RECORDING OF TWELVE-LEAD ECG DURING EXERCISE

By

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Abstract

A wired monitoring system has been developed which will facilitate continuous recording of a 12-lead ECG before, during and after exercise virtually free from interferences, with the Electrocardiographer having the choice to select any of the leads. An unconventional electrode placement on the thorax has been found which gives a multi-lead ECG identical with that obtained with the conventional system for varying electrical axis of the heart. Such a record can thus be easily interpreted using the existing criteria for evaluation of ECG which becomes otherwise difficult with non-standard records. A lighter and a smaller floating electrode of a dome shape has been used which though smaller in size has an effective area twice that of a circular disc floating electrode of the same diameter thus keeping the inter-electrode impedance low.

Introduction

The commonly used physical stress in assessing cardio-vascular system is the two-step exercise test devised by Master. According to this procedure, ECG is recorded after the exercise. No continuous monitoring of ECG during the period of physical stress is carried out. Another limitation with the conventional procedure is the delay in recording due to the time involved in connecting the patient to the record on completion of exercise. Therefore the evidence of arrhythmias and ischaemia if present during the exercise, may not be revealed by the post exercise ECG record. Continuous recording of ECG during the exercise thus provides additional information on the physiological state of the myocardium during stress and hence desirable.

The standard clinical electrodes and the lead system (Einthoven) used in electrocardiography does not give a readable ECG while the subject is exercising. Disturbances are caused by the movement of the surface electrodes over the skin and by the muscle action potentials originating from contracting muscles under the area where electrodes have been placed. Such a record is shown in Fig. 1. For the stated reasons, special electrodes and unconventional lead positions have to be used.

The sites free from muscle movements are selected for the purpose of unconventional lead placement. The records obtained from these sites were identical with those obtained from the conventional 12 lead ECG for varying electrical axis of the heart. Such a record can be easily interpreted using the existing criteria for evaluation of ECG. A wired system has been used. With this system, Multiple-lead ECG was recorded on subjects continuously, before, during and after the exercise (Master two-step test, bicycle ergometer test and sprinting). Good records have been obtained without interferences.

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Monitoring System

(a) Electrode Techniques

The special electrodes known as floating electrodes or liquid junction electrodes were fabricated. With this type, the metal (Silver-Silver Chloride) does not come in direct contact with the skin. The contact is made *via* an electrolytic 'bridge'. The dome shaped Silver-Silver Chloride electrode is fixed rigidly in a plastic housing of the same shape leaving 1 mm. gap between the edge of the electrode and the rim of the plastic housing. Bonding compound Tensol No. 6 manufactured by I.C.I. is used as an adhesive for fixing the electrode inside the plastic housing. After sticking, the assembly is exposed to ultraviolet rays for 30 minutes. This has been found to be the best technique for fixing the silver electrode rigidly inside the plastic dome. The electrode jelly which is filled in the dome does not chemically react with the adhesive material used. Electrode jelly is filled in the dome and the assembly is stuck by means of a double sided adhesive tape to the appropriate area on the thorax which is well rubbed with acetone, during the preparation of the subject.

By this method the electrode is prevented from having a direct contact with the skin and yet the electrical contact is established through the conducting jelly.

The d.c. resistance between a pair of these electrodes applied to human thorax varies with the method of preparing skin, the type of conducting jelly and the area of the electrodes. This d.c. resistance can therefore be reduced by increasing the area of the electrode. But when subjects are exercising, it is desirable to use small electrodes as they are less restraining. However, when small electrodes are employed the d.c. inter-electrode resistance becomes very high. When the value of this becomes an appreciable fraction of the input impedance of the ECG amplifiers, there is a reduction of the voltage of the bioelectric event fed to the input amplifier of the ECG machine and therefore it results in distortions.

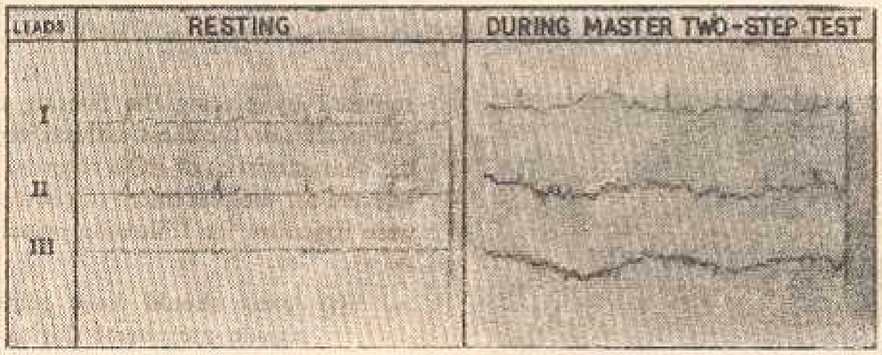


Fig. 1. *ECG obtained during Master two-step test using the standard clinical electrodes and the conventional Einthoven lead system.*

Keeping this in view, unlike the conventional type of circular disc floating electrodes in use, a dome-shaped electrode having a diameter of 10 mm. has been used which though smaller in size has an effective area twice that of a circular disc of the same diameter thus keeping the inter-electrode d.c. resistance low. The surface area of this small electrode is 150 sq. mm. and the d.c. resistance between a pair of applied electrodes is 4-5 K ohms. This value is very low as compared to the input resistance of the commercially available ECG machines which is about 5 M ohms. The electrode

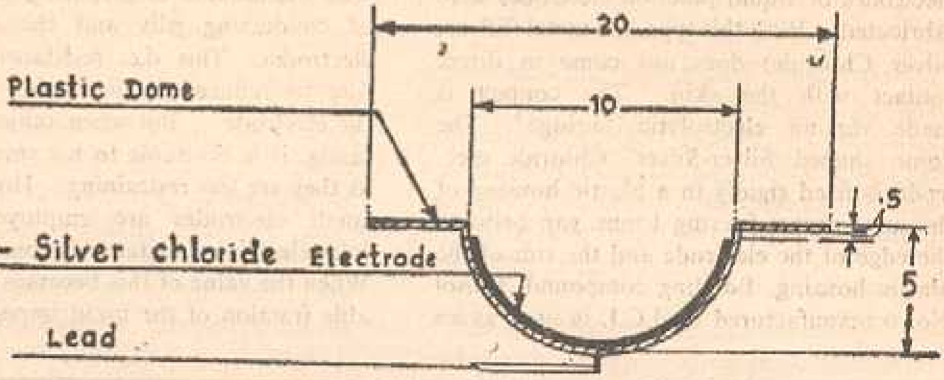


Fig. 2. *Constructional details of the floating electrode (dimensions in mm.).*

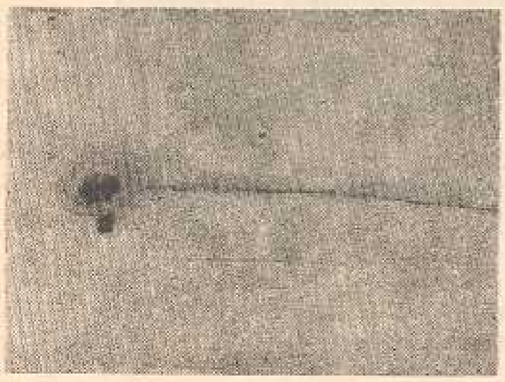


Fig. 3. *Photograph of the floating electrode.*

assembly weighs 600 mgms. The silver electrode has been chlorided for electrical stability. The constructional details and the photograph of the electrodes fabricated are shown in Figs. 2 and 3 respectively.

(b) Lead Placement Techniques

To obtain maximum diagnostic information and to ensure adequate scanning of the entire myocardial surface, it is necessary to use multiple-leads for recording ECG throughout the period of stress, as well as during recovery. For this purpose, the conventional method of placement of limb electrodes, *i.e.*, RA, LA, LL and RL was replaced by placing the floating electrodes at new sites on the chest without jeopardising the characteristics of ECG records. The sites selected for the placement of chest electrodes were based on the following principles:

(i) Areas should have minimum of muscle movement during exercise.

(ii) Electrical potential values and wave forms of all the 12 leads obtained should be the same as those obtained with the conventional system for varying electrical axis of the heart.

(iii) The positioning of the electrodes should not be very critical. Otherwise placement of the electrode a little away from the selected position will result in the electrode lying on a different isopotential line which would result in an ECG record not similar to the conventional one.

To find a solution to this problem, the isopotential map of the body arising during cardiac activity for five different electrical axis of the heart was plotted as shown in Fig. 4 and studied. Each dotted line in the diagram represents an electric potential which is the same all along the dotted line. No potential difference is detected if electrodes are placed on the same dotted line. The following six electrodes placements as shown in Fig. 5 were investigated to find out if they actually give identical records as the standard leads with varying electrical axis of the heart and at the same time remain free of interferences from muscular movements and muscle action potentials:

FIG. 4
Potential distribution due to cardiac activity with varying electrical axis of the heart

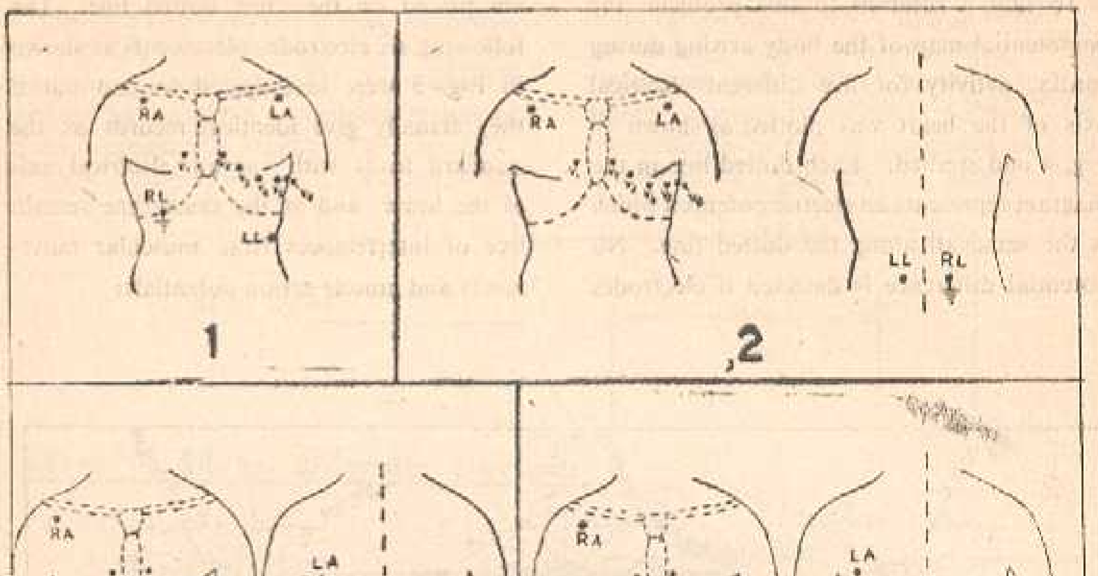


Fig. 5. *Unconventional multiple lead systems.*

System 1

RA } 2 cm. below the junction of middle and lateral thirds of the right and left
LA } clavicles respectively.

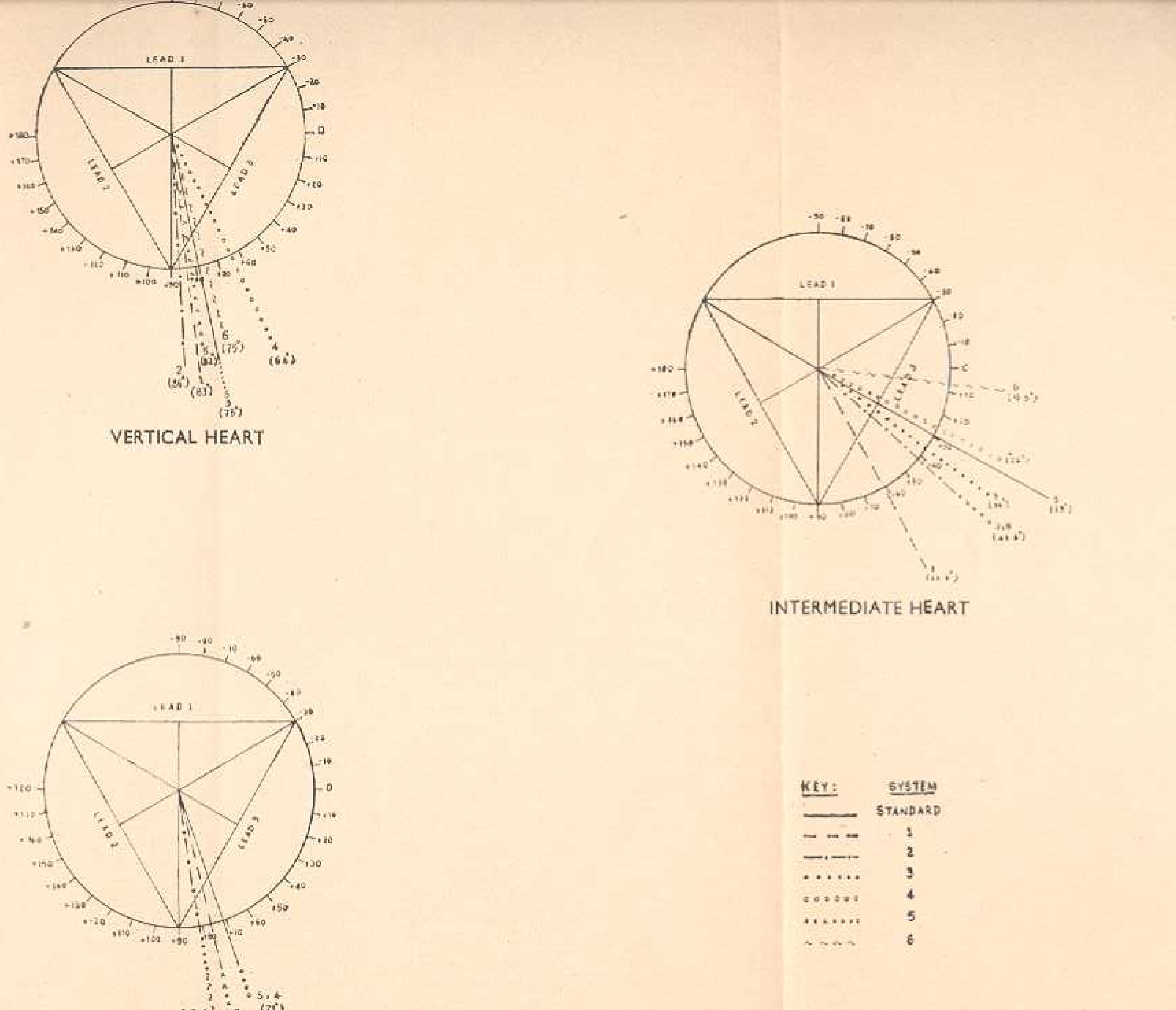
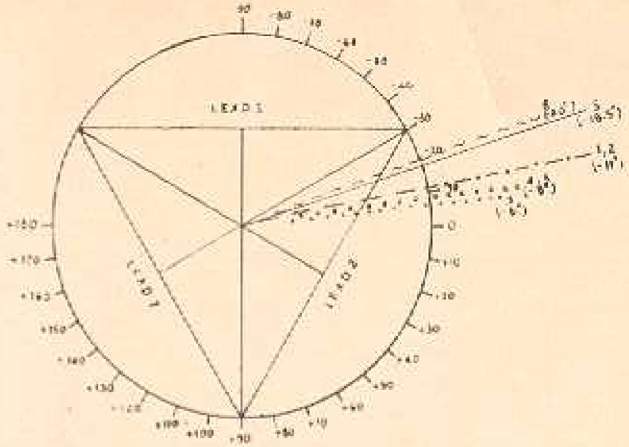
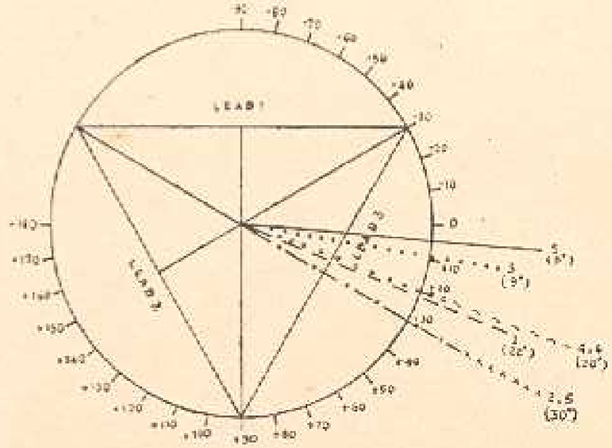


Fig. 6. *COMPARISON OF THE ELECTRICAL AXIS OF HEART OBTAINED FROM STANDARD AND UNCONVENTIONAL LEAD SYSTEMS.*



HORIZONTAL HEART



SEMI-HORIZONTAL HEART

LL — On the anterior axillary line half way between the costal margin and the crest of left ilium.

RL — Junction of the right mid clavicular line and the rib cage.

System 2

RA, LA } Same as System 1.

LL, RL } On the back at the levelof XII vertebra 2 cm. lateral to the spine to the left and right respectively.

System 3

RA — Same as System 1.

LA — 2 cm. medial to the apex of the left posterior axillary fold.

LL, RL } Same as System 1.

System 4

RA, LA } Same as System 3.

LL, RL } Same as System 2.

System 5

RA — 2 cm. medial to the apex of the right posterior axillary fold.

LA — Same as RA but symetrically placed on the left side.

LL, RL } Same as System 1.

System 6

RA, LA } Same as System 5.

LL, RL } Same as System 2.

A comparison of the ECG obtained with the conventional system and the 6 unconventional systems for 5 different electrical axis of the heart was carried out. From these records, using polar co-ordinate methods the electrical axis of the heart was plotted. A comparison of the electrical axis of the heart thus obtained from standard and unconventional lead system is shown in Fig. 6.

Discussion

Had the heart been located exactly in the centre of thorax and if its normal position was vertical with deviation to the left or right, the RA and LA electrodes could be placed symetrically on either side of the thorax at the appropriate isopotential line. But the position of the heart is towards the left side of the thorax and its normal variation is from vertical to horizontal in the third quadrant. In view of that, RA electrode can be placed 2 cm. below the junction of the middle and lateral thirds of the right clavicle which is almost on the same isopotential line as the RA for different electrical axis of the heart. On account of the unsymmetrical location of the heart, a symmetrical location of the LA electrode in the left clavicular region (shown in systems 1 and 2 of Fig. 5.) (system 1 was adopted by Robert E. Mason and Ivan Likar of the Johns Hopkins University, School of Medicine, U.S.A. and system 2 was adopted by H. Sasamoto *et al.* of the Schoolof Medicine, Keio University, Japan) is not ideal as this site does not lie on the same isopotential line as the LA for different electrical axis of the heart. This is very marked in the intermediate position of the heart when identical ECG records as obtained with the conventional system cannot be obtained and the electrical axis derived deviates widely from that derived from the conventional ECG as can be seen in Fig. 6. Therefore a proper location of the LA electrodes should be a little laterally away from this region and the area 2 cm. medial to the apex of the left posterior axillary fold has been chosen as shown in systems 3 and 4 of Fig. 5. The ideal location of the LL electrode would be on the crest of left ilium. But during exercise this area is subjected to considerable movement. Therefore a suitable location would be on the anterior axillary line half way between the crest of ilium and costal margin as shown in systems 1, 3 and 5 of Fig. 5. The location of this is not, however, very critical. Another suitable location of the LL electrode is on the back of the level of the XII vertebra 2 cm. lateral to the spine to the left shown in systems 2, 4 and 6 of Fig. 5. Precordial electrodes are placed as per the conventional system.

Next, the potential difference between the central terminals of the 6 unconventional systems and the Wilson's central terminal of the conventional system was measured. It was found that the potential difference was zero between the central terminal of the unconventional system 3 and the Wilson's central terminal of the conventional system. With the other systems there was a potential difference which varied from 0.1 to 0.3 m volt. Thus the amplitude of the precordial leads (V_1—V_6) recorded with unconventional system No. 3 were the same as those obtained with the conventional system. Whereas with the other unconventional systems in use, the amplitudes of the precordial leads varies as compared to those obtained with the conventional system.

(c) Application of Electrodes and Connection to the ECG Machine:

The area of skin where electrodes are fixed are prepared in the standard manner. This ensures minimum skin resistance. Electrode jelly is filled in the electrode dome and the assembly is stuck firmly to the site by means of a double sided adhesive tape as mentioned earlier. This arrangement holds the electrode firmly to the skin and makes it water tight. The D.C. resistance measured between a pair of attached electrodes ranged from 4 to 5 K ohms. If the skin is not prepared properly the resistance will be very high. The cables which are plugged to the electrodes are guided along the chest towards the left side of the waist and plugged to the socket of the incoming cables from the junction box which has a selector switch to facilitate selection of the precordial leads V_1—V_6. A rubber band is tied around the waist to keep in position the plug and socket. The five leads of the patient cable of the ECG

Fig. 7

machine are plugged into the appropriate output jackets of the junction box. The photograph of a subject with electrodes attached is shown in Fig. 7. Fig. 8 shows

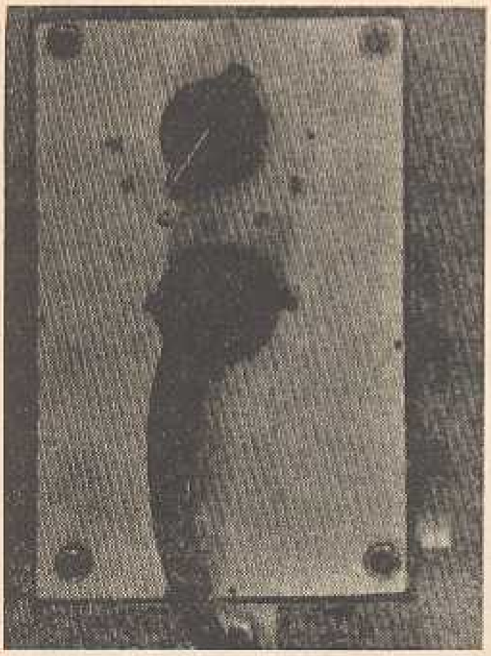


Fig. 8

the junction box which facilitates select io of the precordial leads. Fig. 9 shows a subject performing the Master step-test with the developed system plugged to the ECG machine.

Results

With the above developed system, multi-lead ECG was recorded during Master two-step test, bicycle ergometer test and sprinting. Records of very good quality were obtained as shown in Fig. 10.

Acknowledgement

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Fig. 9

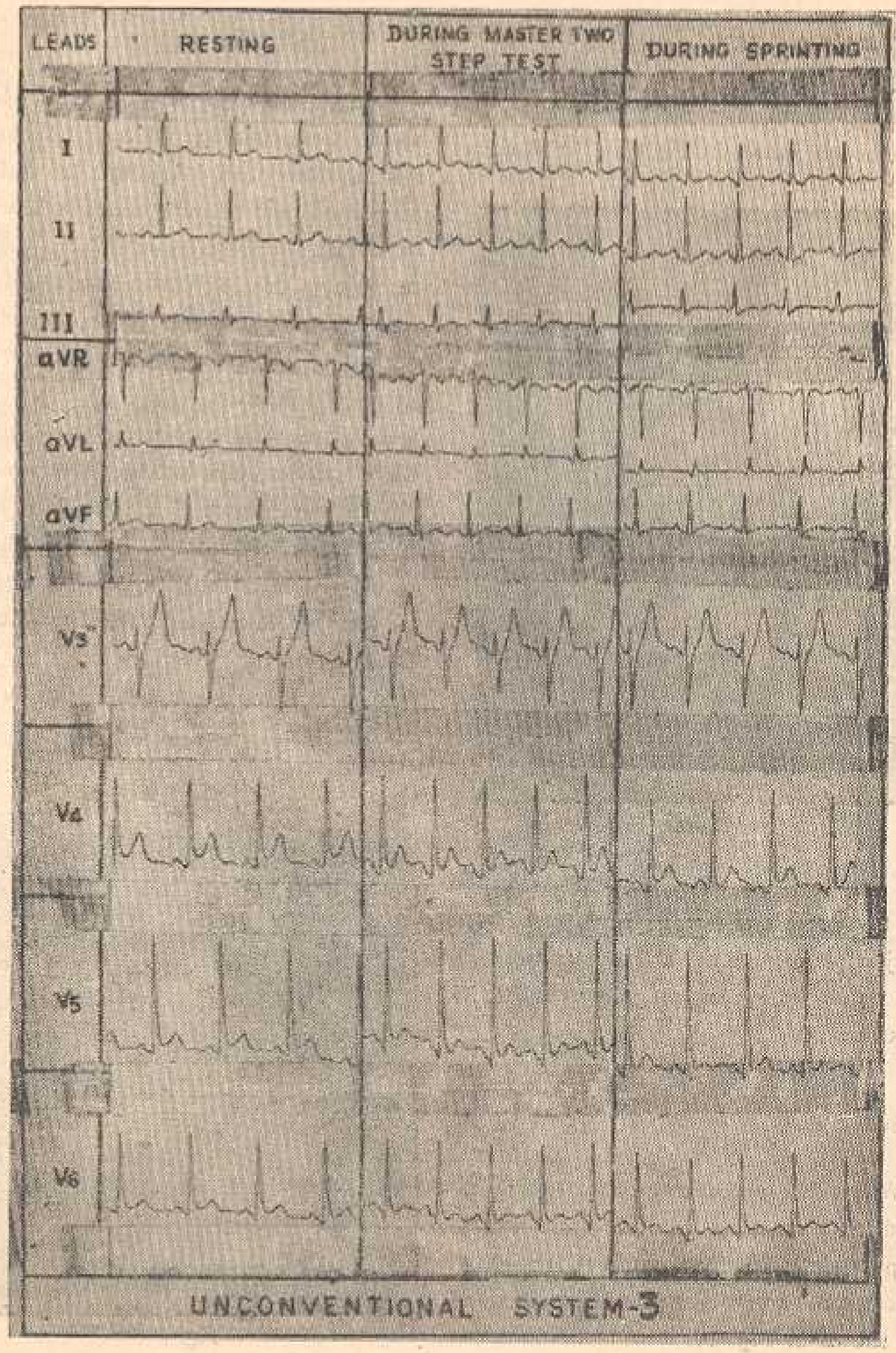
LEADS
RESTING
DURING MASTER TWO STEP TEST
DURING SPRINTING
I
II
III
aVR
aVL
aVF
V3
V4
V5
V6
UNCONVENTIONAL SYSTEM-3

Fig. 10

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