Comparison of Radiocardiography and Conventional Electrocardiography in the Exercise Tolerance Test

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The importance of the exercise tolerance test in the detection of ischaemic electrocardiographic changes in patients with suspected angina pectoris has been well established, but the value of the conventional post-exercise electrocardiogram is limited by obtaining the record after the period of maximum cardiac stress. The introduction of radiotelemetry made possible the constant monitoring of the electrocardiogram during exercise when the heart is subjected to the greatest strain. The value of radiotelemetry during exercise compared with conventional electrocardiography has been questioned by Rosenfeld and Master (1964) who claim that fallacious and less reliable results are obtained with this method. It is, therefore, the purpose of this study to compare the value of radiocardiography and conventional electrocardiography in the detection of ischaemic heart disease by exercise tolerance tests.

PATIENTS AND METHODS

Two groups of patients were included in the study. The first group consisted of 50 patients aged from 33 to 68 years, comprising 26 men and 24 women, with a history suggesting angina pectoris. The second group of 32 hypertensive patients with no previous history of chest pain were aged from 21 to 68 years and included 15 men and 17 women; in this hypertensive group 54 exercise tests were carried out by the 32 patients.

The radiocardiograph consisted of a small, portable, battery-operated, frequency-modulated transmitter which was carried by the patient during exercise, and a battery-operated frequency-modulated receiver which connected with a standard dual-channel electrocardiograph where the tracing was recorded on one of the channels in the usual way. The transmitter was connected to the patient by two metallic ring electrodes attached to the patient's chest wall by plaster strips. The electrode sites were at the base of the heart below the outer third of the right clavicle and at the cardiac

apex, and in each case the patient's skin was thoroughly cleaned with spirit and then dabbed with electrode jelly to improve electrical contact. The tracing produced with the electrodes in these sites most closely resembled V5 of the conventional electrocardiograph (Fig. 1), though there was not always a consistent similarity in individual patients (Fig. 2).

The details of the exercise tolerance test used have been described fully in an earlier publication (Sandler, 1961). Briefly, the technique is a modification of the Master two-step test in which, however, the patient exercises at his own speed and within the limits of his own capacity until he is stopped either by the development of angina or by ischaemic changes in the electrocardiogram; lead V5 is recorded before, and at 30-second intervals after, exercise. In the present study both the conventional V5 and the radiocardiogram were recorded simultaneously before and after exercise on the two-channel electrocardiograph, thus ensuring an accurate comparison between the two tracings. During exercise the radiocardiogram alone was recorded after every 10 circuits over the steps. Exercise was stopped if angina developed, if ischaemic change showed on the radiocardiogram, or in any case after 150 circuits over the steps.

In V5, plane or sagging depression of the S-T segment of at least 0.08 sec. duration (Fig. 3) was accepted as valid evidence of myocardial ischaemia (Lloyd-Thomas, 1961; Master and Rosenfeld, 1961), and similar criteria were adopted for the radiocardiogram (Bellet *et al.*, 1962).

RESULTS

Table I shows the incidence of S-T depression before and after exercise with the radiocardiograph and with lead V5. In the anginal patients, though there was a greater incidence of S-T depression before exercise in the radiocardiogram, this was just not significant, but after exercise S-T depression was significantly more frequent in the radiocardiogram than in lead V5. On the other hand, the hypertensive patients showed no significant

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FIG. 1.—Similarity between radiocardiogram and lead V5.

FIG. 2.—Increased sensitivity of radiocardiogram compared with lead V5.

FIG. 3.—Typical ischaemic S-T depression in radiocardiogram.

differences between radiocardiogram and lead V5 either before or after exercise.

The degree of S-T depression before and after exercise and the change in the amount of S-T depression produced by exercise is shown in Table II. Whereas there was no significant difference

between radiocardiogram and V5 before exercise, both anginal and hypertensive patients showed a significantly greater degree of S-T depression after exercise in the radiocardiogram than in V5; in addition, the change in S-T depression produced by exercise was significantly more marked in the

TABLE I
INCIDENCE OF S-T DEPRESSION IN RADIOCARDIOGRAM AND V5 BEFORE AND AFTER EXERCISE

		Radiocardiogram	V5	Significance of difference	
Angina (50 tests)	Before exercise	36 per cent	22 per cent	$p < 0.1$	> 0.05
	After exercise	76 per cent	54 per cent	$p < 0.01$	> 0.005
Hypertension (54 tests)	Before exercise	39 per cent	24 per cent	$p < 0.05$	> 0.025
	After exercise	67 per cent	65 per cent	$p < 0.45$	> 0.4

TABLE II
COMPARISON OF DEGREE OF S-T DEPRESSION IN THE RADIOCARDIOGRAM AND V5 BEFORE AND AFTER EXERCISE

		Radiocardiogram		V5		Significance of difference
		No. of positive tests	Mean S-T depression (mm.)	No. of positive tests	Mean S-T depression (mm.)	
Angina	Before exercise	18	1.05	11	0.89	$p < 0.3$
	After exercise	38	1.36	27	0.87	$p < 0.01$
	Change	38	0.91	27	0.53	$p < 0.005$
Hypertension	Before exercise	21	1.10	13	0.75	$p < 0.1$
	After exercise	36	1.77	35	0.88	$p < 0.0005$
	Change	36	1.15	35	0.60	$p < 0.0005$

TABLE III
COMPARISON OF DURATION OF S-T DEPRESSION AFTER EXERCISE IN THE RADIOCARDIOGRAM AND V5

		Radiocardiogram		V5		Significance of difference
		No. of positive tests	Mean duration of S-T depression (sec.)	No. of positive tests	Mean duration of S-T depression (sec.)	
Angina		38	367.6	27	306.3	$p < 0.025$
Hypertension		36	409.9	35	320.3	$p < 0.025$

TABLE IV
RADIOCARDIOGRAPHIC FINDINGS DURING AND AFTER EXERCISE IN PATIENTS WITH NORMAL POST-EXERCISE V5

	No. of tests with V5 normal after exercise	Radiocardiogram	
		S-T depression during exercise	S-T depression after exercise
Angina	21	13 (61%)	12 (57%)
Hypertension	19	5 (26%)	5 (26%)

radiocardiogram than in V5, and this also applied to both anginal patients and hypertensive patients. The duration of S-T depression after exercise is shown in Table III and was significantly longer in the radiocardiogram than in V5 in both groups of patients.

The value of the radiocardiogram in detecting ischaemic change not shown by V5 after exercise is indicated in Table IV. Almost two-thirds of the anginal patients who showed no ischaemic S-T depression in V5 after exercise did, in fact, produce

changes during and after exercise in the radiocardiogram; the hypertensive patients showed a reduced frequency of positive results in the radiocardiogram. When a similar assessment was made to determine how frequently V5 detected ischaemic change not shown by the radiocardiogram during or after exercise, only 1 out of 10 anginal patients and 4 out of 16 hypertensive patients showed positive results in V5 after exercise.

Table V compares the value of recordings made during exercise with those after exercise in the radio-

TABLE V
COMPARISON OF CHANGES DURING AND AFTER EXERCISE IN THE RADIOCARDIOGRAM

	No. of tests	S-T depression during exercise			S-T depression after exercise		
<i>Normal before exercise</i>							
Angina	32	56 per cent			66 per cent		
Hypertension	33	51 per cent			48 per cent		
		More S-T depression	Less S-T depression	No change	More S-T depression	Less S-T depression	No change
<i>S-T depression before exercise</i>							
Angina	18	94 per cent	6 per cent	0	89 per cent	0	11 per cent
Hypertension	21	76 per cent	0	24 per cent	86 per cent	0	14 per cent

cardiogram. In both anginal and hypertensive patients the increased incidence of S-T depression during exercise and after exercise did not differ significantly, irrespective of whether the S-T segment was depressed or normal before exercise.

DISCUSSION

It has clearly been shown in normal subjects that the haemodynamic response to exercise reaches a peak within one minute of exercise and may have disappeared within one minute of rest (Donald, 1959; Donald *et al.*, 1955; Lombardo *et al.*, 1953). Patients with advanced coronary artery disease may have an inadequate compensatory haemodynamic response to exercise, resulting in prolonged electrocardiographic abnormality after exercise (Taylor, Donald, and Bishop, 1957; Lombardo *et al.*, 1953). In the early stages of coronary artery disease, however, when the compensating mechanism during exercise has not yet become inadequate, the importance of recording the electrocardiogram in the first minutes of maximal cardiac stress is apparent and the potential value of the radiocardiogram becomes obvious. The present study shows clearly the superiority of the radiocardiogram over the conventional electrocardiogram in detecting myocardial ischaemia, since over half the patients with suspected angina who showed no change in the post-exercise V5 developed S-T depression on the radiocardiogram during exercise (Table IV). However, before accepting an ischaemic basis for the S-T depression recorded on the radiocardiogram during exercise, consideration must be given to the influence of posture on the radiocardiogram since the patient changes from the semi-recumbent posture, in which the pre-exercise recording is made, to the erect posture for the performance of the exercise. The development of postural S-T depression under these circumstances has been documented (Rosenfeld and Master, 1964; Hinkle *et al.*, 1964), but in a recent detailed study by Lachman, Semler, and Gustafson (1965) it was found that orthostatic

changes can be minimized and sometimes eliminated by appropriate positioning of the two electrodes, and the sites recommended are those adopted in the present study, with one electrode below the lateral end of the right clavicle and the other in the region of the cardiac apex. The absence of false-positive results during exercise in the present study is confirmed by the close similarity in the incidence of S-T depression recorded during exercise in the radiocardiogram and that obtained in the radiocardiogram after exercise when the patient had returned to the semi-recumbent posture once more (Table V), thus supporting the ischaemic basis of the S-T depression during exercise in the erect posture.

A major difficulty encountered with the standardized exercise tolerance test of Master and Rosenfeld is knowing whether the amount of exercise is sufficient to induce ischaemic changes in the electrocardiogram. Not infrequently the recommended amount of exercise has been found to be inadequate (Fife, Howitt, and Stevenson, 1958) and considerable controversy still exists as to the type and amount of exercise required for these tests (Scherf, 1960). To some extent this problem can be overcome by the method adopted in the present study which allows the patient to exercise until he develops angina. However, with conventional pre- and post-exercise electrocardiography difficulty is still encountered in knowing how much exercise to allow if angina does not develop, and it is in precisely this respect that continuous radiotelemetry during exercise can be most valuable, since it becomes immediately apparent when sufficient exercise has been carried out to produce ischaemic change in the cardiogram. An even more important advantage of exercise radiotelemetry is that it minimizes the risk of the dangerous sequelae that may develop in the conventional pre- and post-exercise tolerance tests if the subject does not develop angina during exercise and is inadvertently allowed to exercise beyond the point at which silent myocardial ischaemia has developed (Grossman and Grossman, 1955).

The greater sensitivity of the radiocardiogram compared with the conventional electrocardiogram in respect of both the degree and duration of S-T depression recorded after exercise is also clearly shown in the present study (Tables II and III). The superiority in suspected angina of a radiocardiogram after exercise instead of conventional V5 is demonstrated both by the significantly higher incidence of S-T depression after exercise in the anginal patients (Table I) and by the detection of ischaemic change after exercise in the radiocardiograms of over half the patients with a normal post-exercise V5 (Table IV).

The value of the radiocardiogram in recording the electrocardiogram at a considerable distance from the receiver is obvious, the range of the apparatus in the present study being up to a quarter of a mile. However, when used for the purpose of an exercise tolerance test at close quarters the necessity for radiocardiography has been questioned by Rosenfeld and Master (1964) who have shown that the electrocardiogram can be satisfactorily recorded during exercise with a conventional electrocardiograph by direct connexion with the patient. In this interesting study, Rosenfeld and Master doubted the adequacy of the low-frequency response of radiocardiographs, and claimed that the apparatus was less consistent in detecting ischaemic heart disease than the conventional electrocardiograph. In their study, however, accurate comparison of radiocardiogram and electrocardiogram was not possible since the records were not made simultaneously. The spontaneous fluctuations in the natural course of ischaemic heart disease and spontaneous variation of S-T depression in the electro-

cardiogram of anginal patients is well established, and a valid comparison of radiocardiography and conventional electrocardiography can only be made from simultaneous records, as in the present study. This has shown not only the adequacy of the response of the radiocardiograph in detecting ischaemic heart disease but also its increased sensitivity compared with the electrocardiograph, since S-T depression was both more marked (Fig. 3) and more prolonged when simultaneous changes were present in both records (Table III).

The incidence of ischaemic changes on exercise in the hypertensive patients with no previous history of angina was 59 per cent and equally frequent in both men and women (Fig. 4). Although some observers have doubted the association between coronary atherosclerosis and hypertension (Bjurulf, 1964; Evans, 1965), the findings in the present study indicate the frequency of latent ischaemic heart disease in hypertension, and are in accord with the results of the Framingham Survey in which the association of hypertension and coronary artery disease has been quite clearly established (Kannel *et al.*, 1961). Although the presence of latent myocardial ischaemia in hypertension might suggest the need for caution in using hypotensive therapy, recent observations have shown that no deleterious effects have occurred in these patients, and in fact repeat exercise tolerance tests after the blood pressure has been controlled show a reduction in the degree of ischaemic change (A. W. D. Leishman and G. Sandler, unpublished).

It has been pointed out that artefacts may occur with the radiocardiograph as the tracing is subject to influences peculiar to frequency-modulated

FIG. 4.—Ischaemic change in the radiocardiogram during exercise in a hypertensive patient without angina.

systems, such as distortion from the transmitter, from drift and inexact tuning as well as inadequate automatic frequency control. Although artefacts were occasionally evident in the system used in the present study, these were infrequent and easily recognized as artefacts by comparison with the main bulk of the tracing. The possibility of inclusion of artefactual records in the diagnosis of ischaemic changes was also minimized by accepting undoubted plane or sagging S-T depression of 0.08 sec. duration as the sole criterion of ischaemia, thus excluding such variables as alteration in QRS duration, T and U wave changes, etc., accepted by other workers (Bellet *et al.*, 1962).

SUMMARY

A comparison has been made between radiocardiography, allowing continuous monitoring during exercise, and conventional electrocardiography, with pre- and post-exercise recording only, in detecting ischaemic heart disease by exercise tolerance tests in 50 patients with suspected angina and 32 hypertensive patients without angina. Accurate comparison was made possible by simultaneous recording of both tracings on a two-channel electrocardiograph.

The radiocardiogram was clearly superior to the conventional electrocardiogram in detecting cardiac ischaemia, since almost two-thirds of the anginal patients who showed no change in the post-exercise conventional lead V5 had obvious ischaemic changes on their radiocardiograms either during or after exercise. In addition, when S-T depression was present in both radiocardiogram and electrocardiogram, the radiocardiogram consistently showed more marked and more prolonged change, indicating greater sensitivity.

The high incidence of latent ischaemia revealed by the radiocardiogram in hypertensive patients without angina is pointed out.

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