Comparison of 12-lead and computer-analysed 3 orthogonal lead electrocardiogram in coronary artery disease

R. G. Murray, A. R. Lorimer, F. G. Dunn, P. W. Macfarlane, I. Hutton, and T. D. V. Lawrie

From the Department of Medical Cardiology, Royal Infirmary, Glasgow

The computer-analysed 3 orthogonal lead system ('3-lead ECG') provides a rapid and consistent interpretation of the electrocardiogram. In 102 patients undergoing selective coronary arteriography, the ability of such a system to predict the presence or absence of coronary artery disease and the site of myocardial ischaemia was compared with that of the conventional scalar electrocardiogram interpreted by cardiologists ('12-lead ECG'). Each system predicted the site of myocardial ischaemia with equal accuracy. The 3-lead ECG was a more sensitive index (3-lead ECG sensitivity=77%; 12-lead ECG sensitivity=70%) but less specific (3-lead ECG specificity=74%; 12-lead ECG specificity=78%). In coronary artery disease, the predictive 'index of merit' for the 3-lead ECG was 0.51, compared with 0.48 for the 12-lead ECG. These results provide further justification for the routine use of the 3 orthogonal lead electrocardiogram.

The conventional scalar electrocardiogram has for many years proved a useful investigation in the diagnosis of myocardial ischaemia. The limitations of electrocardiography in this field have been stressed (Wood *et al.*, 1950; Doyle *et al.*, 1957; Master and Rosenfeld, 1967; Friesinger and Smith, 1972); approximately 50 per cent of patients with documented coronary atherosclerosis have normal resting electrocardiograms. Despite this, the scalar electrocardiogram remains one of the principal screening procedures in patients presenting with chest pain.

The introduction of selective coronary arteriography has provided a means of establishing the presence or absence of coronary atherosclerosis in the living patient (Kemp *et al.*, 1967; Sones, 1972). Computer-assisted interpretation of the 3 orthogonal lead electrocardiogram has been in operation for some time in this hospital (Macfarlane and Lawrie, 1974) and has removed observer bias and variation in the diagnosis of abnormalities of the electrocardiogram.

It was, therefore, decided to evaluate the usefulness of the computerized electrocardiographic reporting system in the diagnosis of coronary artery

disease in patients undergoing selective coronary arteriography.

Patients and methods

One hundred and two patients presenting with chest pain warranting selective coronary arteriography were studied. The group consisted of 91 men and 11 women with a mean age of 46.8 years (range 32 to 64 years). Patients with rheumatic heart disease or on digitalis therapy were not included in the study.

Selective coronary arteriography was performed by the technique of Sones or Judkins (Sones and Shirey, 1962; Judkins, 1967). Coronary artery disease was considered to be present when reduction in lumen was greater than 50 per cent in one or more of the three major vessels (right, left anterior descending, and left circumflex coronary arteries). The patients were classified as having a normal vasculature, single, double, or triple vessel disease.

Conventional scalar 12-lead electrocardiograms were recorded using either a Cambridge Transrite 4 or Siemens Cardiostat apparatus. The electrocardiograms thus obtained were reported on independently by two of the authors without knowledge

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of the result of the coronary arteriogram. Any discrepancies in reporting were settled in committee. The diagnostic criteria for myocardial infarction and myocardial ischaemia were those in common use (Macfarlane, 1970).

Three orthogonal lead electrocardiograms were recorded using the modified axial system (Macfarlane, 1969). Electrocardiograms were tape recorded, using a multichannel FM tape recorder as described previously (Macfarlane *et al.*, 1972), and were replayed to a PDP8E computing system for analysis using the programme which has been reported in detail elsewhere (Macfarlane and Lawrie, 1974). Essentially 8 seconds of leads X, Y, and Z were replayed simultaneously for interpretation and a typical complex was chosen for analysis. Multiple measurements were made by the programme and the interpretation was made on the basis of a check of over 200 criteria. In a previous paper (Cawood *et al.*, 1974) discussing the day-to-day changes in the 3 orthogonal lead electrocardiogram after myocardial infarction, the criteria for the diagnosis of this abnormality were presented. For the detection of ischaemic changes, multiple measurements of the ST-T segment were made. Full details of the criteria used will be published elsewhere (Macfarlane and Lawrie, 1977). In summary the ST-T segment was divided into eight equal time intervals and the amplitude at the end of each was measured. This allowed the detection of ST abnormalities in the early part of the ST-T segment and of terminal T wave abnormalities in the late ST-T segment. In addition, the total negative area of the ST-T segment was measured and compared with normal. The other criterion used for the diagnosis of myocardial ischaemia was an abnormal T vector orientation in either the frontal or transverse plane denoted T_F and T_T , respectively. The more important criteria for ischaemic changes can be summarized as follows.

- $T_F < 10^\circ$ or $T_T > 70^\circ$.
- $T_X < 0.05$ mV or $T_Y < 0.05$ mV or $T_Z < -0.05$ mV.
- Depression of the ST onset by 0.02 mV or more, together with a flat or downward sloping ST segment in lead X, Y, or Z.
- Inversion of the terminal portion of the T wave in lead X, Y, or Z.

The computer reports thus obtained were reviewed without knowledge of the result of the coronary arteriogram or of the 12-lead electrocardiogram report. Coronary arteriographic assessment of the presence or absence of coronary artery disease was accepted as correct and the sensitivity and specificity (Table 1) of the 3-lead and 12-lead systems were calculated. The 'index of merit' of

Hanssen and Kuipers (1965) was adapted to assess the value of each system in predicting the presence or absence of coronary artery disease (Table 2). The site of myocardial ischaemia predicted from the

TABLE 1 *Formulae for sensitivity and specificity*

$$\text{Sensitivity} = \frac{a_1}{a_2} \times 100\%$$

$$\text{Specificity} = \frac{a_3}{a_4} \times 100\%$$

The coronary arteriographic diagnosis is regarded as correct. a_1 , number with correct ischaemic electrocardiograms; a_2 , number with coronary artery disease; a_3 , number with correct normal electrocardiograms; a_4 , number with normal vessels.

TABLE 2 *Calculation of index of merit (Hanssen and Kuipers, 1965)*

Truth	Prediction	
	Yes	No
Yes	n_1	n_2
No	n_3	n_4

$$\begin{aligned} \text{Index of merit} &= \frac{n_1}{n_1 + n_2} + \frac{n_4}{n_3 + n_4} - 1 \\ &= \frac{a_1}{a_2} + \frac{a_3}{a_4} - 1 \quad (\text{cf Table 1}) \\ &= \frac{1}{100} (\text{sensitivity} + \text{specificity}) - 1 \end{aligned}$$

YES and NO refer to presence or absence of coronary artery disease. The coronary arteriogram result is regarded as 'TRUTH'. The number of cases in each category is given by $n_1 \dots n_4$. The fraction of correct positives

$$\text{is } \frac{n_1}{n_1 + n_2}, \text{ that of correct negatives is } \frac{n_4}{n_3 + n_4}.$$

TABLE 3 *Expected location of arteriographic occlusion associated with myocardial infarction (James, 1968)*

Site of infarct	Associated arterial disease
Anteroseptal	LAD
Anterior	LAD
Anterolateral	LAD + LC _x
High lateral	LC _x
Inferior	RCA (if right coronary dominant) LC _x (if left coronary dominant)
True posterior	RCA (if right coronary dominant) LC _x (if left coronary dominant)

Abbreviations: LAD=left anterior descending coronary artery. LC_x=left circumflex coronary artery. RCA=right coronary artery.

electrocardiogram using each lead system was compared with that predicted from the coronary arteriogram. The expected arterial supply to the various areas of the left ventricular myocardium is summarized in Table 3 (James, 1968).

Results

Twenty-five patients had a normal coronary vasculature on selective coronary arteriography, while 77 patients (75%) were shown to have significant lesions affecting one or more vessels.

TABLE 4 Distribution of coronary artery disease in 77 patients

Coronary arteriogram	Vessel affected	No of patients
Single vessel disease (13)	RCA	4
	LAD	9
	LC _x	—
Double vessel disease (29)	RCA+LAD	20
	RCA+LC _x	4
	LAD+LC _x	5
Triple vessel disease (35)	RCA+LAD+LC _x	35

Abbreviations as for Table 3.

Number in brackets equals total number of patients in each group.

TABLE 5 12-lead electrocardiogram report related to the coronary arteriogram in 92 patients*

Coronary arteriogram	Normal electrocardiogram	Ischaemic electrocardiogram
Normal (23)	18 (78%)	5
Single vessel disease (11)	5	6 (54%)
Double vessel disease (27)	10	17 (63%)
Triple vessel disease (31)	6	25 (81%)
Coronary artery disease		
Total (69)	21	48 (70%)

*Excluding those with left ventricular hypertrophy or left bundle-branch block on 12-lead electrocardiogram.

TABLE 6 'Ischaemic' electrocardiogram (12-lead system) related to the coronary arteriogram*

Coronary arteriogram	'Ischaemic' electrocardiogram	
	Myocardial infarction	ST-T changes
Single vessel disease	3	3
Double vessel disease	11	6
Triple vessel disease	13	12

*Excluding those with left ventricular hypertrophy or left bundle-branch block on 12-lead electrocardiogram.

Of those with coronary artery disease, 13 patients had single vessel disease, 29 double vessel disease, and 35 triple vessel disease. The distribution of affected vessels is shown in Table 4.

12-lead electrocardiogram

Four electrocardiographic categories were encountered in this study: (i) normal tracing, (ii) 'myocardial ischaemia', either with evidence of a transmural infarct, or with ischaemic repolarization abnormalities, (iii) left ventricular hypertrophy (LVH), and (iv) left bundle-branch block (LBBB). The latter two diagnoses (LVH and LBBB) were present in 8 and 2 patients, respectively. Of those with LVH, 2 patients were hypertensive (BP > 140/90 mmHg (18.6/12.0 kPa)); the remainder were normotensive at the time of study. Excluding these two categories, the 12-lead electrocardiogram was normal in 18 out of 23 patients with normal vessels (Table 5). Five patients with normal vessels had 'ischaemic' electrocardiograms, the changes being restricted to repolarization abnormalities (specificity = 78%).

The resting 12-lead electrocardiogram was ischaemic in 48 out of 69 patients with coronary artery disease (sensitivity = 70%). The electrocardiographic criteria for myocardial ischaemia were satisfied more frequently as the extent of coronary artery disease increased (Table 5). The criteria for myocardial infarction were fulfilled in 27 of the 48 'ischaemic' electrocardiograms (56%). The frequency with which electrocardiographic evidence of transmural infarction occurred did not correlate with the extent of disease (Table 6). In all instances of myocardial infarction, the site of ischaemia predicted from the 12-lead electrocardiogram agreed with that predicted from the coronary arteriogram.

The 'index of merit' of the 12-lead system in predicting the presence or absence of coronary artery disease was 0.47.

TABLE 7 3-lead electrocardiogram report related to the coronary arteriogram in 89 patients*

Coronary arteriogram	Normal electrocardiogram	'Ischaemic' electrocardiogram
Normal (23)	17 (74%)	6
Single vessel disease (11)	4	7 (64%)
Double vessel disease (25)	6	19 (76%)
Triple vessel disease (30)	5	25 (83%)
Coronary artery disease		
Total (66)	15	51 (77%)

*Excluding those with left ventricular hypertrophy or left bundle-branch block on 3-lead electrocardiogram.

3-lead electrocardiogram

Computer-assisted orthogonal 3-lead electrocardiogram reports also fell into the same four categories (normal, 'myocardial ischaemia', left ventricular hypertrophy, and left bundle-branch block). The latter two diagnoses were made in 11 and 2 patients, respectively. Of those with left ventricular hypertrophy, 2 patients were hypertensive (BP > 140/90 mmHg (18.6/12.0 kPa)); the other 9 were normotensive at the time of study. Excluding these two diagnoses, the resting 3-lead electrocardiogram was normal in 17 out of 23 patients with normal vessels (specificity=74%). In 5 patients repolarization abnormalities were reported and in one patient an inferior myocardial infarction was diagnosed.

The 3-lead electrocardiogram diagnosed 'myocardial ischaemia' in 51 of 66 patients with coronary artery disease (sensitivity=77%) (Table 7). The diagnosis was made with increasing frequency with increasing extent of coronary artery disease. Transmural myocardial infarction was reported in 25 (49%) of the patients with 'ischaemic' electrocardiograms (Table 8). Again, no correlation was apparent between the frequency with which myocardial infarction was diagnosed and the extent of disease. As with the 12-lead system, the predicted site of ischaemia agreed with that predicted from the coronary arteriogram in all cases of myocardial infarction.

The 'index of merit' for the 3-lead system in predicting the presence or absence of coronary artery disease was 0.51.

Comparison of reports

In 88 patients (86%), the 12-lead and 3-lead electrocardiogram reports were identical. The discordant reports are listed in Table 9. In 6 patients

TABLE 8 'Ischaemic' electrocardiogram (3-lead system) related to the coronary arteriogram*

Coronary arteriogram	'Ischaemic' electrocardiogram	
	Myocardial Infarction	ST-T changes
Single vessel disease	3	4
Double vessel disease	9	10
Triple vessel disease	13	12

*Excluding those with left ventricular hypertrophy or left bundle-branch block on 3-lead electrocardiogram.

with proven coronary artery disease (8%) the 3-lead electrocardiogram diagnosed 'myocardial ischaemia' not reported by the 12-lead system. However, in 4 patients with proven coronary artery disease and 'ischaemic' 12-lead electrocardiograms, the 3-lead system reported left ventricular hypertrophy with accompanying ST and T wave abnormalities. The reverse was reported in one patient. In all, left ventricular hypertrophy was diagnosed in 12 patients, 11 by the 3-lead and 8 by the 12-lead system. One patient had normal vessels, but the remainder had coronary artery disease. Left ventricular hypertrophy was reported, therefore, by the 3-lead system in 13 per cent of patients with coronary artery disease and by the 12-lead system in 9 per cent. Two of these patients were hypertensive (BP > 140/90 mmHg (18.6/12.0 kPa)); the remainder were normotensive (mean BP 131/76 mmHg (17.4/10.1 kPa)).

Discussion

The number of 'ischaemic' electrocardiograms in both systems is higher than reported by certain

TABLE 9 Discordant 3-lead and 12-lead electrocardiogram reports in 14 patients

Coronary arteriogram	12-lead report	3-lead report
Normal	Normal	Inferior ischaemia
Single vessel disease	Inferolateral ischaemia	Inferior infarction
LAD	Normal	Anterolateral ischaemia
Double vessel disease		
RCA+LAD	Normal	Inferior ischaemia
RCA+LAD	Normal	Anterolateral ischaemia
RCA+LAD	Anteroseptal infarction	Left ventricular hypertrophy
RCA+LAD	Normal	Inferolateral ischaemia
RCA+LAD	Inferior ischaemia	Left ventricular hypertrophy
RCA+LC _x	Normal	True posterior infarction
Triple vessel disease		
(RCA+LAD+LC _x)	Lateral ischaemia	Left ventricular hypertrophy
	Anterolateral infarction	Anterolateral ischaemia
	Normal	Subepicardial ischaemia
	Left ventricular hypertrophy	Anterolateral ischaemia
	Anterolateral ischaemia	Left ventricular hypertrophy

authors (Wood *et al.*, 1950; Doyle *et al.*, 1957; Master and Rosenfeld, 1967; Hultgren *et al.*, 1967; Friesinger and Smith, 1972) in patients suspected of having coronary atherosclerosis. Others have reported a similar proportion of abnormal electrocardiograms in patients with clinical ischaemic heart disease and unequivocal coronary artery disease (Elliott and Gorlin, 1966). This discrepancy may be explained by patient selection since, in this study, the majority of patients were drawn from a second referral clinic, often presenting with typical cardiac ischaemic pain. Such a group does not, therefore, represent a true cross-section of the coronary atherosclerosis population.

The 3 orthogonal lead electrocardiogram reporting system described has been shown to predict more accurately the presence or absence of coronary artery disease subsequently proven by selective coronary arteriography (index of merit for 3-lead system=0.51, and for 12-lead system=0.48). It is not feasible to test for a statistically significant difference between these two indices. It is possible to show that there is no statistically significant difference between corresponding components of the index of merit, viz. the fractions of correct positives and correct negatives (Table 2), obtained from 3-lead and 12-lead electrocardiograms. It should be noted, however, that this index is designed to show up differences between diagnostic methods on a scale of 0 to 1. If the sensitivity is 100 per cent and specificity is 0 per cent, then the index of merit is 0; likewise if both sensitivity and specificity are 50 per cent then the index of merit is also 0. If both sensitivity and specificity are ideal at 100 per cent then the index of merit has the optimal value of 1. Thus, the higher the index of merit, the better the technique.

The 3-lead electrocardiogram was a more sensitive index of the presence of coronary artery disease but slightly less specific compared with the 12-lead electrocardiogram. With both systems, the predicted site of myocardial infarction correlated closely with the area of ischaemia predicted from the coronary arteriogram. False positive reports (i.e. 'ischaemic' electrocardiograms in patients with normal coronary vessels) were common with both 3-lead and 12-lead systems. The ischaemic abnormalities encountered were restricted in all but one patient to repolarization changes. The high frequency of 'ischaemic' electrocardiograms in the normal vessel group is not really surprising. The population studied, as discussed above, could scarcely be considered normal since none was asymptomatic. In addition, the paradox of angina pectoris in the presence of normal coronary vessels is well established (Kemp *et al.*, 1973; James, 1970; Waxler, Kimbris, and

Dreifus, 1971; Eliot and Bratt, 1969; Likoff, Segal, and Kasparian, 1967). Many of these patients have objective evidence of myocardial ischaemia, either on the electrocardiogram or on exercise testing or atrial pacing with coronary sinus lactate sampling (Dwyer, Wiener, and Cox, 1969; Bemiller, Pepine, and Rogers, 1973; Arbogast and Bourassa, 1973; Helfant *et al.*, 1970; Boudoulas *et al.*, 1974).

Left ventricular hypertrophy was a fairly common electrocardiographic diagnosis in the patients with coronary artery disease (3-lead system 13%; 12-lead system 9%). Left ventricular hypertrophy in coronary artery disease (in the absence of hypertension) has been reported in necropsy studies (Ellis *et al.*, 1962; McCain, Klein, and Gilson, 1950; Murata *et al.*, 1972) while haemodynamic and angiographic studies *in vivo* have shown increased left ventricular mass in patients with coronary artery disease compared with those with normal coronary arteriograms (Pech *et al.*, 1974). Hence, in the absence of a recognized predisposing factor to left ventricular hypertrophy, such an abnormality may well be a further index of myocardial ischaemia. If this were accepted, the sensitivity of the 3-lead electrocardiogram in diagnosing coronary artery disease would rise to 80 per cent and of the 12-lead to 72 per cent, altering the specificity to 71 per cent for the 3-lead and 75 per cent for the 12-lead electrocardiogram.

In a recent paper, Talbot *et al.* (1973) argued that the 3-lead and 12-lead systems of recording were complementary and that all 15 leads were 'essential' for computer-assisted electrocardiographic interpretation. Our own opinion is that the diagnostic gain in adopting such an approach is negligible when adequate criteria for the 3-lead electrocardiogram are chosen. Furthermore, the increase in computer time to undertake adequate wave recognition procedures on 15 leads so prolongs the analysis that it could become uneconomic. In this particular study, 86 per cent of patients had identical reports. The use of 12 conventional leads as well as the 3 orthogonal leads would have led to 4 (4%) additional reports of myocardial ischaemia or infarction. In each case, however, ST-T abnormalities were already detected by the computer-analysed electrocardiogram but placed in the diagnostic category of left ventricular hypertrophy. Conversely the use of 3 orthogonal leads in addition to the 12 conventional leads would have led to a further 5 (5%) reports of myocardial ischaemia or infarction in patients with single, double, or triple vessel disease who had normal 12-lead electrocardiograms.

In summary, the 3-lead electrocardiogram has been shown to have an enhanced 'index of merit'

for the prediction of the presence or absence of coronary artery disease and has an equal ability to indicate the site of myocardial ischaemia compared with the 12-lead electrocardiogram. The technique is more sensitive than the 12-lead electrocardiogram but at the expense of slight lessening of specificity. This favourable performance provides further justification for the routine use of 3 orthogonal lead electrocardiography.

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Requests for reprints to Dr. A. R. Lorimer, Department of Medical Cardiology, Royal Infirmary, Glasgow G4 0SF.