PAPERS AND ORIGINALS

Diagnostic value of routine exercise testing in hospital patients with angina pectoris

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Summary and conclusions

A group of patients with angina pectoris were investigated prospectively using a simple and well-recognised exercise test protocol, and S-T segment displacements during exercise were correlated with the results of coronary arteriography. Definitive exercise results in 100 patients correlated well with findings on coronary angiograms: 69 out of 70 patients with positive exercise test results had significant coronary disease on angiography, while 23 out of 30 with negative exercise test results had no significant coronary disease. In six patients a period of physical training changed indeterminate initial tests to definitive ones after the training.

These results show that the use of a widely available exercise test and a light physical training programme, with rigid adherence to the protocol, can reduce the overall demand on coronary arteriography.

Introduction

It is now widely accepted that the electrocardiographic (ECG) response to exercise may be used as an objective and non-invasive indicator of myocardial ischaemia, especially in patients

in whom chest pain and other clinical findings are unequivocal.^{1,2} Subsequently selective coronary arteriography serves to define the site of anatomical lesions in the coronary tree.

The predictive value of exercise testing, using S-T segment displacement, suffers, however, from false-positive and false-negative results. Furthermore, some patients cannot attain a sufficiently high heart rate during the test to provide a definite result.³⁻⁵ Various modifications of exercise testing have been introduced to reduce the incidence of false results—in particular, the use of computer-assisted techniques and precordial surface mapping⁶⁻⁹—but the increased diagnostic accuracy obtained with these modifications remains to be established, and the use of modified tests is unlikely to reduce the incidence of indeterminate results. Limited facilities in most hospitals would also confine the use of modified tests to a few centres.

Our purpose was to investigate patients with angina pectoris using conventional exercise tests with relatively simple equipment (which would be available in any general hospital) and using well-established criteria, firstly, to determine the accuracy with which the incidence of radiographically demonstrable lesions could be predicted and, secondly, to find out whether a period of physical training¹⁰ would help in achieving a definitive test result. The results would indicate whether it is possible to identify a group of patients in whom angiography is unnecessary.

Patients and methods

During the 20 months from February 1977 132 patients were investigated. These patients were selected on the basis of a clinical history of angina pectoris and the decision to perform selective coronary arteriography. Patients suffering from valve diseases, hypertension, left ventricular failure, or cardiac arrhythmia and patients taking digoxin or beta-blockers were excluded from the study.

The exercise test—The test was performed on an electrically braked bicycle ergometer (Elema Schönander) with the patient upright. The patients pedalled at 60 rpm against a continuous series of incremental loads, in steps of 150 kpm/min every third minute, the initial load being 150 kpm/min. The procedure was continued until one of the following endpoints was reached: (a) significant depression of the S-T segment as defined below, or (b) a heart rate of 85% of the maximum predicted value for age.¹¹ Apart from these endpoints the

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test was also terminated for any of the following reasons: significant pain in the chest; an incidence of more than six ventricular ectopic beats per minute, consecutive or multifocal; and exhaustion of the patient. The exercise tests in patients failing to attain either of the two endpoints were classified as indeterminate.

The ECG was recorded from CM₅ position using a conventional amplifier and recorder (models 420/3 and 1127/01 respectively; SE Laboratories Ltd, Feltham, England). The frequency response of the system was flat ($\pm 2\%$) to 40 Hz. The ECG was displayed continuously on a memory oscilloscope, and the output of the ECG amplifier was used to drive a cardi tachometer. The heart rate was also obtained by counting the cardiac cycles on the ECG tracing. ECG records were obtained at a paper speed of 25 mm/s for 15 seconds at the end of each three-minute period during the exercise and at the end of the first, third, and fifth minutes after stopping the exercise. The tracings were analysed independently by two observers, using a transparent ruler with gradation of 0.5 mm without any magnification of the tracings. The ability of the observers to discriminate small displacements of the S-T segment was assessed separately. The same record interspersed blindly among other records was analysed repeatedly at different times. The displacement of the S-T segment was measured during the exercise test, and the decision regarding significant S-T depression was accepted only when both observers agreed. Significant S-T depression was defined as a net change of 1.0 mm or more from the resting value (on a tracing calibrated at 1 mV=10 mm) at a point 80 ms after the QRS complex in three consecutive cardiac cycles. The level of the P-R segment was taken as the zero reference.

Physical-training programme—In patients in whom the first exercise test was regarded as indeterminate because the appropriate heart rate was not attained, a further exercise test was performed after a period of 10-12 weeks of physical training according to the Canadian Air Force (5BX/XBX) programme.¹⁰

Selective coronary arteriography—For the study coronary arteriography was performed without any knowledge of the results of the exercise test, and the angiograms were reported on independently as a routine hospital procedure. These reports were used for the analysis, and the patients were classified into (a) those with no significant coronary disease, when the luminal narrowing of any coronary artery was less than 75%, and (b) those with significant coronary disease, when more than 75% narrowing existed in a major coronary artery. Percentage narrowing was essentially a visual impression based on views of the vessels in more than one plane.

Results

One hundred and thirty-two consecutive patients were investigated. Initially, definitive test results were obtained in 94 patients. In two patients the two observers failed to agree that the S-T depression was in excess of 1.0 mm and these were not considered further. Thirty-six patients (28%) failed to reach the defined endpoint of the test in terms of predicted heart rate and their results were thus indeterminate; six of these patients underwent exercise training, after which they gave definite results. Thus 100 patients gave definite results. They comprised 90 men and 10 women, and their average ages were 46.5 years (range 26-67) and 49.1 years (range 42-58) respectively.

The results of exercise tests were positive in 70 patients, 25 of whom gave a previous history of myocardial infarction. Comparison of the results with findings on coronary angiography is shown in table I. A false-positive result was obtained in one out of 24 patients with no significant coronary disease (4%). In 30 patients, five of whom gave a previous history of myocardial infarction, exercise testing gave negative results; false-negative results were obtained in seven out of 76 patients with significant coronary artery disease (9%). Three of these seven patients had a history of myocardial infarction and there were no false-negative results in patients with lesions in three coronary arteries or in the main stem of the left coronary artery.

Thus the test results showed a sensitivity of 91% (percentage

of patients with coronary disease having a positive exercise test) and a specificity of 96% (percentage of patients with no coronary disease having a negative exercise test).

Accuracy of measurements—In the patients who yielded a positive exercise test, the S-T depression averaged $1.8 \pm \text{SD } 0.6$ mm. In the patients with a negative result the S-T depression averaged 0.09 ± 0.1 mm. The accuracy of four measurements of the same trace expressed as 2 SD was 0.17 mm (mean depression 1.87 mm) in one observer and 0.24 mm (mean depression 1.93 mm) in the other.

Effect of physical training—In six of the 36 patients who failed to achieve the target heart rate the exercise test was repeated after a physical-training period. In these patients the average heart rate achieved in the first test was 110 beats/min (range 98-110); after training it was 146 beats/min (range 138-155). In all six patients a definitive result was obtained, and all were included in the comparison with the results of coronary arteriography. In the remaining 30 patients we decided on clinical grounds to proceed directly to coronary arteriography and treatment.

Discussion

Depression of the S-T segment of the ECG during exercise has been widely used as a diagnostic procedure in patients suffering from coronary artery disease. Numerous exercise test protocols and ECG criteria have been adopted in a variety of patients, ranging from those with classical angina pectoris to those with no symptoms, in attempts to establish the diagnostic accuracy of these tests.¹ In general, the accuracy with which the existence of the disease is predicted has varied with the test protocol, the ECG criteria adopted, and the population studied.^{1 2 12-16} Furthermore, the evidence on the predictive accuracy of the exercise test has been drawn mainly from correlations with results of coronary arteriography. This approach suffers from obvious drawbacks. For instance, coronary artery narrowing does not necessarily imply myocardial ischaemia, and vice versa.^{1 16 17} Nor does a normal coronary arteriogram consistently exclude the presence of anatomical coronary obstruction¹⁸; in addition, luminal narrowing is estimated in relation to the lumen of a diseased arterial segment. In fact there is uncertainty about what constitutes a significant degree of obstruction, and the random error of the estimation is unknown.¹⁹ These considerations place obvious limits on the significance of "false" results in conventional exercise testing when the standard for estimating the degree of obstruction to blood flow in coronary arteries rests on the results of angiography. Nevertheless, coronary arteriography is still the best technique available to define the anatomy of the coronary arteries in patients in whom a decision to operate has been made—for example, because medical treatment has failed.

Coronary arteriography is, however, available only at a few regional centres. Hence a simple exercise test which serves as an objective indicator for the need for coronary arteriography is desirable. Such an investigation needs to be easy to perform, widely available, correlate well with the results of coronary arteriography, and be safer than angiography itself.

Viewed from this standpoint, any of the recent modifications in the assessment of S-T segment in exercise testing would either introduce a new systemic error¹ or make the procedure less available for widespread use. Examples of these limitations are clearly demonstrated with the use of computer technology,⁶ which is available only in a few centres. Fox *et al* used precordial mapping in exercise testing, but because of difficulties introduced by the effect of respiration on the ECG records these could be adequately assessed only after termination of the exercise.⁹ The systematic error of this method is as yet uncertain. Fox *et al* assessed the diagnostic accuracy of this method by comparing it with the use of a single V5 lead method.²⁰ While the single V5 lead method results in a significant negative error,^{14 16 21} false-negatives (5%) as well as a significant incidence of false-positive results (8%) were encountered using the mapping method.²⁰ Thus, in the context of reducing the demand on coronary arteriography, it remains to be shown that the precordial mapping method reduces the incidence of false-

TABLE 1—Results of exercise testing in 100 patients with angina pectoris

		Significant coronary disease			No significant coronary disease	Total
		1 vessel	2 vessels	3 vessels		
Positive	..	30	22	17	1	70
Negative	..	4	3	0	23	30

positive results and increases the specificity of the test. The specificity of the surface mapping method was 91⁰,²⁰ which is less than the specificity with our method. Furthermore, the use of post-exercise S-T segment depression results in a higher incidence of false-positive results, especially when slowly rising S-T segments are included.²²

We used a simple and easily available exercise test in a selected group of patients according to well recognised criteria to reduce any systematic error. And our results showed that in a highly selected group of symptomatic patients the discrepancies between the test of function and the extent of the radiographically demonstrable lesions were minimised. Our method predicted the existence of radiologically demonstrable lesions with greater accuracy than other reported methods (table II).^{3 5 14 20 23-32} This improvement was achieved merely by

TABLE II—Investigations correlating the results of exercise electrocardiography with the finding of coronary arteriography in symptomatic patients

Investigator	No of patients	Sensitivity	Specificity
Mason <i>et al</i> (1967) ²²	84	78	89
Hultgren <i>et al</i> (1967) ²³	55	60	100
Kasserbaum <i>et al</i> (1968) ²⁴	68	54	97
Roitman <i>et al</i> (1970) ⁵	46	80	88
Ascoop <i>et al</i> (1971) ²⁶	96	59	94
Martin and McConahay (1972) ²⁷	100	62	89
Kelemen <i>et al</i> (1973) ²⁸	74	54	96
Bartel <i>et al</i> (1974) ³	650	65	92
Froelicher <i>et al</i> (1976) ¹¹	52	77	—
Goldschlager <i>et al</i> (1976) ²⁹	330	64	93
Detry <i>et al</i> (1977) ³⁰	278	86	70
Chaitman <i>et al</i> (1978) ³¹	100	88	82
Fox <i>et al</i> (1979) ²⁰	109	95	91
Baron <i>et al</i> (1979) ³²	72	91	86

carefully selecting the patients with anginal pain and adhering rigidly to an exercise test protocol. The question which remains to be resolved is whether such an approach to exercise testing is of value clinically.

A positive exercise test result was obtained in all but one of our patients with demonstrable lesions in the coronary arteries. No patients with significant disease in the three major vessels or in the left main stem were “missed.” Thus a positive exercise test in these patients indicated a very strong probability that radiologically significant lesions were present in the coronary arteries. Since only those patients with lesions in all three major vessels or in the left main stem have their mortality favourably affected by surgery,³³⁻³⁶ a case could be made for performing angiography only on those in whom a provisional decision to proceed to surgery on clinical evidence plus a positive exercise test has already been made. In such patients the main value of the angiogram would be in showing the surgeon the site of the lesion. If a decision not to proceed to surgery has been made there is probably no case for performing angiography.

In patients with negative exercise test results most showed no evidence of radiographically significant lesions. A few had significant lesions in one or two vessels. The present evidence is that the mortality in these patients is not favourably affected by surgery, though there is a belief that the symptoms are improved.^{33 35 36} Thus in patients with a negative result on exercise testing a decision to proceed to angiography should be made only if the decision to perform surgery has already been made on the basis of the symptoms. Such an approach would reduce the overall demand for coronary angiography.

Additional refinements of technique, such as a second exercise test after a period of physical training, are valuable in patients who cannot attain a sufficiently high heart rate during an exercise test to give a definite result. Previously the incidence of indeterminate tests has ranged from 14.5⁰, to 33⁰.^{3-3 28} In our investigation all six patients who failed to yield a result on the first test and who were tested after physical training, produced a definitive result on the second test. Their ability to

attain the required heart rate on the second occasion was probably the result of increased confidence and not necessarily a gain in physical fitness.

We have therefore shown that, provided strict criteria are adhered to, it is possible to devise a simple exercise testing programme without recourse to advanced equipment for analysing the exercise ECG in hospital practice.

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ONE HUNDRED YEARS AGO Surgeon-Major Starcke, in a Vienna medical journal, has stated that by mixing with castor-oil as much raw sugar as will convert the whole into a thick muddy consistency (about three-parts of sugar to one of oil is necessary), flavouring with a little cinnamon or other spice, children will swallow the medicine eagerly. “They will struggle,” he says, “for the favour of licking the spoon.” The dose for adults prepared in this way is so great that he recommends in preference the addition of a little compound liquorice powder to the oil (about one to two), to make boluses, which are easily swallowed. (*British Medical Journal*, 1879.)