Myocardial ischaemia in patients with frequent angina pectoris

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Summary and conclusions

One hundred patients with angina pectoris underwent 16-point electrocardiographic (ECG) mapping of the left hemithorax during a standardised exercise test. Forty-five patients had maximum ST-segment depression at position V5, while 35 had no ECG signs of ischaemia at this position. In 20 V5 was on the edge of the precordial area, which showed less severe ST-depression than the central positions. An Oxford ECG recorder and high-speed analyser were modified and used in 50 of the patients with daily angina for recording ST-segment changes over 24 hours. Serial 24-hour ambulatory recordings from the edge of the precordial area of ischaemia identified during exercise detected a mean of only $14 \pm 3\%$ of the episodes of ST-segment changes recorded from the centre of the same area. Only $16 \pm 2\%$ of the episodes detected by ECG were accompanied by chest pain. More episodes occurred between 4 am and 6 am than at any other time during the night.

This study shows the importance of recording ECG evidence of ischaemia from the precordial position showing maximum changes during exercise. ECG evidence of ischaemia occurs more frequently than anginal pain. These objective measurements add important information to the frequency of chest pain reported by patients with ischaemic heart disease.

Introduction

Recording the frequency of chest pain in patients with ischaemic heart disease is a subjective assessment. Non-invasive and repeatable methods are needed that provide a sensitive measure of the underlying pathophysiology. An objective method, particularly one that might be used during a patient's daily activities, would be useful in controlled trials of medical or surgical treatment.¹

The purpose of this study was to use isopotential mapping of the electrocardiogram (ECG) in an exercise test to describe the precordial distributions of pathological ST-segment changes. Ambulatory recordings of the ECG were taken over 24 hours from the precordial position that showed the earliest and maximum ST-segment changes of ischaemia during exercise. We present the findings in patients with daily angina as an objective assessment of the condition and its relation with chest pain.

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Patients and methods

One hundred patients (81 men, 19 women) aged 31-72 (mean 50) years were selected consecutively from a cardiological outpatient clinic according to the following criteria: all had a typical history of angina pectoris on effort, and results of an exercise test were positive²; they complained of at least one episode of chest pain per day. Sixty-one patients were taking sublingual nitroglycerine as required and 39 nitroglycerine and 40-120 mg of propranolol by mouth three times daily.

EXERCISE TEST

All the patients underwent precordial mapping of the ECG before and for 10 minutes after maximum exercise on a bicycle ergometer.³ Sixteen adhesive electrodes were equally spaced to cover the left hemithorax. A four-way switch and four-channel Elema-Schonander ECG were used to record rapidly the 16 complexes of each map. The technical details and reproducibility of this method have been described.³ ST-segment depression of 1 mm or more and sustained for 0.08 s or longer was regarded as significant. The calibration was 10 mm = 1 mV. The TP or PQ segment was used as the isoelectric line. In each map a record was made of the number of positions showing ST depression at 0, 1, 3, 5, 8, and 10 minutes after exercise. We recorded the work load and maximum heart rate achieved by each patient.

AMBULATORY MONITORING OF ST-SEGMENT CHANGES

For this part of the study we used an Oxford portable ECG tape recorder (Series 6000) and a Pathfinder high-speed ECG analyser. The low- and high-frequency filter settings were maintained at zero. The patient leads, recorder, tape, and analyser were tested together to determine the frequency response of the system to a square wave (67% loss of amplitude at two seconds) and a sine wave (< 3 dB down at 0.15 Hz). The signal was less than 3 dB down up to 50 Hz. The indifferent electrode was positioned on the bony prominence of the right sternoclavicular joint. The exploring electrode was placed on the precordial position of maximum ST-segment changes identified during the exercise test (Hewlett-Packard 14245A electrodes). The leads were fixed to the chest with adhesive tape.

In 10 of the patients the ECG was recorded continuously during five-minute periods of deep and shallow breathing, coughing, sitting, standing, lying, and bending. In addition the Elema-Schonander four-channel ECG was used for recording before, during, and after a maximum exercise test as described above in order to compare the ECG complexes and ST-segment changes recorded on the two systems simultaneously.

The ambulatory recorder was fitted to 50 of the patients two hours after precordial ECG mapping on exercise. A 1 mV calibration signal was recorded on the tape via the patient leads. Each patient was then encouraged to return to full daily activities, continue any drug treatment, and record separately (in a diary) any episodes of chest pain. After each 24-hour period the tape was replayed at 60 times real time. Each episode of ST-segment shift was replayed in real time. The time of onset, duration, and maximum ST-segment shift (in mm) were recorded with a graphic tracing. The tapes and ST-segment changes were individually assessed by two observers.

Results

EXERCISE TEST

All the patients showed significant ST-segment depression during the exercise test, and 80 experienced anginal chest pain. In 35 patients

FIG 1—Maximum precordial area of ischaemia and ECG complexes after exercise in man aged 48, one of the 35 patients in whom position V5 (C3) showed no significant ST-segment changes.

FIG 2—Precordial area, time course, and severity of ischaemic ECG changes after exercise in man aged 66 in whom V5 was positioned on edge of ischaemic area. Conventional position V5 is marked as C3 and indicated by a triangle.

FIG 3—Left: example of maximum precordial area of ischaemia after exercise in man aged 39. Twenty-four-hour ambulatory ECG recordings were made simultaneously from centre (B) and edge (A) of this area. Right: examples of pathological ST-segment depression detected over 24 hours. P indicates angina pectoris recorded by patient. Examples of ECG complexes are shown: recordings from edge of ischaemic area (A) identified 16% of episodes recorded from centre (B).

there were no significant ECG changes of ischaemia at the conventional precordial position V5, and in 20 the maximum ECG changes did not occur at this position. Figures 1 and 2 show the precordial positions and raw data recorded during exercise tests from two patients in whom the maximum ECG changes did not occur at V5. The sequence of precordial ECG changes (fig 2) showed in every patient that the precordial positions with the maximum ECG changes were also the first and last positions to show significant ST-segment depression during the exercise test.

AMBULATORY MONITORING OF ST-SEGMENT CHANGES

Changes of respiratory effort and posture produced a mean of $18 \pm \text{SD } 6\%$ alterations of R-wave amplitude, and alterations of J-point and T-wave morphology. None of these manoeuvres produced planar depression of the ST segment of 1 mm or more lasting 0.08 s or longer. A comparison of ECG tracings with those of the ink-jet recorder (Elema-Schonander) showed differences in R-wave amplitude of $\pm 15\%$ and minor differences of T-wave morphology. We detected no differences in the appearance or disappearance of significant ST-segment changes when using the two recorders simultaneously. Only 45 minutes or less out of the 24-hour ECG recordings were rejected because of baseline instability.

In 55 of the patients the maximum ECG changes during exercise did not occur at V5. In 10 of these patients we used two recorders for simultaneous 24-hour recordings from V5 and from the position of maximum change identified from the precordial maps. The recordings from V5 detected $14 \pm 3\%$ of the episodes of significant ST-segment depression detected from the central position. As an example of this fig 3 shows the precordial area of maximum ST-segment changes during exercise (left), and the ECG changes occurring during a 24-hour period and the episodes of chest pain reported by the patient (right).

In the 50 patients monitored continuously we detected 703 episodes of ST-segment depression, the mean being 14 ± 4 per day in each patient. Only $16 \pm 2\%$ of these episodes were accompanied by reported chest pain. No episodes of pain were reported without ST depression. Of all the episodes, $74 \pm 7\%$ occurred during the day (6-10 pm). The 24-hour ECG tracings from each patient were divided into 12 two-hour periods and the number of episodes of ECG changes in each period recorded. There was no pattern with time for the frequency of myocardial ischaemia during the day. At night (10 pm to 6 am), however, more episodes occurred between 4 am and 6 am than at any other time ($P < 0.001$, unpaired t tests).

Discussion

Angina pectoris is an important symptom of ischaemic heart disease, and the recorded frequency of pain is used in controlled trials of medical and surgical treatments. Although relieving pain is an essential part of clinical practice, uncertainties exist about whether angina accurately represents the severity of the underlying condition.^{4 5}

Precordial mapping of the left hemithorax provides a measure of area, time course, and severity of ischaemic ECG changes. In addition it permits the identification of the precordial position showing the earliest and maximum ECG signs of ischaemia. In 35 of the patients this area was separate from the conventional V5 position.⁴ The implications of this finding became clear when 24-hour recordings of the ECG in these patients were taken from V5 and the precordial area of maximum change. More episodes of ischaemia were recorded from the centre of the projected area of abnormal ECG signs in each patient than from V5.

The technical requirements for ambulatory monitoring of ST-segment changes have been examined by other workers.⁶ Baseline stability, adequate low-frequency response, the effects of posture, and respiration are all important.⁷ Although the low-frequency response of our recorder was adequate to 0.15 Hz, the tests used could not detect important differences when comparing its results with those of an ink-jet recorder responding to 0.05 Hz (<3 dB down). In particular, false-positive planar ST-segment depression could not be detected under any circumstances.

Several studies have shown that planar depression of the ST segment of 1 mm or more lasting for 0.08 s or longer is a consistent and discriminate sign of myocardial ischaemia.² This study found many more episodes of ischaemia than might have been suspected from the reported chest pain, and only 16% of ischaemic episodes were accompanied by reported pain. If this percentage is variable then the frequency of angina may not accurately represent the severity of the condition.

The 24-hour recordings provide a measure of frequency, severity, and timing of ischaemic episodes and of their relation to chest pain, activities, heart rate, and drug administration. Ischaemic episodes were recorded at night during sleep and

particularly between 4 am and 6 am. It might be interesting and of therapeutic importance to relate this finding to blood concentrations of antianginal drugs, the arterial oxygen content, heart rate, blood pressure, circulating catecholamines, and the presence or absence of rapid-eye-movement sleep.

Thus this study showed that precordial ECG mapping during exercise and 24-hour ambulatory recording of ST-segment changes provide objective measurements that may be of value in assessing angina and myocardial ischaemia. More information is obtained when the individual precordial area of maximum ECG changes in each patient is used for 24-hour recording of ischaemic episodes. Under one-fifth of the ECG episodes of myocardial ischaemia were accompanied by pain, and ischaemic episodes occurred during sleep, particularly between 4 am and 6 am.

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Precordial exercise mapping: improved diagnosis of coronary artery disease

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Summary and conclusions

Surface mapping of the exercise electrocardiogram (ECG) provides a measure of the precordial area, severity, and time course of ST-segment changes occurring after exercise. Sixteen-lead isopotential surface maps were recorded before and after exercise in 109 patients with probable angina who subsequently underwent coronary arteriography. In addition, exercise ECGs with three orthogonal leads were obtained in 53 of these patients, and with a single unipolar chest lead in all 109. Of the 109 patients, 85 had significant ($\geq 70\%$) narrowing of at least one major coronary artery. The sensitivities of the precordial surface mapping, orthogonal leads, and

single chest lead (V5) when compared with the findings at coronary arteriography were 95%, 68%, and 64% respectively, while the specificities of the three lead systems did not differ significantly.

The technique of precordial surface mapping after exercise may easily be applied in clinical practice and requires only conventional equipment available in most hospitals. It effectively aids diagnosis of coronary artery disease.

Introduction

Exercise electrocardiography is a well-established non-invasive aid in diagnosing coronary artery disease.^{1 2} Initially only a single chest lead was used, but in an attempt to improve the specificity and sensitivity new lead systems have been tried. Recent studies have used the 12-lead electrocardiogram (ECG) and the Frank system of three orthogonal leads.^{3 4} A technique has been described for recording the precordial surface map before and after exercise using conventional equipment available in most hospitals.⁵ The purpose of this study was to show the superiority of this technique over the orthogonal and single chest-lead systems in diagnosing coronary artery disease.

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