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Problems and Perspectives of Mapping the Cardiac Electric Field

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Summary

The cardiac electrical field is important not only because of its diagnostic significance, but also as a biological and biophysical phenomenon. As such, it has become a research target of biologists, biophysicists and biomathematicians. It has also been an impetus for constructing more and more sophisticated measuring devices. Criteria for the diagnostic evaluation of body surface potential maps have often been derived from clinical studies based on a restricted number of cases. Further clinical research is therefore a *conditio sine qua non* for the acceptance of mapping as a routine diagnostic procedure. In the future, body surface potential distributions will be used as the input for computer simulation of potential distribution and activation chronograms on the geometric surface closely encompassing the heart. In such a way, electrocardiographic signals will be interpreted in terms of activation and repolarization sequences on the cardiac surface.

Key words

Electrocardiology – Potential mapping – Computer simulation

Augustus Waller's measurements, employing a capillary electrometer and recording of electric potential fluctuations using about 20 electrodes situated on the body surface, may be regarded as the earliest potential mapping. This manner of data acquisition, along with his interpretation of body surface potential distribution, due to the operation of a source characterized by a physical dipole, already forecasted the two main pathways in the further development of the theory and measurement of the cardiac electric field. One path led to Einthoven's electrocardiography and to physically corrected orthogonal leads of vectorcardiography, the other to the present art of body surface potential mapping.

The standard 12-lead electrocardiogram contains both approaches in a rudimentary form: the first is represented by the limb leads, the second by the precordial leads. Since the composition of our present day set of 12 standard ECG leads is a product of historical evolution, it is far from being rational and perfect. The information content of limb leads is restricted only to the frontal plane projection of the cardiac electric field and the precordial electrodes are not situated at points from where maximum information may be obtained, especially in cases of cardiac pathology (Kornreich *et al.* 1988).

Unfortunately, further development of vectorcardiography and of body surface potential mapping did not go hand in hand either with their theoretical basis or the technology of their recording. The convergency of these approaches may be attained in the future by attempting to find some practically acceptable solution to the inverse problem of electrocardiology, aided by computer-based simulation and modelling. It is hoped that this will result in a qualitative improvement of electrocardiological diagnostics.

Methods

Isopotential contours of the precordium, obtained by hand measurements of analog signals, were first published by Koch and Schneyer in 1934. A relatively complete thoracic surface potential distribution during successive instants of the QRS complex was already computed by Groedel in 1940. The first detailed body surface maps of isopotential lines calculated from hundreds of points 1 cm apart in the precordial region and 2 cm apart elsewhere, were published by Nahum and co-workers in 1953. The history of electrocardiographic thoracic mapping was presented in more detail by Lepeschkin (1974).

The present development of body surface potential mapping as a method of experimental physiological and clinical research, as well as its subsequent diagnostic utilization, was initiated in the early sixties by the work of Taccardi (1963, 1966).

The still unsolved methodical problems of mapping are partly common to other methods of noninvasive electrocardiology, e.g. construction of surface electrodes with optimal parameters, and partly specific, e.g. the number and localization of electrodes, acquisition and presentation of a large amount of partially redundant data, as well as their statistical evaluation. Since the aim of mapping is to obtain the possibly most detailed image of potential distribution, there is a natural tendency to use the maximum possible number of surface electrodes. For instance, one of the equipments recently used (De Ambroggi *et al.* 1989) has 219 Ag-AgCl electrodes, 8 mm in diameter, regularly distributed on the thoracic surface. Unipolar ECGs, using Wilson's central terminal as the reference point are recorded simultaneously by an automated 240-channel instrument, which performs on-line amplification, multiplexing of 500 samples per second per channel and analog-to-digital conversion of signals into 8-bit bytes. The digital data are processed on-line by a minicomputer. Such systems for "total" sampling of ECG waveforms employ 80-250 electrodes at present.

The tendency to find a practically optimal minimum number of electrodes led to the construction of the so called "limited" lead systems, using only 24-32 electrodes (Barr *et al.* 1971, Lux *et al.* 1978). It has been shown that clinically important basic information about the cardiac electric field may be already obtained from 20-30 recording sites (Lux 1989). Increasing their number also increases their redundancy. However, the practical problem of "total" or "limited" sets of electrodes does not concern so much their number, as their correct localization. The correct placement of a large number of regularly distributed electrodes is not as critical as the placement of a limited set of electrodes at predetermined points on the chest surface. This may cause problems with the reproducibility of recordings.

Theory and utilization

The subset of precordial electrodes of the standard 12-lead ECG may also be regarded as a rudimentary set of mapping electrodes. Mapping is thus in part an extension of unipolar chest lead electrocardiography and there are also similarities in its interpretation. While the signals of limb leads are interpreted as reflecting periodic changes of the equivalent dipolar source, neither the signals of Wilson's chest leads, nor the signals of mapping leads are related to any kind of mathematically or physically defined source. On the other hand, proximity effects are stressed and it is expected that they will furnish additional diagnostic information.

From the medical point of view, the crucial problem concerns the question whether and to what extent mapping is able to give more diagnostically useful information than the standard electrocardiogram or vectorcardiogram. This problem may, of course, be solved only by comparing standard ECG records, vectorcardiograms and body surface potential maps obtained from a single cardiac beat. Equipments such as the diagnostic system Cardiag (Stojan 1991), permitting such comparative studies in healthy and diseased subjects, are therefore indispensable for further progress of electrocardiologic diagnostics.

Of course, the cardiac electric field is interesting not only for its diagnostic usefulness, but also as a biological and biophysical phenomenon. As such, it is a research target of biology, biophysics and biomathematics, and also serves as an impetus for constructing more and more sophisticated measuring devices. The recording equipment should therefore be devised so that it will meet not only the practical needs of contemporary medicine, but it should also provide possibilities for more widely conceived studies, measurements, data handling and interpretation. In this way technical sciences should precede the progress and needs of physiology and medical sciences. A recent survey of trends in this area of research was published elsewhere (Kneppo and Titomir 1992).

As regards the practical diagnostic interpretation of body surface potential maps, their visual assessment still remains in the foreground. Attention is usually paid to the trajectories of potential maxima and minima throughout the cardiac cycle as well as to the timing and localization of their onset and disappearance. It is evident that these characteristics are closely related to the parameters of the vectorcardiographic loop. Their additional diagnostic information content may be disclosed with the aid of non-electrocardiologic diagnostic methods. It may be hidden mainly in the irregularities of the shape of the potential surface surrounding the maximum and minimum values (like the irregular surface of a mountain or a valley), that do not significantly influence the localization and magnitude of the instantaneous vectorcardiographic vector. Much promising work aimed at the quantification and diagnostic evaluation of this additive information is in progress and is based on the concept of non-dipolar content of the cardiac electric field (Drška *et al.* 1988).

The great advantage of the mapping techniques is the possibility of producing iso-integral maps of the whole QRST complex or of its parts. It remains to be demonstrated in clinical correlative studies to what extent such data reduction will enrich our diagnostic possibilities. The same holds for isochrone contour maps. Many problems are encountered in the statistical treatment of the huge amount of rather variable and partially redundant data furnished by the mapping procedures. A sophisticated solution of this problem has already been proposed (Lux *et al.* 1981, Evans *et al.* 1981). According to these authors each recorded body surface potential distribution may be represented as a linear combination of 12 independent, so-called basis maps (eigenvectors), derived from a set of maps on over 200 patients and normal subjects. As a result, the instantaneous potential distribution recorded at 196 electrode sites is converted to 12 numbers and the sequence of map frames is replaced by a set of 12 waveforms. After removing the interdependency and redundancy in the temporal waveforms by the same approach, the original body surface potential map is replaced with an equivalent set of 216 independent variables from which the original map may be reconstructed at a high level of accuracy. This 216 dimensional vector can then be used for comparative and diagnostic purposes.

Perspectives

Criteria for diagnostic evaluation of body surface potential maps have often been derived from clinical studies based on a rather restricted number of cases. The continuation of clinical research is therefore a *conditio sine qua non* for the acceptance of mapping as a routine diagnostic procedure.

Interdisciplinary effort in biomathematics, biophysics, physiology and clinical medicine backed by achievements of computer science and technology are a good basis for making promising progress in the practical solution of the inverse problem of electrocardiography. Body surface potential distributions will be used as input for computer-aided simulation of potential distributions and activation chronograms at a geometric surface closely encompassing the heart. In such a way, the interpretation of electrocardiographic signals will be possible in terms of activation and repolarization sequences on the cardiac surface. At present body surface potential mapping is primarily a method of clinical cardiac physiology and pathophysiology and is utilized for diagnostic purposes only in advanced and specialized clinical research centers.

References

BAR R.C., SPACH M.S., HERMAN-GIDDENS G.S.: Selection of the number and position of measuring localizations for electrocardiography. *IEEE Trans. Biomed. Eng.* **18:** 125 – 138, 1971.

DE AMBROGGI L., MUSSO E., TACCARDI B.: Body surface mapping. In: *Comprehensive Electrocardiology,* vol. 2. P.W. MACFARLANE, T.D. VEITCH LAWRIE (eds), Pergamon Press, New York, 1989, pp. 1015 – 1049.

DRŠKA Z., VALOVÁ D., MÁLKOVÁ A.: Higher degree multidipolar components sum on the VCG spherical surface. In: *Electrocardiology '87.* E. SCHUBERT (ed), Akademie-Verlag, Berlin, 1988, pp. 165 – 167.

EVANS A.K., LUX R.L., BURGESS M.J., WYATT R.F., ABILDSKOV J.A.: Redundancy reduction for improved display and analysis of body surface potential maps. II. Temporal compression. *Circ. Res.* **49:** 197 – 203, 1981.

KNEPPO P., TITOMIR L.J.: Topographic concepts in computerized electrocardiology. *Crit. Rev. Biomed. Eng.* **19:** 343 – 418, 1992.

KORNREICH F., MONTAGNE T.J., RAUTAHARJU P., KAVADIAS M., HORÁČEK M.: Identification of best electrocardiographic leads for diagnosis of left ventricular hypertrophy by statistical analysis of body surface potential maps. *Am. J. Cardiol.* **62:** 1285 – 1291, 1988.

LEPESCHKIN E.: History of electrocardiographic thoracic mapping. *Adv. Cardiol.* **10:** 2 – 10, 1974.

LUX R.L.: Mapping techniques. In: *Comprehensive Electrocardiology,* vol. 2, P.W. MACFARLANE, T. D. VEITCH LAWRIE (eds), Pergamon Press, New York, 1989, pp. 1001 – 1017.

LUX R.L., EVANS A.K., BURGESS M.J., WYATT R.F., ABILDSKOV J.A.: Redundancy reduction for improved display and analysis of body surface potential maps. I. Spatial compression. *Circ. Res.* **49:** 186 – 196, 1981.

LUX R.L., SMITH C.R., WYATT R.F., ABILDSKOV J.A.: Limited lead selection for estimation of body surface potential maps in electrocardiography. *IEEE Trans. Biomed. Eng.* **25:** 270 – 276, 1978.

STOJAN M.: Principles of the analysis of the electrical cardiac field for clinical purposes. (in Czech), ZPA Čakovice, Prague, 1991.

TACCARDI B.: Distribution of heart potentials on the thoracic surface of normal human subjects. *Circ. Res.* **12:** 341 – 352, 1963.

TACCARDI B.: Body surface distribution of equipotential lines during atrial depolarization and ventricular repolarization. *Circ. Res.* **19:** 865 – 878, 1966.

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