A PACEMAKER DIGITAL ELECTROCARDIOGRAPH FOR ACCURATE ASSESSMENT OF IMPLANTED CARDIAC PACEMAKERS*

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Abstract—During the past 8 yr over 170 patients in the Glasgow area have received cardiac pacemaker implants. All such patients attend pacemaker clinics at which both clinical and electronic examinations are carried out. The Pacemaker Frontal Plane Vector technique developed in Glasgow has enabled many changes in pacing function to be detected, often before clinical symptoms appear. Hitherto, measurements have been made using a calibrated differential oscilloscope: the Pacemaker Digital Electrocardiographic described in this paper offers improved accuracy in the measurement of the pacemaker frontal plane vector thus enabling further development of the above technique. The instrument also measures pacemaker pulse width and rate with an accuracy of ±0.1 per cent which should be sufficient to detect ageing of the newer Medtronic 'rate-stable' generators (type 5862—fixed rate and type 5842—QRS blocking).

1. INTRODUCTION
During the past 8 yr over 170 patients in the Glasgow area have received pacemaker implants. Such patients usually leave hospital within ten days of receiving the implant and thereafter they are usually able to lead a normal active life. Although most of the earlier pacemakers did not function satisfactorily for very long, more recent experience (GREEN et al., 1970; GREEN et al., 1971) is more encouraging and any patient today who receives a pacemaker can reasonably expect 2–3 yr of satisfactory pacing before re-operation becomes necessary. When this does become necessary, replacement of the generator is in most cases all that is required.

All pacemaker patients are asked to attend pacemaker clinics at intervals of between 2–4 months. Clinical examination of the patient is supported by electronic investigations to detect both technical faults in the pacemaker itself and other changes, such as displacement of a catheter electrode, which may affect the pacing function. Some changes or faults do not produce clinical symptoms and would otherwise remain undetected until pacing became intermittent or ceased completely. The early detection of faults, changes, and premature failure of one or more mercury cells enables re-operations to be arranged on a planned basis during normal operating hours, rather than for such operations having to be carried out on an emergency basis. Determination of the nature of the fault or difficulty prior to re-operation ensures that the generator and electrode lead systems are not replaced unnecessarily.

Initially the electronic properties of the implanted generators and electrode lead systems were investigated with the aid of a standard oscilloscope having a differential input: measurements were made after photographing the oscilloscope trace on polaroid film. Subsequent acquisition of a storage oscilloscope made direct measurement from the oscilloscope face practical. In the latest development, which is the subject of this paper, increased consistancy and accuracy in the measurement of pacemaker pulse amplitude, width and rate are achieved by the use of a ‘Pacemaker Digital Electrocardiograph’

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which exploits the inherent precision of modern digital electronic techniques. The storage oscilloscope is retained not so much as a measuring instrument but because of its excellent visual display of the pacing stimulus and its relation to the electrophysiological signal (ECG).

2. PACEMAKER FRONTAL PLANE VECTOR TECHNIQUE

The method which has been developed in Glasgow for detecting faults and changes in pacemaker function is based on the Pacemaker Frontal Plane Vector technique (Green et al., 1969; Green, 1971). Immediately after a pacemaker operation a Pacemaker Frontal Plane Vector is plotted: its direction depends on the polarity of the electrodes and the relative locations of the electrodes at the heart, or at the heart and elsewhere in the body, whilst its magnitude for a given location of electrodes will depend on the output from the generator. The first vector becomes the reference vector for future measurements. Initially, the technique depended on the detection of gross changes in the direction and magnitude of the Pacemaker Frontal Plane Vector. More recently, the development of the technique has depended on the detection of smaller changes in the magnitude of the vector and it is believed that the digital equipment described in this paper, because of its increased accuracy, will make detection of technical faults and other changes even more certain. It may also be of use in studying normal battery run-down.

In principle the technique is simple and is based on Einthoven's hypothesis (Einthoven et al., 1913) that the electrical activity of the heart at any instant can be represented by an electric dipole. Pacemaker electrodes on, or inside the heart likewise produce an electric dipole and the component of this in the frontal plane can be represented by a vector. The vector is drawn from measurements of the magnitude and sense of pacemaker signals as obtained from electrodes placed on the patient's limbs, Fig. 1(a). In theory any two of the three components are sufficient to construct the desired vector and if all three are used the lines 1, 2 and 3, in Fig. 1(b) should intersect in a point. In practice, however, it is found that the three lines intersect to form sides of an 'error triangle' and the size of this error triangle is a quantitative measure of the accuracy of the measurements. The main reason for this is that there is a considerable variation in the pacemaker pulse amplitude on any Lead with breathing. However to ensure that the position of the dipole is as near as possible the same during consecutive measurements on Leads I, II and III it has been the practice to ask the patient to breathe 'fully-in'. This greatly decreases the size of the error triangle referred to above. Nevertheless, when a calibrated storage oscilloscope is used to determine the Pacemaker Frontal Plane Vector, the lines 1, 2 and 3 in Fig. 1(b) often do not intersect in a point so that an error triangle is obtained. This is thought to arise because of the errors discussed below which are inherent in the use of a storage oscilloscope for these pulse height measurements.

There is a random observational error in