Sex (M/F)</strong></td>
</tr>
<tr>
<td><strong>Age (yr)</strong></td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
</tr>
<tr>
<td><strong>Goldman grade</strong></td>
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<tr>
<td><strong>Cardiac history</strong></td>
</tr>
<tr>
<td>Angina pectoris</td>
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<tr>
<td>Previous myocardial infarction</td>
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<tr>
<td>Hypertension</td>
</tr>
<tr>
<td>Age &gt; 65 yr</td>
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<tr>
<td>Current smoker</td>
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<tr>
<td>Diabetes</td>
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<tr>
<td>&gt; Two cardiac risk factors</td>
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<tr>
<td><strong>Operation</strong></td>
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<tr>
<td>Lobectomy</td>
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<tr>
<td>Pneumonectomy</td>
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<tr>
<td>Oesophagectomy</td>
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<tr>
<td>Other thoracic procedure</td>
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<tr>
<td>One lung/two lung ventilation</td>
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</tbody>
</table>
Table 2 Presentation of the characteristics of preoperative and postoperative myocardial ischaemia. *P<0.05, **P<0.01 compared with before operation

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total monitoring time (h)</td>
<td>1266</td>
<td>3892</td>
</tr>
<tr>
<td>Incidence of ischaemia (%)</td>
<td>73.9 (12.9)</td>
<td>84.5 (14.8)*</td>
</tr>
<tr>
<td>Total ischaemic time (min)</td>
<td>50</td>
<td>423</td>
</tr>
<tr>
<td>Mean (SD) No. of ischaemic events per hour of monitoring</td>
<td>0.32 (1.3)</td>
<td>1.36 (4.6)*</td>
</tr>
<tr>
<td>Mean (SD) minutes of ischaemia per hour of monitoring</td>
<td>0.039 (0.155)</td>
<td>0.119 (0.34)**</td>
</tr>
</tbody>
</table>

Myocardial ischaemia

Nine (11%) patients had myocardial ischaemia monitored before operation. This increased to 20 (24%) after operation. In six of the nine patients with myocardial ischaemia before operation it also occurred after operation. The characteristics of myocardial ischaemia are shown in Table 2. A total of 50 episodes of myocardial ischaemia with a mean duration of 8.2 min were detected before surgery. This increased to a total of 423 events with a mean duration of 11.9 min after operation. There was no change in the duration of individual myocardial ischaemic events, but the number of events per hour of monitoring increased from a mean of 0.039 to 0.119. The increased number of events per hour resulted in an increase in monitored myocardial ischaemia from 0.32 min per hour before operation to 1.36 min per hour after surgery.

Heart rate and rhythm

Changes in heart rate and rhythm are presented in Table 3. Before operation, mean heart rate was 74 beat min⁻¹ and increased to 84.5 beat min⁻¹ after operation. In the preoperative period there was no difference in heart rate between patients with or without myocardial ischaemia. In the postoperative period, patients with myocardial ischaemia had a faster heart rate than those without myocardial ischaemia (92.8 vs 81.8 beat min⁻¹) (P<0.05).

The number of patients in whom supraventricular tachycardia was detected increased from one before operation to 12 after surgery (P<0.01). Supraventricular tachycardia was not associated with postoperative myocardial ischaemia or adverse outcome. The number of patients who had ventricular arrhythmia was nine before operation and 15 after operation (ns). Postoperative ventricular arrhythmia was associated with preoperative ventricular arrhythmia (P<0.01). There was no association between postoperative ventricular arrhythmia and postoperative myocardial ischaemia or adverse outcome.

Adverse operative outcome

Nine patients (11%) had an adverse outcome. Two patients had non-fatal myocardial infarction and seven patients died. Two of the patients died after myocardial infarction and death occurred on days 1 and 5 after operation. Myocardial ischaemia was not detected in either of these patients before operation and in one after operation. Three patients died of bronchopneumonia, on days 5, 6 and 7 after operation. One patient died from secondary haemorrhage on day 4 after operation and one from systemic sepsis on day 3 after operation. Only one of the nine patients with adverse outcome had preoperative myocardial ischaemia. Adverse outcome was not associated with preoperative myocardial ischaemia. Five of the nine patients (55%) with an adverse outcome had postoperative myocardial ischaemia. An adverse outcome was associated with postoperative myocardial ischaemia (P<0.05). Six of seven patients who died underwent a post-mortem examination and severe atheroma was evident in five.

Discussion

This was an observational study of myocardial ischaemia, heart rate and arrhythmia in patients undergoing thoracic surgery. Brennan and Croft, when considering observational studies, concluded that they are notoriously difficult to interpret because of the possibility of introducing bias into the study population. Thus it is important to indicate areas of potential bias. They also recommended that in observational studies probability values and comments on statistical significance were of little meaning and should not be quoted. We have quoted statistical data to help illustrate findings, but recognize the limitations.

Study design and limitations

The case mix of the operations in the study population was not different from that for all thoracic operations at this institution. During the study period there were a total of 334 thoracotomies; 55% were lobectomy, 18% pneumonectomy, 5% oesophagectomy and 22% other thoracic procedures. The mortality rate was also similar; 8.5% in the study compared with 6% for all thoracic operations. It is difficult to determine an appropriate population size for an observational study. This patient population was not large but compares with some observational studies that have used ambulatory monitoring in 100 patients or fewer. Patients had a high incidence of cardiac risk factors; only six patients had none. Exclusions on the basis of abnormal ECG or digoxin therapy probably excluded some high-risk patients.
Ambulatory monitoring is useful for determining perioperative myocardial ischaemia, and is robust and reliable. It can monitor the ambulant patient at all times, except in the shower or bath, and monitoring with two leads does not cause underestimation of the true incidence of myocardial ischaemia.17 Twelve patients were withdrawn from analysis because of insufficient monitoring time. Before operation we had emphasized the voluntary nature of this study and these 12 patients, already with chest drains, ECG, pulse oximeter, arterial pressure and added oxygen, found it too many and requested its removal.

We limited the study to 72 h after operation, the time of greatest postoperative myocardial ischaemia,4 14 and monitored an average of 72% of the total time during the 4 perioperative days. Although this compares well with other studies,5 13 we are aware of the deficit of 28% of the study period and the remainder of the hospital stay. For example, five deaths occurred after 72 h when myocardial ischaemia was not being monitored. McHugh and colleagues,18 using the automated Compas system and a definition of myocardial ischaemia of ST elevation $\geq 2$ mm above baseline or depression $\geq 1$ mm below baseline lasting more than 1 min, reported an incidence of myocardial ischaemia in high-risk patients undergoing non-cardiac surgery of 81%. This incidence of myocardial ischaemia was higher than reported in other studies, including those in high-risk patients. Many of the studies had used the same definition of myocardial ischaemia, but some had used a Holter-type continuous tape ambulatory monitoring system. We adopted the rigorous criteria of Edwards and colleagues7 with their Compas system to minimize false positive diagnoses of myocardial ischaemia.

Comparison with studies using ambulatory monitoring

The pattern of myocardial ischaemia in this population, an increase in incidence and time after operation compared with before operation, is in agreement with the findings of others.5 8 13 14 18 However, in contrast with some,5 13 we did not demonstrate a change in the duration of individual ischaemic events between the preoperative and postoperative period. Variations in incidence and character of ischaemic events between studies may be because of different monitoring systems or definitions of myocardial ischaemia.

In this study, adverse outcome was associated with postoperative but not preoperative myocardial ischaemia. Therefore, although there was an association between postoperative and preoperative myocardial ischaemia, it was not surprising that in the majority of patients (14 of 20) myocardial ischaemia was first detected after operation. The poor predictive value of preoperative myocardial ischaemia in this study is in accordance with studies by Mangano and colleagues5 13 who used multivariate analysis of cardiac factors in populations of 100 and 474 high-risk general surgical patients, but at variance with others.3 4 Fleisher and colleagues,3 also using multivariate analysis, found that the absence of preoperative myocardial ischaemia predicted an excellent outcome in 79 patients undergoing non-vascular surgery but was less robust in 67 vascular surgical patients.

Not all deaths were primary cardiac deaths but five of seven had severe coronary atheroma at post mortem. It is important to recognize the relationship between postoperative myocardial ischaemia and adverse outcome. The systemic stress of a complication, in this study infection and haemorrhage, can cause or be reflected as myocardial ischaemia. Severe postoperative myocardial ischaemia developed in a patient with a low-grade pyrexia 2 days before clinically apparent bronchopneumonia. Did the presence of postoperative myocardial ischaemia increase the patient’s fatigue and vulnerability to chest infection or did it reflect the infective process during its sub-clinical stage? What is evident from this study is that patients with postoperative myocardial ischaemia are more likely to die of their complications.

The observed increase in heart rate after operation was no surprise.5 13 14 We had assumed that the stress response, discomfort, anxiety and altered fluid balance would increase sympathetic nervous system activity in all patients. Other studies have reported increased heart rate after operation and detected no temporal relationship between tachycardia and myocardial ischaemic events.5 8 13 14 However, a study by Mangano and colleagues of perioperative beta block in a general surgical population showed a decrease in cardiovascular mortality and morbidity.15 In our study the difference in heart rate after operation between patients with and those without postoperative myocardial ischaemia was interesting, potentially a useful indicator and worthy of more investigation. It is possible that interventions, such as beta blockade, in patients with increased heart rate after operation may affect outcome.

Comparisons with studies of thoracic surgery

Von Knorring and co-workers retrospectively analysed the records of 598 patients undergoing thoracic surgery for lung cancer.10 Exercise ECG was performed before operation in 557 patients and was positive in 11%. After operation 12-lead ECGs were recorded on day 1 and serially when indicated. In contrast with our study myocardial ischaemia was detected in only 5% of patients after operation.

Three studies which have analysed the incidence of atrial arrhythmia after thoracic surgery reported 16% for all thoracotomies10 and 23% after pneumonectomy.10 11 19 In contrast with our study these detected an association between postoperative arrhythmia and adverse outcome. The populations were different. Two studies were in patients after pneumonectomy11 19 and in the other pneumonectomy comprised one-third of the surgical population.10 In addition, monitoring extended beyond the third postoperative day.

In summary, we observed an increased incidence and duration of myocardial ischaemia after thoracotomy. Postoperative myocardial ischaemia was associated with increased heart rate and adverse outcome.
Acknowledgements

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