PERIOPERATIVE MYOCARDIAL INFARCTION

R. HAAGENSEN AND P. A. STEEN

The risk of developing myocardial infarction (MI) in connection with surgery and anaesthesia has been recognized for at least 75 years [19, 79, 93, 101]. Since then numerous reports have been published, some describing the incidence and characteristics of perioperative myocardial infarction (PMI), others the risk factors involved.

To compare these publications is difficult because of the great span in years between various studies, and the variability in study conditions such as selection and size of population, the use of a retrospective or a prospective approach, variations in postoperative care, the method of diagnosis of PMI etc. These factors can at least partly explain the variability and even contradictions observed in results. In most of these studies statistical evaluation also leaves much to be desired. The questions are often multifactorial, without the appropriate tests being performed. Performing simple chi-squared tests on whether sex, age, type or duration of anaesthesia etc, influence the infarction rate, does not provide a correct picture. There is often some co-variation between many of these factors, such as duration of anaesthesia and type of surgery. Thus the papers should be evaluated critically and the effects of a single factor reported in a single paper should be interpreted with caution.

Even more impressive, therefore, are the similarities in some of the results in spite of these differences in methodology, and certain trends appear in the literature that are important to the daily work of the anaesthetist.

In this review we have concentrated on the epidemiological aspects of PMI and the risk factors that have practical consequences in the treatment of patients. Frontline research concerning the pathophysiology of myocardial ischaemia and infarction and possible effects of different drugs are discussed elsewhere in this symposium issue.

Because of the paucity of information (with a few exceptions, such as the paper by Rao and colleagues [80]), we can only hint at perhaps the most important issue: will any diagnostic or therapeutic intervention change the outcome, and at what cost? These types of question are of vital importance to the Health Industry today. It is estimated that, every year in the United States alone, 1 million patients with documented ischaemic heart disease undergo a surgical procedure under anaesthesia. There is rapid development in our ability to diagnose and treat myocardial ischaemia. It is expensive to provide tests such as preoperative ECG, dipyramidole-thallium scintigram, preoperative stress test or coronary angiography for all the patients. What are their benefits? Should all patients at risk be monitored with pulmonary artery catheters; should they be placed in an intensive care unit (ICU) after operation? Should all patients with signs of myocardial ischaemia on a perioperative or postoperative ECG or ECHO be assessed for possible MI after operation? Such question are important. What is the cost:benefit ratio? In the North Sea oil industry an estimated £1.5 million are spent per life saved. How much can we allocate per life possibly saved in the context of PMI?

Perhaps these questions should be asked even before the studies are designed? This is even more controversial. Although freedom of research should be sacred, are we willing to accept the consequences supplied by the results? If some technique can reduce the operative mortality at the cost of £3 million per life, should the technique be implemented, or is the money better spent elsewhere? If we do not reach a decision ourselves, the medical technology industry, combined with our own fear of litigation, may soon make this a "standard of care". We feel that this point should be kept in mind when studying, and possibly implementing, results from the literature.

In this review PMI is defined as an infarct that
becomes apparent during the operation, or the first week after operation. There is a high incidence of MI throughout the first postoperative week, and as most of the studies in this field are retrospective, the exact moment of infarction often cannot be defined. This is especially true as a large number of the infarcts, varying from 21% [96] to more than 60% [6, 34, 94], are silent. The first indication of an infarction has often been cardiovascular collapse [76, 94], or hypotension or arrhythmia which have led the attending physician to investigate [6, 80, 94, 96]. It is, therefore, perhaps not surprising that PMI have been revealed throughout the peri- and postoperative periods. Steen, Tinker and Tarhan [94] reported that 25% and Plumlee and Boettner [76] that 41% of MI were discovered during the operation, while both Tarhan and colleagues [96] and Rao, Jacobs and El-Etr [80] reported a peak incidence on the 3rd day after operation.

INCREASE OF PMI

Some studies [3, 34, 40, 76] do not distinguish between patients with and those without previous MI, and report PMI rates varying from 0.08% to 2.4%, the highest tending to be in studies reporting mainly on patients with previous MI. In addition, the study by Baur, Nakhjavan and Kajani [6] reported an extreme 16% incidence in 150 patients selected at random from a surgical list. From these and other studies, it soon became apparent that whether or not the patient had had a previous MI was the factor most profoundly affecting PMI rate. While Goldman and colleagues [40] undertook a thorough multifactorial analysis of risk factors, including previous MI, from the outset most other authors have classified the patients into those with and those without previous MI. In this review, evaluation of other risk factors therefore refers mostly to patients with previous MI, as the infarction rate in patients without previous MI is so low that it is difficult to obtain data that are statistically evaluable.

Patients without previous MI (table I)

A PMI rate of 0.65% was reported by Knapp, Topkins and Artusio [57], and this study was later expanded, with the same results [98]. Others have later reported an incidence of 0.1-0.4% [58, 88, 96].

Patients with previous MI (table II)

There is remarkable little variation in the overall PMI rate in these patients, varying between 3.2% and 7.7% for most of the studies, with a median mortality rate among those developing PMI of 70%, independent of when it appeared in the postoperative course. There are a few exceptions to these data.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Authors</th>
<th>Years</th>
<th>Patients</th>
<th>Operations</th>
<th>PMI rate</th>
<th>Mortality</th>
<th>Type of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>[98]</td>
<td>Topkins and Artusio</td>
<td>1959-63</td>
<td>M &gt; 50 yr</td>
<td>12054</td>
<td>0.66%</td>
<td>27%</td>
<td>Prospective</td>
</tr>
<tr>
<td>[96]</td>
<td>Tarhan et al.</td>
<td>1967-68</td>
<td>All &gt; 30 yr</td>
<td>32455</td>
<td>0.13%</td>
<td>69%</td>
<td>Retrospective</td>
</tr>
<tr>
<td>[58]</td>
<td>von Knorring</td>
<td>1975-77</td>
<td>?</td>
<td>12497</td>
<td>0.20%</td>
<td>36%</td>
<td>Prospective</td>
</tr>
<tr>
<td>[88]</td>
<td>Schoeppel et al.</td>
<td>1980</td>
<td>All &gt; 40 yr</td>
<td>928</td>
<td>0.40%</td>
<td></td>
<td>Retrospective</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Authors</th>
<th>Years</th>
<th>Operations</th>
<th>PMI rate</th>
<th>Mortality</th>
<th>Type of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>[98]</td>
<td>Topkins and Artusio</td>
<td>1959-63</td>
<td>658</td>
<td>6.5%</td>
<td>70%</td>
<td>Prospective</td>
</tr>
<tr>
<td>[96]</td>
<td>Tarhan et al.</td>
<td>1967-68</td>
<td>422</td>
<td>6.6%</td>
<td>54%</td>
<td>Retrospective</td>
</tr>
<tr>
<td>[99]</td>
<td>Vormittag et al.</td>
<td>1965-72</td>
<td>334</td>
<td>7.5%</td>
<td>92%</td>
<td>Retrospective</td>
</tr>
<tr>
<td>[94]</td>
<td>Steen, Tinker and Tarhan</td>
<td>1974-75</td>
<td>587</td>
<td>6.1%</td>
<td>69%</td>
<td>Retrospective</td>
</tr>
<tr>
<td>[58]</td>
<td>von Knorring</td>
<td>1975-77</td>
<td>157</td>
<td>15.9%</td>
<td>28%</td>
<td>Prospective</td>
</tr>
<tr>
<td>[36]</td>
<td>Eerola et al.</td>
<td>1979</td>
<td>111</td>
<td>5.4%</td>
<td>50%</td>
<td>Retrospective</td>
</tr>
<tr>
<td>[88]</td>
<td>Schoeppel et al.*</td>
<td>1980</td>
<td>63</td>
<td>3.2%</td>
<td>50%</td>
<td>Prospective</td>
</tr>
<tr>
<td>[80]</td>
<td>Rao, Jacobs and El-Etr</td>
<td>1973-76</td>
<td>364</td>
<td>7.7%</td>
<td>54%</td>
<td>Retrospective</td>
</tr>
<tr>
<td>[1977-82]</td>
<td></td>
<td></td>
<td>733</td>
<td>1.9%</td>
<td>36%</td>
<td>Prospective</td>
</tr>
</tbody>
</table>
TABLE III. Reinfarction rate v. interval from previous MI

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Authors</th>
<th>0-3 months</th>
<th>4-6 months</th>
<th>7-12 months</th>
<th>&gt; 12 months</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>[98]</td>
<td>Topkins and Artusio</td>
<td>55% (12/22)</td>
<td></td>
<td>25% (9/36)</td>
<td>3% (19/593)</td>
<td>43% (3/7)</td>
</tr>
<tr>
<td>[96]</td>
<td>Tarhan et al.</td>
<td>37% (3/8)</td>
<td>16% (3/19)</td>
<td>5% (2/42)</td>
<td>6% (20/353)</td>
<td></td>
</tr>
<tr>
<td>[94]</td>
<td>Steen, Tinker and Tarhan</td>
<td>27% (4/15)</td>
<td>11% (2/18)</td>
<td>7% (2/31)</td>
<td>4% (17/430)</td>
<td>12% (11/93)</td>
</tr>
<tr>
<td>[58]</td>
<td>von Knorring</td>
<td>25% (4/16)</td>
<td></td>
<td>18% (2/11)</td>
<td>11% (10/89)</td>
<td>22% (9/41)</td>
</tr>
<tr>
<td>[36]</td>
<td>Eerola et al.</td>
<td>8% (1/12)</td>
<td>6% (1/17)</td>
<td></td>
<td>5% (4/82)</td>
<td></td>
</tr>
<tr>
<td>[88]</td>
<td>Schoeppel et al.</td>
<td>0% (0/1)</td>
<td>0% (0/8)</td>
<td>0% (0/10)</td>
<td>6% (2/44)</td>
<td></td>
</tr>
<tr>
<td>[80]</td>
<td>Rao, Jacobs and El-Etr Retrospective</td>
<td>36% (4/11)</td>
<td>26% (8/31)</td>
<td>5% (6/127)</td>
<td>5% (10/195)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rao, Jacobs and El-Etr Prospective</td>
<td>6% (3/52)</td>
<td>2% (2/86)</td>
<td>1% (1/104)</td>
<td>2% (8/491)</td>
<td></td>
</tr>
</tbody>
</table>

Von Knorring [58] reported a reinfarction rate of 16% in general surgical and orthopaedic patients with previous MI. He claimed that 40% of these infarcts would not have been detected without a prospective ECG study after operation, suggesting this to be part of the reason for the high reinfarction rate compared with the retrospective data from other studies. While this might be true, the number of silent infarcts was not greater in this study than in the retrospective studies, and many of the others with lower reinfarction rates were also prospective (table II). The mortality rate for PMI patients was low in this study (28%), making the mortality from PMI not different from that from the other studies.

All the above data have been challenged by Rao, Jacobs and El-Etr [80] and Wells and Kaplan [100]. In a retrospective study, the former group found a reinfarction rate similar to that reported by other investigators (tables II and III). This was reduced dramatically in a follow-up prospective study. The authors' findings were explained by their extensive haemodynamic monitoring and treatment of the patients in both the peri- and postoperative periods. More than 80% of the patients had pulmonary catheters and radial artery cannulae. Heart rates and arterial pressures were not allowed to fluctuate more than 20% from preoperative values, and arrhythmias and tachycardias were treated immediately. The first 210 patients were monitored in the ICU for 24 h after operation with a 3.8% reinfarction rate. As in previous studies, many of the infarcts occurred later in the postoperative period, and the next 439 patients were therefore followed for 3-4 days, with a further significant reduction in the reinfarction rate to 1.4%. This study indicates that prolonged monitoring improves the results, despite the statistical objection presented by Lowenstein, Yusuf and Teplick [63] that the first 210 patients were made a control group because of the poor results.

Wells and Kaplan [100] reported no reinfarctions in 48 patients who had sustained a prior MI within 3 months of surgery. To our knowledge these data [55, 100] have not appeared in an original article yet. Ten percent of the patients in the study had previously undergone coronary artery bypass graft (CABG) surgery, but no further data are available on type of surgery, monitoring, definition of PMI, postoperative care, etc.

These reports do indicate that it is possible to reduce the high overall PMI rate in patients with previous MI. The questions are: at what cost and, if the expense is too high, which are the subgroups in whom more extensive monitoring and treatment would be more cost effective? Unfortunately, the level of uncertainty increases when one examines the influence of factors other than a previous MI on the PMI rate.

Interval from previous MI (table III)

The second most important factor in this multifactorial picture appears to be the interval from the previous MI. In all studies the reinfarction rate is greater if surgery is performed within 6 months of MI, with the highest rate occurring within the first 3 months. This was true even in the prospective study by Rao, Jacobs and El-Etr [80], which reported a low overall reinfarction rate.

Site of previous MI

Steen, Tinker and Tarhan [94] found no significant correlation between the PMI rate and the site of a previous MI. On the other hand, Eerola and colleagues [36] found that a previous
posterior infarction was a significant risk factor, while Arkins, Smessauer and Hicks [3] found lower mortality rates if earlier infarction was subendocardial.

Other Factors Relevant to Coronary Artery Disease

Congestive heart failure

This has also been identified as a risk factor [26, 36, 40, 80]. In addition, Pasternak and colleagues [75] found a higher infarction rate in patients with a low preoperative ejection fraction (less than 35%).

Angina pectoris

Angina is the main symptom of coronary artery disease (CAD). Patients suffering from angina pectoris run a higher risk of cardiac complications such as MI than the general population. It is, therefore, somewhat surprising that, although some authors report that many of the patients suffering a PMI had preoperative angina [6, 36, 76, 83, 96], most studies, including those with a more thorough multifactorial analysis, found stable angina not to be a significant independent risk factor [20, 26, 40, 58, 80, 94].

Coronary artery disease shown by angiography

Mahar and colleagues [67] reported that three-vessel disease was a significant risk factor for developing PMI.

ECG changes before and after operation (excluding signs of previous MI)

Many patients with CAD present with a normal resting ECG before operation. In patients admitted for peripheral vascular surgery, Tomatis, Fierens and Verbrugge [97] found that, among those with a normal resting ECG, 30% (11/37) had severe CAD, with 75–100% obstruction of a major coronary vessel, and 14% (5/37) had a 50–75% obstruction. Of these patients, some show typical ST-depression as a sign of myocardial ischaemia during exercise testing. Thus Cutler and colleagues [29] found that 73 of 100 patients admitted for vascular surgery had no ischaemic signs on a resting ECG, but 14 (19%) of these had ischaemic signs during exercise testing. Of the 27 patients with signs of ischaemia on the resting ECG, 18 (67%) had additional ST-changes during exercise. In these patients 48 operative procedures were performed, and PMI occurred in six, all of whom exhibited ischaemic signs on the exercise ECG. Arous, Baum and Cutler [4] similarly found that PMI occurred in 25% of patients with positive preoperative exercise test who underwent major peripheral vascular surgery.

Von Knorring [58] reported that patients with preoperative ST-segment and T-wave changes, but no other indication of CAD, had a higher incidence of subendocardial infarction than patients with previous MI from history or ECG (12% v. 6%). Others [23, 70] have studied selected groups of patients with ischaemic heart disease and abnormal ECG before operation, and reported high incidences of a further deterioration in the ECG after operation, with a 4–9% infarction rate.

Most authors have suggested that a preoperative ECG indicating pre-existing ischaemic heart disease is linked to perioperative cardiac complications [6, 20, 23, 26, 34, 49, 58, 70, 82]. On the other hand, Goldman and colleagues [40] found not ischaemic signs on the ECG, but preoperative arrhythmias (both ventricular and supraventricular) or recent MI, to be independent predictors of postoperative cardiac complications. Breslow and colleagues [14] reported that, while 19% (71 of 394 consecutive patients) had ECG abnormalities 1 h after operation, nearly all were T-wave changes (flattening or reversal), and the incidence was not greater in patients with known CAD than in those without. In 70 of these 71 patients, the authors discovered no episodes suggestive of myocardial ischaemia in the postoperative period. They suggested that T-wave abnormality in the immediate postoperative period was a frequent event not linked to the development of cardiac complications and probably not a marker of myocardial ischaemia. Thus there is considerable difference of opinion as to the importance of T-wave abnormalities, particularly when they are transient. Driscoll and colleagues [34] used deeply inverted T-waves as the diagnostic criterion for PMI in 75% of the cases. These changes were normalized in all patients followed up a few months later (four of nine patients). Thus the issue remains controversial.

Preoperative hypertension

This is defined very differently: either as a given arterial pressure value on a preoperative evaluation [26, 99] or as patients receiving antihypertensive medication [94]. There is a positive
correlation between hypertension and ischaemic heart disease [54], and Prys-Roberts, Meloche and Foex [78] reported that patients with untreated hypertension had the largest perioperative haemodynamic alterations which, again, has been reported to correlate with a high PMI rate (see below). It would therefore not be surprising if chronic hypertension also correlated with a high PMI rate, as reported by Eerola and colleagues [36], von Knorring [58], Steen, Tinker and Tarhan [94] and Vormittag and colleagues [99]. On the other hand, there was no significant correlation in the study by Rao, Jacobs and El-Etr [80] or that of Riles, Kopelman and Imparato [81] or in the multivariate analyses performed by Goldman and colleagues [40] and by Cooperman and colleagues [26]. Thus this issue also remains controversial. In the first group of studies the statistical evaluation might have been inadequate, with no sequential multivariate analysis, and the latter studies reported on smaller numbers of PMI with a greater possibility of incorporating a type-II error statistically.

**Diabetes mellitus**

Patients with diabetes have a two- to three-fold increase in prevalence of atherosclerotic disease [53]. Most authors have therefore included diabetes in their investigations of risk factors for PMI. To our knowledge, only Driscoll and colleagues [34] have suggested a possible connection (but without statistical analysis), and the statistical data seem to refute such a connection [40, 58, 70, 94, 99].

**Age**

The patient population is growing older and, with age, there is an increasing prevalence of ischaemic heart disease and associated diseases. This makes independent evaluation of age as a PMI risk factor more difficult, although Goldman and colleagues [40] reported that age exceeding 70 yr was an independent risk factor for development of cardiac complications. The population in a great number of the studies referred to here were patients with previous MI, and a patient who has experienced MI before the age of 30 yr must have a serious underlying disease. It is, therefore, perhaps not so surprising that approximately 50% of the authors [3, 34, 36, 80 (retrospective), 88] reported advanced age to be a risk factor, while the other 50% have not found a significant correlation [58, 80 (prospective), 89, 94, 96].

**Sex**

In one study the reinfarction rate was higher among men [96]; in another the mortality from PMI was greater among females [3]. Others have failed to find a sex-linked difference [40, 58, 80, 94, 99].

**Risk indices**

Some authors have attempted to combine all these (and other) factors to make risk indices as a tool for better preoperative evaluation of cardiovascular risks [26, 33, 40, 51, 86]. On this subject the reader is referred to the article by Goldman in this symposium issue.

**Pre- and Perioperative Ischaemia**

Although all data that have been referred to previously in this review have related to patients admitted to non-cardiac surgery, it is of interest to note that Slogoff and Keats [90], in their study of 1023 patients scheduled to undergo elective coronary artery bypass grafts (CABG) found no single or multiple preoperative patient characteristics to correlate with the PMI rate. What did correlate were signs of pre- and perioperative ischaemia. This is not surprising, since PMI must result from a disturbance in the oxygen demand:supply ratio, but this was the first time the relationship had been shown clearly in a large clinical series. PMI was almost three times as frequent in patients with ischaemia (6.9 v. 2.5%) and was independent of when ischaemia had occurred.

These ischaemic episodes (and thus PMI) were further correlated with tachycardia, but not with intraoperative hyper- or hypotensive episodes. There was, furthermore, a strong temporal relationship to anaesthetic or surgical events known to produce intense sympathetic stimulation, such as intubation and surgical stimulation.

Slogoff and Keats [91] have subsequently reconfirmed these results in another prospective study of 495 patients admitted for CABG, using different criteria for intraoperative hyper- or hypotension, because their first definitions were criticized by Lowenstein [62]. It is remarkable that approximately 50% of the episodes of myocardial ischaemia in the perioperative period were not associated with a marked change in systemic arterial pressure or heart rate. This is in
acCORDANCE WITH THE FINDING OF DEANFIELD AND COLLEAGUES [30], THAT ONLY 23% OF ISCHAEMIC EPISODES DURING DAILY LIFE IN PATIENTS WITH STABLE ANGINA PECTORIS WERE PRECEDED BY HEART RATE INCREASE OF MORE THAN 10 BEAT MIN⁻¹. Thus although SLOGOFF AND KEATS [90] FOUND THE CHOICE OF ANAESTHETIST TO BE CLOSELY CORRELATED WITH THE NUMBER OF ISCHAEMIC EPISODES, AT THE PRESENT STATE OF KNOWLEDGE THE ANAESTHETIST DOES NOT, PERHAPS, HAVE TO FEEL GUILTY FOR EVERY EPISODE OF ISCHAEMIA OBSERVED DURING ANAESTHESIA.

**Per- and Postoperative Factors Correlating with PMI Rate**

**Haemodynamic changes**

Although there is no uniform definition of hypotensive episodes, most authors have reported an increased PMI rate (up to five-fold [94] with intraoperative hypotension [23, 36, 58, 70, 76, 80, 88, 99]. It could not be determined, of course, if the hypotensive episode was the cause of or a result of myocardial ischaemia. Rao, Jacobs and El-Etr [80] also found hypertensive episodes to be predictor of PMI, while the difference did not reach the significance level \( P < 0.05 \) in the study by Steen, Tinker and Tarhan [94].

**Type of anaesthesia**

The importance of choice of anaesthetist, rather than of anaesthetic agent, was stressed as long ago as 1928 [68]. While the choice of anaesthetist might be important, the choice of anaesthesia (regional v. general, different general agents) has not been shown to influence the PMI rate [3, 36, 58, 72, 94, 96, 98]. The only exception is an observation by Rao, Jacobs and El-Etr [80] in their prospective study, where the use of a nitrous oxide-opioid technique was associated with a significantly higher incidence of PMI than use of other anaesthetics. Whether or not the use of a nitrous oxide-opioid narcotic technique was associated with a significantly higher incidence of PMI than use of other anaesthetics, whether or not the use of a nitrous oxide-opioid narcotic technique correlated with other risk factors was apparently not tested. Thus although the influences of different anaesthetics on the cardiovascular system vary, and some actions might have theoretical advantages, this has not been enough to cause differences in PMI rates in large epidemiological studies. For ophthalmic surgery under local anaesthesia or retrobulbar block, Backer and colleagues [5] found no PMI with 288 operations in patients with previous MI. The number of ophthalmic procedures performed under general anaesthesia was not large enough for a statistical comparison, but the study does indicate that this type of procedure and anaesthesia does not pose a special risk for PMI. McAuley and Watson [64] have also reported a lack of cardiac complications with 50 consecutive herniorrhaphies performed under local anaesthesia upon 45 patients with previous MI. However, as all the infarcts were more than 6 months old, the reinfarction rate suggested from the larger studies would be only 3–4%; thus the data are too few for appropriate evaluation.

**Duration of anaesthesia and surgery**

The influence of the duration of the procedure on the PMI rate is controversial. Von Knorring [58], Eerola and colleagues [36], Rao, Jacobs and El-Etr [80, prospective], Tarhan and colleagues [96] and Topkins and Artusio [98] all failed to find a correlation, while Arkins, Smessaert and Hicks [3], Rao, Jacobs and El-Etr [80, retrospective], Skinner and Pearce [89] and Steen, Tinker and Tarhan [94] all found a positive correlation, the last even with an increase from 2% for procedures lasting less than 1 h, to 17% for procedures lasting more than 6 h (\( r = 0.994 \)). It is easy to be misled by statistics, however, and closer evaluation revealed, as expected, that the duration of the procedure and the type of surgery correlated. Consequently, the patients were classified into four groups: those with upper abdominal, intrathoracic and great vessel surgery lasting more than 3 h or less than 3 h, and other operations lasting more than 3 h, or less than 3 h. Then it became apparent that only patients with upper abdominal, thoracic or great vessel surgery lasting more than 3 h had a higher reinfarction rate than all others (16% v. 3–6%).

**Site and type of surgery**

These appear to be important risk factors for PMI. Eerola and colleagues [36], Goldman and colleagues [40], Rao, Jacobs and El-Etr [80], Steen, Tinker and Tarhan [94] and Tarhan and colleagues [96] all agree that there is a two- to four-fold increase in the PMI rate for thoracic and upper abdominal surgery compared with other sites, while von Knorring [58] did not find the site to be of significance.

**Vascular surgery.** Goldman and colleagues [40], Schoeppel and colleagues [88], Steen, Tinker and Tarhan [94] and Tarhan and colleagues [96] also
Table IV. Peri/postoperative myocardial infarctions in patients admitted for vascular surgery

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Authors</th>
<th>Operations</th>
<th>PMI rate</th>
<th>Mortality</th>
<th>Type of study</th>
<th>Note</th>
</tr>
</thead>
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<tr>
<td>[47]</td>
<td>Hicks et al.</td>
<td>298</td>
<td>10%</td>
<td>79%</td>
<td>Retrospective</td>
<td>Aortic aneurysms ruptured and elective</td>
</tr>
<tr>
<td>[4]</td>
<td>Arous, Baum and Cutler</td>
<td>102</td>
<td>25%</td>
<td>72%</td>
<td>Retrospective</td>
<td>Treadmill test positive</td>
</tr>
<tr>
<td>[45]</td>
<td>Hertzer</td>
<td>951</td>
<td>3.8% fatal MI</td>
<td>31%</td>
<td>Retrospective</td>
<td>Carotid endarterectomy</td>
</tr>
<tr>
<td>[81]</td>
<td>Riles, Kopelman and Imparato</td>
<td>683</td>
<td>2.3%</td>
<td></td>
<td>Retrospective</td>
<td></td>
</tr>
<tr>
<td>[26]</td>
<td>Cooperman et al.</td>
<td>566</td>
<td>3.2%</td>
<td></td>
<td>Retrospective</td>
<td>Three x cardiovasc. complications with previous MI</td>
</tr>
<tr>
<td>[12]</td>
<td>Bernhard, Johnson and Peterson</td>
<td>15</td>
<td>13%</td>
<td>50%</td>
<td>Prospective</td>
<td></td>
</tr>
<tr>
<td>[29]</td>
<td>Cutler et al.</td>
<td>48</td>
<td>12.5%</td>
<td>33%</td>
<td>Prospective</td>
<td>All MI occurred with positive exercise tests</td>
</tr>
<tr>
<td>[16]</td>
<td>Brown et al.</td>
<td>422</td>
<td>1.7% fatal MI</td>
<td></td>
<td>Retrospective</td>
<td>Aortic aneurysms, elective</td>
</tr>
<tr>
<td>[52]</td>
<td>Källerö et al.</td>
<td>380</td>
<td>5.5%</td>
<td>43%</td>
<td>Retrospective</td>
<td></td>
</tr>
<tr>
<td>[51]</td>
<td>Jeffrey et al.</td>
<td>99</td>
<td>5%</td>
<td>20%</td>
<td>Prospective</td>
<td>Aortic aneurysms, elective</td>
</tr>
</tbody>
</table>

found a high PMI rate correlated with vascular surgery. These patients, who usually have generalized atherosclerotic disease, are known to have a high frequency of cardiac complications. Many studies have specifically addressed the problems in these patients without comparing them with other patient groups, and without restricting the studies to patients with previous MI [4, 12, 16, 26, 29, 33, 44-47, 51, 52, 97]. Even without selecting only patients with previous MI, the PMI rate in patients undergoing vascular surgery is high, varying from 2.3% to 25% in large series with mortality rates from 20% to 80% (table IV). The highest PMI rate, 25%, appeared in a series of patients who all had a positive ECG exercise test before operation [4]. That the rate seems as high in this patient population as in the general group with previous MI is perhaps not so strange: there is obviously a close connection between coronary artery disease and other vascular disease. Källerö and colleagues [52], who studied 380 patients for aorto-iliac or femoro-distal surgery found a 10% infarction rate (21/210) in patients with angiographic popliteal trifurcation disease, compared with 0% (0/170) in those without.

Because of the high incidence of concomitant arteriosclerotic heart disease in patients scheduled for vascular surgery, it has been suggested that coronary angiography and, if indicated, coronary artery bypass grafting (CABG) should be performed before other vascular surgery is contemplated [44-46]. Hertzer [44] reported a 59% incidence of significant anatomical coronary artery disease in patients with abdominal aortic aneurysms and no clinical evidence of ischaemic heart disease, increasing to 95% if the patients also had clinically suspected ischaemic heart disease. He also reported an overall mortality rate of 2.1% for 188 aortic and coronary operations in patients who had coronary angiography performed as a preoperative evaluation in patients with abdominal aortic aneurysms (AAA) or occlusive aorto-iliac atherosclerosis. Arous, Baum and Cutler [4] reported 25% PMI for vascular operations in 102 patients with positive treadmill tests, but no PMI in 14 patients who first underwent CABG. Brown and colleagues [16], on the other hand, found that only 1.7% (7/422) died after operation from PMI after elective operations for AAA at the Mayo Clinic in 1978-1980, although only six patients underwent CABG before their AAA surgery and 35% of the patients had previous MI. This mortality rate is no higher than that reported by Hertzer [46] and Brown and colleagues [16] did not find it justifiable to perform routine coronary angiography before elective AAA surgery. Furthermore, they found that only 2% (3/146) of the patients with previous MI died from PMI. This is much lower than reported previously from the same institution for the same procedures [94, 96].

PMI with Non-Cardiac Surgery in Patients with Previous Coronary Artery Bypass Grafts

In the past 15 years CABG has become a common procedure, and it is presently estimated that 20% of these patients may require some form of non-cardiac operations in the future. Therefore,
studies not restricted to staged CABG/vascular surgery are appearing, to evaluate the cardiac risk from subsequent non-cardiac surgery in these patients. Unfortunately, the effect of previous CABG surgery on the PMI risk is difficult to evaluate from these studies; most do not have a control group, and most do not report the number of previous MI in the patients. Scher and Tice [85] produced the first report in 1976, with one probable PMI for 20 non-cardiac operations in patients with previous CABG. McCollum and colleagues [65] found no PMI after 77 operations and Edwards, Mulherin and Walker [35] reported 74 vascular procedures with no cardiac deaths. From these data, but without any statistical evaluation, it was suggested that patients with previous CABG not only are “acceptable risks” for surgery, but perhaps are even a lesser cardiac risk than the routine patients [65]. The conclusion that CABG can protect against cardiac complications and PMI in patients with ischaemic heart disease is shared by Akl and colleagues [2], Prorok and Trostle [77], Schoeppel and colleagues [88] and Crawford and colleagues [27]. The last study was of 358 patients with prior CABG, 70 of whom had an elective staged operation with a subsequent operation being performed 6–12 weeks after bypass, with no cardiac complications. The other operations were performed 10 days to 89 months after bypass, with three deaths and a significant number of cardiac complications (six MI), of which most occurred in patients subjected to the second operation within 30 days of CABG. The authors therefore suggest postponing elective surgery for at least 6–12 weeks after CABG.

A 6-month interval (as after an MI) was suggested by Cruchley and colleagues [28], who found that two of 121 patients with previous CABG infarcted, and that both PMI occurred within 6 months of the CABG. Patients operated upon within 6 months of the CABG had a 17% risk of cardiac complications, compared with only 2% and no infarcts if the interval was more than 6 months. Factors that increased the complication rate included congestive heart failure (33% complications) and surgery on the large vessels (40%).

In a retrospective study Mahar and colleagues [67] compared patients who had undergone CABG followed by a non-cardiac operation, with a patient group with angiographically demonstrated similar ischaemic heart disease who did not undergo CABG, but also required a non-cardiac operation. No PMI was seen after 168 operations in 99 patients with CABG, 65% of whom had a previous MI, whereas there was a 5% incidence of PMI with 58 operations in the 49 patients treated only medically, of whom a similar proportion (63%) had a previous MI. The authors did not exclude the possibility that the intervening CABG consisted of a “survival test” or caused MI in those patients who might not otherwise have had an MI after the non-cardiac operation.

The combined results of all these studies do seem to indicate that survivors of CABG appear to be reasonably good cardiac risks for subsequent operations, at least if surgery is postponed for some time (6 weeks to 6 months?). The merit of elective surgery with prophylactic CABG is not established and, as pointed out by Schoeppel and colleagues [88], there are no studies of PMI with non-cardiac surgery being performed more than 5 years after CABG. The long term prophylactic effects of CABG surgery are currently unknown and may be different because of continued progression of the coronary artery disease.


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Perioperative Myocardial Infarction (PMI) in Relation to Coronary Artery Bypass Grafting

The goal of CABG is to improve coronary blood flow and thereby relieve angina and prevent myocardial damage in patients with ischaemic heart disease. As mentioned above, the CABG procedure itself is associated with a certain myocardial damage and operative mortality, dependent on multiple interrelated variables of patient characteristics and perioperative management methods.

Diagnosis

The diagnosis of PMI in association with CABG may be difficult. Three factors commonly used as good indicators of PMI are serial ECG, serial cardiospecific enzyme liberation assessments and serial technetium 99-m-labelled pyrophosphate scans, all of which have limitations and possibilities for misinterpretation of the results [7].

ECG. The appearance of new Q-waves of 0.04 s or more duration is an accepted criterion of transmural myocardial infarction. The existence of old Q-waves or bundle branch blocks limits the usefulness of this criterion. Furthermore, the
occurrence of new Q-waves in the inferior leads after CABG has been claimed, in some cases, not to present a new MI, but rather the unmasking of a pre-existing infarction [8]. Subendocardial infarctions manifest themselves through changes in the ST-T segment. Observation of transient changes in that segment is a common phenomenon after revascularization, probably because of postoperative pericarditis or metabolic alterations, and cannot be used in the diagnosis of PMI. In general, the use of new Q-waves as the only criterion of MI after CABG underestimates the frequency of its occurrence.

Enzymes. Serial creatine phosphokinase iso-enzyme (CK mb) concentrations obtained before operation and at well defined intervals during the postoperative period, are frequently used to measure myocardial damage after CABG. A certain amount of enzyme release always occurs following revascularization, probably because of surgical trauma to the heart, ischaemic injury to the cells, washout from previously jeopardized myocardium, lung damage, haemolysis or defibrillation [31, 32, 42, 60, 66]. Thus the peak increase in CK mb is of limited value. The enzyme release from patients with severe myocardial damage (infarction) is characterized by a high peak and a prolonged release, and thus the measure of total CK mb liberation gives the most reliable result in the diagnosis of PMI [32].

Radionuclide imaging. Myocardial cell death is accompanied by cellular influx of calcium ions which localize within the mitochondria in the crystalline structure, hydroxyapatite. By using 99-m stannous technetium pyrophosphate, scintillation images of recent myocardial infarction can be produced [13] and this is used widely for the detection of new MI after CABG [17, 69].

There is no clinical “gold standard” for the diagnosis of perioperative myocardial infarction in association with CABG. When using all three of these diagnostic tests (ECG, enzymes and scanning) it is commonly concluded that a patient has suffered PMI when at least two tests are positive. One positive test alone, is regarded as a false positive [7, 60].

Frequency and consequences of PMI

The occurrence of, diagnostic criteria for and mortality from PMI are listed in table V. In these CABG patients PMI is a serious event, with mortality rates varying between 3% and 34% [21, 37, 41, 42, 84, 92] and it accounts for almost 50% of the mortality during CABG. The occurrence of PMI is associated also with arrhythmias, cardiac insufficiency and a longer stay in the ICU [9].

While there is little disagreement that PMI is associated with higher morbidity and mortality in the immediate postoperative period, the long term consequences are controversial. Bateman, Matloff and Gray [9] claimed that, while PMI may confer an ominous short-term outcome, the long term prognosis might be essentially benign, as most of the PMI are small electrophysiological events, thus explaining the lack of influence on long term clinical status or mortality. This is in agreement with the data of Codd and colleagues [24], Gray and colleagues [41] and Balderman and colleagues [7]. On the other hand, Chaitman and colleagues [22], Fennell and colleagues [38], Hacker and colleagues [43] and Namay and colleagues [73], in their follow-up studies, claimed that long term survival is significantly shorter in patients who suffered PMI compared with those who did not, even when allowance is made for the higher perioperative mortality rate in the former group. In the CASS-report on 9777 patients who underwent CABG between 1974 and 1979 [84], actuarial survival, including hospital deaths, at 1, 3 and 5 years was significantly greater in patients without infarction than in patients with PMI (96%, 94% and 90% v. 78%, 74% and 69%).

Variables associated with an increased risk of PMI

As with patients admitted for non-cardiac surgery, there is much controversy in the literature regarding preoperative variables that might predispose to PMI during CABG. According to various authors [11, 43, 66, 87, 90], age and sex are not risk factors for developing PMI during revascularization. The CASS studies [39, 84] indicated that age older than 65 years was associated with both a higher perioperative morbidity, including MI, and mortality, but there was no difference between the sexes in this older age group. Patients older than 65 years had a significantly higher incidence of multiple chronic medical diseases, thus it was difficult to single out age per se as a risk factor. On the other hand, previous illness such as hypertension or previous MI, diabetes mellitus or preoperative use of beta-blockers or anticoagulants have not been found to
be independent risk factors for PMI in these patients [22, 39, 86, 90]. Unstable angina was not associated with a higher incidence of PMI compared with patients with stable angina in the studies by Schneider, Pichard and Mindich [87] and Hultgren and colleagues [48], while Fennell and colleagues [38] and Gersh and colleagues [39] found a significant association between unstable angina and PMI.

Patients with severe pathology of the coronary tree and decreased ventricular performance have a higher risk of developing PMI. Angiographic findings of left main coronary artery stenosis, high LVEDP or a decreased ejection fraction are all associated with a higher incidence of PMI [10, 42, 71].

**Methods for intraoperative management.** The PMI rate increases with duration of cardio-
pulmonary bypass [10, 21, 42, 74]. The myocardial preservation technique used during aortic cross clamping is of great importance [1, 10, 24, 25, 56, 92]. The technique with cold potassium cardioplegia currently used is claimed to be among those factors that have contributed most to the reduction in the frequency of PMI during CABG [56, 59]. This must be seen in connection with the duration of ischaemic cardiac arrest, as an arrest time of more than 40 min increases PMI rate [42, 43, 90, 92]. The surgical technique, number of grafts and graft flow seem to be of importance [11, 42, 74, 90]. Although Slogoff and Keats [90] found that the quality of a distal anastomosis, as rated by the operating surgeon before removing the aortic cross clamp, was one of the independent predictors of PMI, graft occlusion per se does not seem to influence the PMI rate [15, 18, 24, 38].
Two distinct types of necrosis have been found by histological and electron microscopic studies in patients with PMI. First, ordinary coagulation necrosis found in areas with transmural infarction supplied by an occluded graft. Second, contraction band necrosis found in infarcted areas supplied with narrow native vessels, poorly developed collateral vessels and wide open grafts [15, 18, 95]. This contraction band necrosis is seen experimentally when a coronary artery is occluded long enough to cause severe ischaemic changes within the muscle cell before reperfusion [95] — a situation probably not different from that found during CABG when the metabolic protection during aortic cross clamping distal to a severe stenotic vessel is inadequate.

That an area of the myocardium may become ischaemic or damaged during CABG even before the patient is on cardiopulmonary bypass has been demonstrated by spillage of cardiospecific enzymes or ischaemia on the ECG [50, 74, 90].

CONCLUSION

In high risk groups of patients, especially those with previous myocardial infarction, the risk of developing and the mortality from perioperative myocardial infarction is high. It seems possible to reduce this risk by the use of "intensive" monitoring and immediate intervention when haemodynamic abnormalities occur. We still believe it is wise to postpone surgery until 6 months after myocardial infarction, if possible. As with all the other risk factors mentioned in this review, this factor must be evaluated when consulting with the patient on whether or not he or she should undergo surgery and anaesthesia. The risks of operating should always be evaluated against what is likely to happen if the patient does not undergo surgery. The possibility of reducing myocardial ischaemia and infarction in the peri- or postoperative period should be closely scrutinized in a cost–benefit evaluation.

REFERENCES

20. Carliner NH, Fisher ML, Plotnick GD, Garbart H, Rapoport A, Kelemen MH, Moran GW, Gadacz T, Peters RW. Routine preoperative exercise testing in...


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