High Frequency Electrocardiography in Ischaemic Heart Disease

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Scalar electrocardiograms contain high frequency components which are not recorded with conventional electrocardiographic apparatus (Dower, 1964). The clinical value of these high frequency components has been questioned (Scher and Young, 1960), but there is evidence that they may be of help in the diagnosis of ischaemic heart disease (Langner, 1953). A study of the electrocardiogram in normal subjects and patients with undoubted ischaemic heart disease has been made using an instrument with a high frequency response.

SUBJECTS AND METHODS

The 34 normal subjects were chosen from the medical and technical staff of the National Heart Hospital and Institute of Cardiology. All were men, aged between 18 and 65 years (14 aged 18–29 years, 12 aged 30–39 years, 8 aged 40–62 years), and gave no history of heart disease. All had normal conventional electrocardiograms.

The 38 patients studied were attending the National Heart Hospital. In all cases a firm diagnosis of ischaemic heart disease had been made previously on clinical and conventional electrocardiographic grounds. All the patients were men. They were divided into 3 groups: (1) conventional electrocardiograms showing pathological Q waves (16 patients); (2) conventional electrocardiograms showing normal QRS complexes but abnormal ST-T or T waves (12 patients); (3) conventional electrocardiograms, normal (10 patients). The majority of patients in group (3) had had abnormal electrocardiograms previously. In all cases there was sinus rhythm and the QRS duration did not exceed 0.10 sec. No patient had had fresh ischaemic episodes in the three months before study.

Electrocardiograms were taken using an Electronics for Medicine Simultrace Recorder Model DR8, Amplifier Model EEP-8 which gives tracings with a high frequency cut off (3 decibels down) at 2,000 c.p.s. Three types of 12-lead electrocardiograms were taken from each subject: (1) paper speed 25 mm./sec., sensi-

tivity 1 cm./1 m. volt, high frequency cut off at 50 c.p.s. This is referred to as the "conventional tracing"; (2) paper speed 200 mm./sec., sensitivity 2.5 cm./1 m. volt, no high frequency filter. This is referred to as the "high fidelity tracing"; (3) an approximation of the first derivative of the electrocardiogram using a differentiating circuit consisting of a simple CR network, supplied by Electronics for Medicine, with a time constant of 0.5 sec. For this tracing paper speed was 200 mm./sec. and sensitivity 2.5 cm./15 m.volt/sec. The tracing is referred to as the "differentiated tracing". For each lead the three tracings were examined and the number of changes of direction of the QRS complex was counted. Thus an RSR complex has 5 changes of direction and a QS complex 3 (Fig. 1 and 2).

Because of the high sensitivity and frequency response used, great care was taken to reduce interference and muscle tremor to a minimum, this being particularly important in the differentiated tracing. Where base line tremor was excessive the tracings were disregarded. In each tracing only changes in direction found constantly in three consecutive QRS complexes were counted.

The findings in the high fidelity and differentiated records are expressed as the number of additional changes of direction as compared with the conventional record; these additional changes of direction are described as the "high frequency components". This method of analysis has been used to eliminate the effect of low frequency changes of direction and to permit comparison between groups of tracings in which the conventional electrocardiograms show different numbers of changes of direction.

Statistical comparisons between different groups of patients and normal subjects were made using the "t" test. Values of "p" less than 0.05 were considered significant.

FINDINGS

Table I and Fig. 3 show the mean values for changes of direction of the QRS in the conventional electrocardiogram, and the mean values of the high frequency components of the high fidelity and differentiated tracings in normal subjects. Analysis of the values obtained in the different age-groups shows no consistent trend and there are no

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FIG. 1.—High fidelity and differentiated electrocardiograms from a normal subject.

FIG. 2.—High fidelity and differentiated electrocardiograms from a patient with ischaemic heart disease.

TABLE I
NORMAL SUBJECTS

Electrocardiogram				Leads										
				I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5
*Conventional	Mean		4.2	4.4	4.7	4.5	4.5	4.4	4.2	4.2	4.1	4.2	4.4	4.5
	S.D.		0.5	0.9	0.8	0.7	0.8	0.7	0.4	0.6	0.4	0.5	0.6	0.5
†High fidelity	Mean		0.9	0.8	3.0	0.4	2.1	1.9	1.6	1.5	1.5	0.9	0.6	0.7
	S.D.		1.2	1.2	2.2	1.1	2.1	1.7	1.9	1.8	1.5	1.0	1.0	0.9
‡ Differentiated	Mean		2.1	1.7	4.6	1.0	4.4	3.5	3.3	4.2	4.0	2.9	1.2	1.2
	S.D.		1.6	1.9	2.5	0.9	2.7	2.0	2.2	2.0	2.2	2.3	0.9	0.9

* Changes of direction in the conventional electrocardiogram.

† High frequency components of high fidelity tracing.

‡ High frequency components of differentiated tracing.

significant differences; the normal subjects are, therefore, treated as a homogeneous group. The mean number of changes of direction in the conventional tracings is just over 4 in each lead. The mean number of high frequency components in the

high fidelity tracings is small, varying from 0.4 (aVR) to 2.1 (aVL). In the differentiated tracings the number is somewhat larger, 1.0 (aVR) to 4.4 (aVL).

Table II and Fig. 3 give comparable figures for

FIG. 3.—Histogram showing mean values for high frequency components of the high fidelity and differentiated electrocardiograms in normal control subjects and patients with ischaemic heart disease.

TABLE II
PATIENTS WITH NORMAL ELECTROCARDIOGRAMS

				Leads											
				I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Electrocardiogram	..	..		4.6 1.0	4.6 1.1	5.2 1.3	4.4 0.8	4.9 0.7	5.5 1.2	4.4 0.7	4.3 0.7	4.2 0.6	4.3 0.5	4.7 0.8	4.4 0.7
Conventional	..	..	Mean S.D.	0.9 0.8	1.3 1.0	4.4 1.0	0.1 0.4	3.1 2.0	2.9 2.4	2.1 1.6	1.8 1.5	1.6 1.3	1.2 1.5	0.7 0.8	0.8 0.9
High fidelity	..	..	Mean S.D.	3.3 0.7	6.7 2.3	8.4 1.2	3.6 2.9	6.2 1.2	8.3 2.4	6.6 3.4	7.8 3.6	6.8 3.2	5.1 3.0	2.8 2.1	4.0 1.8
Differentiated	..	..	Mean S.D.												

Note: Mean values of the high frequency components of the high fidelity and differentiated tracing that are significantly higher than those of normal subjects are shown in italics.

the group of patients with ischaemic heart disease whose conventional electrocardiograms are regarded as being within normal limits. The mean number of changes of direction in the conventional electrocardiogram is only slightly greater than in the normal group. The mean number of high frequency components in the high fidelity tracing is higher in this group than among the normal subjects (aVR is the only exception), but with the number of patients studied the difference is not significant. Mean values for the high frequency components of the differentiated tracings are higher

in this group than among the normal subjects, and this difference is significant except in leads I or V4.

Tables III and IV and Fig. 3 give comparable values for those groups of patients whose conventional electrocardiograms are abnormal. The mean number of changes of direction in the conventional electrocardiogram is again only slightly greater than normal. The mean values of the high frequency components of the high fidelity tracings are generally higher, both in those patients with only ST-T abnormality and in those with pathological Q waves, than in the group of normal

TABLE III
PATIENTS WITH ST-T WAVE ABNORMALITY IN ELECTROCARDIOGRAM

Electrocardiogram				Leads											
				I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Conventional	Mean	S.D.		4.7 1.1	4.7 1.3	5.1 1.1	4.2 1.0	5.0 1.1	5.0 1.4	4.3 0.8	4.3 0.6	4.5 0.8	4.1 0.1	4.4 0.5	4.0 1.9
High fidelity	Mean	S.D.		1.1 1.4	2.4 2.1	2.9 2.3	1.2 1.6	1.2 1.7	3.2 2.2	2.8 2.8	2.1 1.9	0.8 1.4	1.3 2.1	0.8 0.7	1.3 1.4
Differentiated	Mean	S.D.		6.1 3.8	8.2 3.1	7.7 2.1	5.7 3.3	5.2 1.9	8.6 3.3	9.2 3.6	8.9 3.5	8.1 4.2	6.2 3.2	4.3 2.4	3.9 2.4

Note: Mean values of high frequency components of the high fidelity and differentiated tracings that are significantly higher than those of normal subjects are shown in italics.

TABLE IV
PATIENTS WITH Q WAVE ABNORMALITY IN ELECTROCARDIOGRAM

Electrocardiogram				Leads											
				I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Conventional	Mean	S.D.		4.1 0.6	4.6 0.9	4.6 0.9	4.9 1.0	4.3 0.9	4.9 1.4	4.3 1.1	4.5 1.5	4.4 1.1	4.6 0.6	4.6 1.0	4.6 0.6
High fidelity	Mean	S.D.		2.4 1.8	3.2 1.5	5.0 3.0	1.4 1.4	2.1 1.8	3.7 2.3	2.4 2.0	2.3 1.7	2.9 2.5	2.8 2.1	1.9 1.7	2.0 2.6
Differentiated	Mean	S.D.		6.4 3.0	6.8 4.2	9.7 3.3	5.6 2.2	7.5 3.0	7.6 2.9	7.6 2.7	7.8 3.3	7.4 3.9	7.0 4.3	7.9 2.9	5.6 3.1

Note: Mean values of high frequency components of the high fidelity and differentiated tracings that are significantly higher than those of normal subjects are shown in italics.

TABLE V

NORMAL UPPER LIMIT FOR NUMBER OF HIGH FREQUENCY COMPONENTS OF THE DIFFERENTIATED TRACING (TWO STANDARD DEVIATIONS ABOVE MEAN, CORRECTED TO FIRST WHOLE NUMBER ABOVE A FRACTION)

I 6	II 6	III 10	aVR 3	aVL 10	aVF 8	V1 8	V2 9	V3 9	V4 8	V5 3	V6 3
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subjects. However, when patients with ST-T abnormality are compared with the normal subjects, the difference is significant only in lead II. Significant differences are found more frequently when patients with Q wave abnormality are contrasted with the normal subjects (leads I, II, III, aVF, V2, V4, V5). Mean values for the high frequency components of the differentiated tracings in both groups of patients with abnormal electrocardiograms are higher than in the normal subjects, and these differences reached significant levels in all the leads used.

The mean number of high frequency components in each lead in the different groups of patients has been compared. Usually the values are highest in the group with Q wave changes, and lowest in those with normal conventional electrocardiograms, but these differences rarely reached significant levels. Patients with abnormal conventional electrocardiograms were also divided into those showing dominantly anterior ischaemic and those showing dominantly inferior ischaemic changes. Comparing these two groups no significant difference in the mean values for the high frequency components of the differentiated tracings was found in any lead.

The upper limit of normal for the high frequency components of the differentiated tracings has been derived from the normal subjects as two standard deviations above the mean value, the result being expressed as the first whole number above a fraction. The value varies from 3 in leads V5 and V6, to 10

in leads aVL and III (Table V). Using these figures it is possible to assess how many patients have high frequency component values outside the normal limits (Table VI). No individual lead was particularly successful in separating normal subjects from ischaemic patients, but when all the leads were assessed, only one patient had normal values in all the leads studied. Among normal subjects, 5 had abnormal high frequency components in one or two leads.

DISCUSSION

Conventional electrocardiographic technique, in which machines with a frequency response of less than 50 c.p.s. are not uncommon, tends to obliterate high frequency components. These are evident in tracings taken with a high frequency response and fast paper speed as notching, slurring, and beading. Although these signs are often disregarded in conventional electrocardiograms, they have frequently been correlated with pathological states of the heart muscle (Carter, 1914; Oppenheimer and Rothschild, 1917; Wilson and Herrmann, 1920; Weinberg *et al.*, 1950; Evans and McRae, 1952; Durrer *et al.*, 1961; Battaglia, Maschio, and Zotti, 1964).

The use of high fidelity recording apparatus to quantitate the high frequency components of the electrocardiogram has been described by Langner (1952, 1953), Langner and Geselowitz (1960), and Langner, Geselowitz, and Mansure (1961) who used

TABLE VI

INCIDENCE OF ABNORMAL HIGH FREQUENCY COMPONENTS IN THE DIFFERENTIATED TRACINGS

	I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Normal subjects	34	34	34	34	34	34	34	34	34	34	34	34
Abnormal high frequency components ..	0	2	1	0	2	0	1	0	0	1	1	0
Percentage	0	6	3	0	6	0	3	0	0	3	3	0
Patients: normal electrocardiogram ..	8	6	7	7	6	8	9	10	10	9	10	8
Abnormal high frequency components ..	1	4	1	2	0	3	2	2	2	1	3	5
Percentage	12	67	14	29	0	38	22	20	20	11	30	62
Patients: abnormal ST-T	9	9	6	9	8	10	12	11	12	11	11	11
Abnormal high frequency components ..	4	6	1	7	0	5	8	5	4	2	8	5
Percentage	44	67	17	78	0	50	67	45	33	18	73	45
Patients: abnormal Q	11	11	12	11	10	10	15	16	16	16	15	14
Abnormal high frequency components ..	5	7	3	10	0	5	6	4	4	5	13	8
Percentage	45	64	25	91	0	50	20	25	25	31	86	57
Patients: total	28	26	25	27	24	28	36	37	38	36	36	33
Abnormal high frequency components ..	10	17	5	19	0	13	16	11	10	8	24	18
Percentage	36	65	20	70	0	46	44	30	26	22	67	55

a paper speed of 350 mm./sec. and a frequency response of up to 1,000 c.p.s. These authors were able to define criteria for normal subjects, which were exceeded in 19 of 21 patients with healed myocardial infarction. Difficulty in interpretation of these criteria arises in the definition of "notching, slurring, and beading". These disturbances are accentuated in the differentiated electrocardiogram which records the rate of change of electrical potential. Differentiated electrocardiographic tracings have been studied by Angelakos (1962, 1963) and by Langner (Langner and Geselowitz, 1962; Geselowitz, Langner, and Mansure, 1962). While differentiating a curve does not add any information not present in the initial curve, it makes the information easier to extract by accentuating the high frequency components.

The present study was designed to assess the importance of high frequency components of the electrocardiogram in the diagnosis of ischaemic heart disease. It soon became apparent that the recognition of "notching, slurring, and beading" varied from observer to observer, and from time to time with the same observer. We found that a count of the number of changes of direction of the curve was a more objective measure of these disturbances, and consistent results could be obtained in this way. Slurring of the QRS complex was usually evident as a change in direction in the differentiated electrocardiogram. As we employed a simple C.R. network accurate for frequencies of up to 70 c.p.s. as a differentiating circuit, the record obtained does not truly represent the first derivative of the electrocardiogram. We have used this tracing only as a means of reducing the subjective element in counting irregularities in the electrocardiogram. The differentiated electrocardiogram was more successful than the high fidelity electrocardiogram in detecting high frequency components in the patients with ischaemic heart disease with the criteria used in the present study.

The normal subjects showed few high frequency components in any lead, and the number did not increase with age. Patients with ischaemic heart disease showed more high frequency changes of direction in all leads. Expressing the results as the number of high frequency components in the differentiated trace, mean differences between the normal subjects and the three groups of ischaemic heart patients were significant at the 5 per cent level in all leads (except I and V4 in the ischaemic group with normal conventional electrocardiograms). Differences between the three groups of patients with ischaemic heart disease were small and rarely reached significant levels.

The results indicate that high frequency components of the electrocardiogram occur more often in patients with ischaemic heart disease than in normal subjects. The high frequency components of the QRS complex probably indicate disorderly ventricular activation which may result from local myocardial ischaemia. It is unlikely that the findings are specific to ischaemic heart disease, and they may occur in other myocardial conditions where ventricular excitation is disturbed (Caster and Ahn, 1963).

These findings suggest that it is possible to distinguish normal subjects from patients with ischaemic heart disease using a 12-lead high fidelity differentiated electrocardiogram, when the conventional electrocardiogram is within normal limits.

SUMMARY

Conventional, high fidelity, and differentiated electrocardiograms have been recorded in 34 normal men and in 38 men with ischaemic heart disease.

The high frequency components of the high fidelity and differentiated tracings have been studied. In normal men the high frequency components do not alter with age.

Patients with ischaemic heart disease have more high frequency components in the electrocardiogram than do normal subjects. A similar increase in the number of high frequency components is found in patients with normal conventional electrocardiograms, in those with ST-T abnormalities only, and in those with pathological Q waves.

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