Relationship between nocturnal hypoxaemia, tachycardia and myocardial ischaemia after major abdominal surgery

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Background. Episodic hypoxaemia, cardiac arrhythmias, and myocardial ischaemia may be related after major abdominal surgery.

Methods. We studied 52 patients on the second and third nights after major abdominal operations, using continuous pulse oximetry and Holter ECG. We recorded the amount of time spent with oxygen saturation values less than 90, 85, and 80% during the night, and noted episodes of hypoxaemia, tachycardia, bradycardia, and ST-segment changes.

Results. In 87 study nights there were 2403 (individual range 1–229) episodes of hypoxaemia, 3509 (individual range 1–234) episodes of tachycardia, and 265 (individual range 1–73) episodes of ST segment deviation. Of the 52 patients, 50 had episodes of hypoxaemia and tachycardia, and 19 patients had one or more episodes of ST segment deviation. For 38% of the episodes of ST deviation, there was an episode of hypoxaemia at the same time and in 16% there was an episode of tachycardia. ST deviation was only noted in 4% of the episodes of hypoxaemia and in 1% of the episodes of tachycardia.

Conclusion. Episodes of hypoxaemia and tachycardia frequently occur together after surgery but are rarely associated with ST deviation. Hypoxaemia or tachycardia is often present at the same time as ST deviation occurs.

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Constant and episodic arterial hypoxaemia is well-known after surgery.1–3 Constant hypoxaemia may last for almost 1 week after surgery.1 Episodic hypoxaemia has been attributed to changes in sleep pattern resulting in rapid eye movement (REM) sleep rebound, causing breathing disturbances primarily during postoperative nights 2–5.4 Late postoperative hypoxaemia could increase postoperative wound infection, cerebral dysfunction, and cardiac complications.5

Previous studies suggested that nocturnal episodic hypoxaemia is linked to cardiac ischaemic events and arrhythmias.1 2 6 Rosenberg and co-workers found episodes of desaturation at the same time as tachyarrhythmias, that is ventricular extrasystoles and periods with bigeminy, in patients after major abdominal surgery,1 and a close relationship between episodic tachycardia, hypoxaemia, and more pronounced ST depression after surgery.2 Gill and colleagues concluded that the severity and duration of hypoxaemia affected the risk of ischaemia.6 More unexpected deaths during the night and early morning hours suggest a possible link between these events.7

We set out to examine the potential relationship between postoperative episodic hypoxaemia and cardiac events using continuous pulse oximetry and Holter monitoring.

Methods

The study was approved by the local ethics committee. Patients gave written informed consent. We studied 52 patients (31 men). We excluded patients with neurological or respiratory disease including excessive daytime sleepiness. No patient had a history of cardiac disease or of regular use of hypnotics, sedatives, opioids, or other drugs that could affect cardiac rhythm. All patients
had a normal 12 lead-ECG, before the Holter monitoring was started. All patients had elective open abdominal surgery and received routine postoperative care. Oxygen treatment was not given after surgery other than for a few hours in the recovery room.

Anaesthesia was with thiopental and isoflurane, supplemented with a thoracic epidural block to provide analgesia for the incision. Postoperative analgesia was by continuous epidural infusion of a mixture of bupivacaine 0.25% at 4 ml h⁻¹, and morphine 0.02 mg h⁻¹ for 2–3 days, supplemented with acetaminophen 4 g day⁻¹.

Recordings were made on the second and third nights after operation. All patients completed at least 8 h of continuous monitoring on each study night, from 23:00 to 07:00 h.

Oxygen saturation (SpO₂) was measured with a Nellcor N-200 pulse oximeter (Nellcor Puritan Bennett Inc., Pleasanton, CA, USA) using an adhesive finger probe. Holter monitoring was with an amplitude modulated two-channel tape-recorder (Spacelabs 90205, Spacelabs Inc., Redmond, WA, USA). The frequency response was 0.05–100 Hz (−3 dB), and the tape speed was 1 mm s⁻¹. Recordings were made with two separate bipolar leads, CM₂ from electrodes placed in the second right intercostal space close to the sternum and in the V₅ position, and a modified orthogonal lead from electrodes just to the left of the spine, one on the superior angle of the scapula and one above the iliac crest. Recordings were analysed semi-automatically (Arrhythmiamaster, Spacelabs Inc.). All episodes of arrhythmia detected during the automatic analysis were checked carefully from full records from both leads. The result of ST segment analysis was presented in 1-min epochs from each lead. All episodes of ST segment changes were verified by at least three ECG recordings of each episode (beginning, maximum, and end of change). Horizontal or down-sloping ST depression (1 mV) or 1.5 mV ST elevation from isoelectric baseline (measured 60 ms from the J-point) for more than/equal to 1 min was defined as myocardial ischaemia. Each episode of ST segment change was separated by a time period of at least 1 min. As the resolution of ST segment analysis was limited to 1 min averages, any possible association between episodes of hypoxaemia and ST depression and elevation could only be determined when episodes of hypoxaemia lasted more than 1 min. All the correlating events were analysed in a blinded fashion by two individual assessors who were both cardiologists experienced in Holter analysis.

An episode of hypoxaemia was defined as a decrease in SpO₂ more than/equal to 5% from baseline, where the decline lasted less than 2 min but more than 30 s.² An episode of tachycardia was defined as an increase more than 10% in heart rate (HR) lasting 1–20 min, and an episode of bradycardia was a decrease more than 10% lasting 1–20 min. Sinus tachycardia was defined as a mean heart rate more than 100 min⁻¹, and constant hypoxaemia as a mean SpO₂ less than 90%. Maximum and minimum HR were defined as the highest and lowest values during a specific study night.

Group data are presented as median (range) unless stated otherwise. We analysed the data with the Wilcoxon signed rank test, Mann–Whitney and Spearman tests. A P<0.05 was considered significant.

Results
Thirty-six patients underwent colorectal surgery, eight gastric surgery, five exploratory laparotomy, and three lysis of adhesions. Median age was 62 yr (range 22–83), weight 65 kg (40–105), and height 172 cm (159–190). The median duration of surgery was 135 min (30–300) and median intra-operative blood loss was 450 ml (50–4300).

Of the 52 patients who participated in the study, 35 were studied for the second and the third nights, 14 patients were studied only during the second postoperative night, and three patients only during the third postoperative night. Details of the nights are given in Table 1. There were no differences in any of the variables between the two study nights (P>0.05). In total there were 87 study nights.

Episodes of hypoxaemia were found in 50 of the 52 patients (96%) and episodes of tachycardia were noted in 50 (96%). ST segment changes were detected in 19 patients. In the 35 patients studied for two nights, 15 had one or more periods of ST-deviation. Of these, eight had an episode or episodes of ST deviation on both nights, four on the second night, and three on the third night. There was no significant difference between the age of the patients with and without ST changes.

The median of the individual mean SpO₂ values for the 87 study nights was 95% (84–100) and the minimum SpO₂; was 81% (58–96). The patient (age 59, sigmoid resection) who had the least mean SpO₂ (84%) had the greatest number of hypoxaemic episodes (229 episodes on the second postoperative night), had no ST deviations, but 27 episodes of tachycardia, which were all temporally related to an episode of hypoxaemia. The patient (age 74, low anterior resection of rectum) with the greatest mean SpO₂ (100%) had a minimum SpO₂ of 96%, no hypoxaemic episodes and no episodes of ST deviation, but 38 episodes of tachycardia on the second postoperative night.

In the 87 study nights, there were 78 nights in which SpO₂ values became less than 90%, 53 nights with episodes of SpO₂ less than 85%, and 32 nights with episodes of SpO₂ less than 80%. We found statistically significant correlations between

| Table 1 Data for postoperative nights 2 and 3. Values are median (range) |
|------------------|------------------|------------------|------------------|
| Variable                  | Night 2          | Night 3          | P-value          |
| Mean SpO₂ (%)           | 95 (84–100)      | 95 (86–98)       | 0.24             |
| Minimum SpO₂ (%)        | 81 (58–96)       | 81 (60–92)       | 0.98             |
| Mean heart rate (min⁻¹) | 82 (62–126)      | 77 (62–102)      | 0.16             |
| Maximum heart rate (min⁻¹) | 106 (72–152) | 104 (78–184)    | 0.63             |
| Episodes of hypoxaemia | 14 (0–229)       | 18 (0–138)       | 0.51             |
| Episodes of tachycardia | 27 (0–173)       | 27 (0–234)       | 0.46             |
| Episodes of ST-segment deviation | 0 (0–73) | 0 (0–59)       | 0.75             |
| Number of patients studied | 49               | 38               |                  |
the fraction of the night that $S_pO_2$ values were less than 90, 85, and 80% saturation and the number of episodes of hypoxaemia ($r_s=0.502, P<0.001; r_s=0.597, P<0.001; and r_s=0.353, P<0.05$, respectively). For all the 87 study nights, there were significant correlations between the number of episodes of tachycardia and the number of episodes of hypoxaemia ($r_s=0.53, P<0.01$), and between the number of episodes of tachycardia and the number episodes of ST-deviation ($r_s=0.39, P<0.05$).

Table 2 shows the total number of events for the 87 study nights and the proportion of the study nights where events occurred. Figure 1 shows the relationships between episodic hypoxaemia, episodic tachycardia, and episodes of ST deviation. In 4% (101/2403) of the episodes of hypoxaemia, ST deviation occurred at the same time and in 1% (42/3509) of the episodes of tachycardia there was ST deviation. On the other hand in 38% of the episodes of ST deviation (101/265) an episode of hypoxaemia was also present, and in 16% of the episodes of ST deviation (42/265) an episode of tachycardia was also present. In 37% (894/2403) of the episodes of hypoxaemia, tachycardia was present, and a hypoxaemic event was present during 25% (894/3509) of the episodes of tachycardia. In the patient with the most ST deviations (73 episodes on a single night) an episode of hypoxaemia was present at the same time, but only seven episodes of ST deviation were coupled to episodic tachycardia. In 92% of the study nights, we found episodes of tachycardia at the same time as episodes of hypoxaemia. In 62% of the study nights, episodes of hypoxaemia were noted in relation to episodes of bradycardia (Table 1).

The median duration of an event of ST deviation was 90 s (60–5730), the median ST depression was $-1.2$ mV ($-1.1$ to $-2.7$) and ST elevation was $1.6$ mV ($1.5$ to $5.2$). The $S_pO_2$ at onset of ST deviation was 93% (85–99) and the minimum $S_pO_2$ during an episode was 91% (76–99). The median heart rate at onset was 84 beats $min^{-1}$ (56–148). We related the duration and direction of the ST deviations to the prevailing conditions (mean $S_pO_2$, minimum $S_pO_2$, and heart rate at the time of onset). Comparing the features present for episodes of ST segment change for more than 90 to less than/equal to 90 s, there was a significant difference between the heart rate at onset, the mean $S_pO_2$, and the minimum $S_pO_2$ (Table 3). When comparing mean $S_pO_2$, minimum $S_pO_2$, and heart rate at the time of onset in relation to ST depression and ST elevation, there were also significant differences. At the onset of ST depression, heart rate was significantly greater and mean and minimum $S_pO_2$ were significantly less during ST depression episodes (Table 3).
Table 3 Heart rate at onset, mean and minimum SpO2 during the episode, compared with respect to whether the episodes of ST deviation lasted <90 or >90 s, and according to the type of change (depression or elevation). Values are median (range)

<table>
<thead>
<tr>
<th>Type of ST depression</th>
<th>Rate at onset</th>
<th>Mean SpO2</th>
<th>Minimum SpO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-segment change &lt;90 s (n=148)</td>
<td>84 (56–148)</td>
<td>94 (85–99)</td>
<td>92 (76–99)</td>
</tr>
<tr>
<td>ST depression (n=64)</td>
<td>86 (62–132)</td>
<td>90.5 (85–99)</td>
<td>85.5 (76–99)</td>
</tr>
<tr>
<td>ST elevation (n=84)</td>
<td>78 (56–148)</td>
<td>94 (85–98)</td>
<td>93 (78–98)</td>
</tr>
<tr>
<td>ST segment change &gt;90 s (n=117)</td>
<td>84 (68–134)</td>
<td>93 (85–99)</td>
<td>91 (76–96)</td>
</tr>
<tr>
<td>ST depression (n=74)</td>
<td>86 (68–132)</td>
<td>90 (85–99)</td>
<td>85 (76–96)</td>
</tr>
<tr>
<td>ST elevation (n=43)</td>
<td>80 (70–134)</td>
<td>94 (88–98)</td>
<td>92 (82–95)</td>
</tr>
</tbody>
</table>

Discussion

In patients after major abdominal surgery, we found a possible link between episodes of hypoxaemia and cardiac events such as tachycardia and ST changes suggesting myocardial ischaemia. We found frequent episodes of hypoxaemia and tachycardia during the second or third postoperative night, in 50 of the 52 patients. ST segment changes were also frequent as at least one event was found in 19 of the 52 patients.

An episode of hypoxaemia was present in association with 38% of the episodes of ST segment deviation, and tachycardia was present in association with 16% of the episodes of ST segment deviation. However, ST deviation was only noted in 4% of the episodes of hypoxaemia, and in 1% of the episodes of tachycardia. Thus, although episodes of hypoxaemia and tachycardia are frequent after surgery, they are only infrequently associated with episodes of change in the ST segment.

ST segment changes and other cardiac abnormalities can occur for reasons other than myocardial ischaemia.8 Day to day variation can cause bias. Some episodes of ST elevation during Holter monitoring can be artefacts. The possibility of false-positive changes should not preclude the use of Holter monitoring for this purpose.

Movement artefacts affect interpretation of continuous pulse oximetry after surgery. A substantial number of postoperative alarms from oximeters may be false, when arterial blood gases, ECG and clinical features are compared.9 10 More recently developed oximeters are designed to be less susceptible to movement artefact.9 In postoperative patients, Stausholm and colleagues11 compared the Nellcor 200 pulse oximeter with a transcutaneous oxygen tension monitor, which was not sensitive to motion artefact. They found that an episode of desaturation more than/equal to 5% from baseline that lasted for over 30 s was a ‘true’ desaturation in at least 78% of the cases. If the desaturation lasted more than/equal to 1 min this likelihood increased to at least 95%. Studies of body movements with a static charge sensitive bed and pulse oximeter measurements, show that movement related artefacts are usually for a very short time.12 In our study, we did not control for body position, and thus episodes of desaturation were at least 78% likely to be genuine. When relating hypoxaemia with possible ischaemia, there was at least 95% likelihood of the desaturation being true, because the resolution of ST segment analysis was limited to 1 min averages, and an association between episode of hypoxaemia and an episode of ST segment change would be detected only when the hypoxaemic event lasted for more than 1 min.

Late postoperative constant hypoxaemia after major abdominal surgery results from a reduction in functional residual capacity caused by the surgery, and can last for up to 1 week.13 After minor surgery such as middle ear surgery, there is no hypoxaemia even if the anaesthetic technique was similar.14 In the immediate postoperative period, episodes of hypoxaemia result from residual effects of general anaesthesia together with morphine analgesia, which can cause obstructive apnoea, paradoxical breathing, and periods of slow ventilatory frequency.15 In the late postoperative period, disturbances in the circadian regulation of the autonomic nervous system,16 hormones,17 18 temperature regulation (unpublished data) and sleep architecture4 can contribute. REM suppression in the first nights after operation is followed by a rebound of REM sleep on postoperative nights 2–5. Thus, hypoventilation and apnoeas during REM rebound is thought to cause the late postoperative episodes of hypoxaemia.4 Giving 37% oxygen during the second postoperative night did not reduce episodes of hypoxaemia.19 The rebound of REM is thought to be a central response caused by the surgical trauma and/or opioid administration and not by anaesthesia per se.4

As expected, the mean HR after surgery was greater than in healthy persons,16 probably because of autonomic disturbances and a lack of sympathetic withdrawal during the night.16 20 In normal subjects, REM sleep is associated with profound sympathetic activation.21 Increased sympathetic tone in the late postoperative period, caused by the surgical trauma, could increase the risk of cardiac ischaemia and arrhythmic events during REM sleep.

A causative link between episodes of hypoxaemia and cardiac events after surgery has been suggested in previous studies.1 2 6 Myocardial ischaemia is frequent and severe during the first 3 days after major non-cardiac surgery and most of these events are clinically silent.22 23 Cardiac morbidity after surgery can have many causes, and most are probably related. Surgical trauma and anaesthesia is not itself related to more ischaemia. Ischaemia is not more common or severe during surgery than before.22 23 In the ischaemic myocardium, repeated episodes of hypoxaemia may worsen ischaemia. In patients with ischaemic heart disease,
autonomic balance is shifted towards sympathetic predominance during episodes of hypoxaemia with a greater risk of myocardial ischaemia and cardiac arrhythmias. This has also been noted in patients after myocardial infarction, where electrocardiographic abnormalities are frequent during a hypoxaemic event. Hypoxaemia may be an important risk factor after non-cardiac surgery, when oxygen demand is increased because of the surgical trauma and sympathetic stimulation. Giving oxygen 37% did not reduce the number of hypoxaemic episodes, but reduced constant hypoxaemia.19 Further studies are needed to determine if preventing hypoxaemia with oxygen therapy will affect cardiac events in patients without cardiac disease, or other cardiac risk factors.

In the obstructive sleep apnoea syndrome (OSAS) arterial hypoxaemia occurs during apnoea and hypopnoea. OSAS is associated with an increased risk of hypertension, cardiac ischaemia, and rhythm disturbances, but only a few case reports address this problem after major surgery. REM sleep causes irregular ventilation with brief periods of apnoea. The arousal threshold to inspiratory drive is increased, causing prolonged apnoeic periods and increased desaturation. Reduced functional residual capacity and rebound of REM sleep after major surgery would probably increase the risk of averse cardiac events in patients with known OSAS. Such possibilities require further investigation, to allow anaesthetic and surgical risk evaluation in patients with OSAS.

We recorded 265 episodes of ST deviations (138 depressions and 127 elevations). At onset of an episode of ST depression, oxygen saturation was less and heart rate greater than at the onset of an episode of ST elevation. This suggests that greater heart rate and reduced saturation may cause ST depression, while ST elevation may result from other factors, such as coronary spasm or local electrolyte disturbances in the myocardium.

In conclusion, we found frequent episodes of hypoxaemia and tachycardia after major non-cardiac surgery, and these episodes are often present when ST segment changes occur.

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