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The Present Status of Body Surface Potential Mapping*

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More extensive sampling of electrocardiographic potentials than is provided by the usual 12 lead examination has promise of significant medical utility. The broad objective is to improve the electrocardiographic examination in general and the more specific objective is to achieve a regionally selective evaluation of the electrophysiologic state of the heart. Examples of particular clinical aims of such selective examinations are the estimation of myocardial infarct size, detection, localization and quantification of localized cardiac hypertrophy, localization of sites of preexcitation and arrhythmia origin and detection of arrhythmia-prone states.

Historically, the probable utility of extensive sampling has been recognized since early studies of the electrocardiogram. In 1889, Waller (1) illustrated the body surface distribution of "inequalities of potential" as a diagrammatic isopotential map. The six precordial leads that are a part of the routine 12 lead electrocardiogram were introduced as a limited form of body surface mapping compatible with available instrumentation and practical for clinical application (2). The relation of these leads to the objectives of body surface potential mapping was clearly expressed by Wilson et al. (3), who described them as the best available substitute for direct leads from the surface of the heart and reported evidence for the conclusion that they were "in effect semidirect leads from that part of the ventricular surface which is nearest the precordial electrode." These investigators (2) also expressed a certainty that the future would see a "great increase in the use of precordial and other special leads and that it will bring us far greater knowledge of the electrocardiogram."

Problems in Methodology

Precordial mapping. Precordial lead arrays of more than the usual six leads have been used to detect ischemic heart disease with stress testing and to estimate the size of an ischemic lesion. Evidence of improved detection of ischemic disease and useful estimates of anterior lesion size have been reported and suggest the possibility of improved electrocardiographic examination by more extensive sampling (4–7). Precordial mapping should, however, be differentiated from efforts to obtain potential distributions over the entire thorax and achieve regionally selective examination of the entire heart (8).

Potential distributions over the entire thorax. Substantial systematic studies of the extensively sampled body surface electrocardiogram over the entire thorax have required modern electronics and computer science for the acquisition and processing of the large amount of data collected in each examination. Such studies are now in progress and have provided convincing evidence that an improved, clinically practical electrocardiographic examination is feasible. It has been unequivocally demonstrated that sufficient sampling of body surface potentials provides selective sensitivity to individual cardiac regions and greater information content than that of vectorcardiographic or 12 lead examinations. This evidence ranges from the simple presence of multiple poles in isopotential maps to the detection of epicardial breakthrough of ventricular excitation and localization of sites of preexcitation and ectopic ventricular excitation (9–12). Identification of preexcitation sites and sites of arrhythmia origin are examples of medically useful information in addition to providing evidence of regional sensitivity of mapping. There has been remarkable progress in the development of instrumentation for the simultaneous acquisition of large numbers of electrocardiographic leads and in the use of computers to utilize cardiac-generated potential distributions for medical purposes. In other work,

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redundancy in the extensively sampled body surface potential distribution has been systematically investigated and it has been shown that a relatively small number of appropriately chosen electrode sites can be used to estimate the total body surface potential distribution with a high degree of accuracy. Specific lead sets consisting of 24 and 32 electrodes have been designed and are in use in clinical studies (13,14).

Computer processing of map data. There has also been substantial progress in the computer processing of map data for medical purposes. In one approach, body surface map data are used together with models of varying complexity to predict the cardiac surface potential distribution or arrangement of cardiac sources necessary to account for the body surface data. This approach can be considered a form of cardiac imaging in which various aspects of the electrophysiologic state of the heart are the items responsible for the image. Another approach to processing map data for medical purposes consists of reducing spatial and temporal redundancy in maps by calculating sets of independent basis functions applicable to all maps and specifying the characteristics of individual maps by coefficients (15,16). This approach permits efficient storage of complete map data using slightly more than 200 numbers, in contrast to the 100,000 or 200,000 numbers required to specify the original data. More importantly, the relatively small number of coefficients are amenable to standard statistical methods for separation of data into diagnostically significant categories and may permit automated classification.

Clinical Applications

Problems in clinical applications. Despite the promise of substantial utility and several years of extensive theoretical, experimental and clinical study, body surface potential mapping still requires further research to establish its place in medical practice. The scientific and technical problems are formidable, and while notable progress has been made, the technique is not yet suitable for widespread medical application. The overriding problem is common to all clinical research involving a new or modified technique, namely, that of obtaining adequate independent confirmation that the technique provides valid and useful information. This problem is particularly difficult in the case of body surface potential mapping because the objective of improving electrocardiographic examination in general is extremely broad.

Closely related problems are those of establishing criteria for diagnostic classification of body surface potential features and defining optimal methods of display and analysis to detect these features. These are also particularly difficult problems for body surface potential mapping because of the large amount of data collected in each examination. In view of these problems, the most likely route by which body surface potential mapping may become a part of actual medical practice is by sufficient validation that it is a source of substantial useful information in one or a few disease states. In particular, significant information that is not furnished by other procedures would justify inclusion of the technique in medical examinations.

Ischemic heart disease. Because the unique feature of body surface potential mapping is its ability to provide evidence of the regional electrophysiologic state of the heart, the most likely areas of clinical utility are ones involving that state. A possible example is the evaluation of ischemic heart disease. Coronary arteriography is the definitive means of recognizing coronary obstruction but does not reflect myocardial ischemia as such. Detection of regional electrocardiographic abnormalities due to ischemia may therefore have different diagnostic and prognostic significance and therapeutic implications than arteriographic findings. Meaningful use of body surface potential mapping for this purpose, however, will require independent validation of the presence of ischemia. It will also be necessary to identify sensitive and specific map features that are caused by ischemia and to obtain evidence that these features are importantly related to the clinical course of patients with ischemic heart disease.

Electrophysiologic abnormalities of the heart. In principle, the same steps—namely, independent demonstration of disease, identification of characteristic map features and evidence of the medical significance of these features—are required to establish the utility of body surface mapping for each disease entity to which maps are applied. Considering the numerous states in which mapping has possible value, this would represent a substantial effort, and it is appropriate to inquire whether such effort is justified. Although a final answer cannot be given in advance of the actual studies, a variety of considerations strongly suggest the effort is justified. One item is the very substantial utility of the currently used 12 lead examination. It is highly unlikely that this constitutes the optimal electrocardiographic examination and its considerable value despite its defects strongly suggests that a more nearly ideal examination would have major medical significance.

Justification for continued study of body surface potential mapping is also provided by the great medical importance of electrophysiologic abnormalities of the heart. Although these abnormalities are usually secondary to some form of organic heart disease, they are an extremely important mechanism of death and disability due to disordered cardiac rhythm. It is virtually a truism that electrophysiologic abnormalities are most likely to be detected by examination of the electrophysiologic state of the heart. Some aspects of that state can be inferred from abnormalities of wall motion and some are appropriately evaluated by invasive procedures such as intracardiac stimulation and electrographic recording; however, the body surface electrocardiogram is the most widely

applicable method of examination. The regional sensitivity of body surface potential mapping has special relevance to arrhythmias because localized abnormalities of conduction and repolarization are important factors in these disorders.

Recognizing states predisposing to ventricular arrhythmias. One of the most promising areas in which body surface potential mapping may provide medically significant information not available from other techniques is that of recognizing states predisposing to ventricular arrhythmias. The QRST deflection area has been documented to reflect disparity of repolarization duration, which is an established factor in reentrant arrhythmias (17–19). By combining the regional selective sensitivity of body surface mapping and the physiologic significance of the QRST deflection area, it may be possible to identify the local inequalities of repolarization that predispose the ventricles to arrhythmias. Both experimental and clinical observations support this possibility. In dogs, a quantity based on analysis of the body surface distribution of QRST deflection areas was shown to increase in states of enhanced arrhythmia vulnerability (20). In clinical studies (21,22), multipolar distributions of QRST deflection area have been noted in patients resuscitated from ventricular fibrillation and in the postexercise maps of patients who also exhibited ectopic ventricular complexes. The optimal analysis of QRST deflection area distributions for the possible recognition of states at risk of arrhythmias is not yet certain, but the maximal gradient of areas in local body surface regions and the nondipolar content of distribution are promising possibilities. In a recent study (23), the multipolar content of QRST deflection area distribution in 25 patients with recurrent ventricular tachycardia was 34% while in an age-matched group of normal subjects, it was 12%.

In summary, clinically practical body surface potential mapping is feasible and has promise of significantly improving electrocardiographic examination by providing selective sensitivity to regional electrophysiologic conditions. The procedure is still at a research stage of development although a variety of findings strongly suggest its medical utility. Justification for its inclusion in clinical practice requires additional studies with independent documentation of disease. More evidence that it provides useful information in addition to that furnished by other examinations is also needed. The recognition of arrhythmia-vulnerable states of disparate ventricular repolarization is a particularly promising area of clinical utility.

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