REVIEW

Quantitative characterization of the relief of body surface potential distribution

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Abstract

The body surface distribution of the cardiac electric field is best represented as reliefs of positive and negative potentials, or their time integrals. The objective of this study was to design a methodology of their quantitative evaluation. QRST isointegral maps were obtained from 45 healthy subjects (35 men, 10 women, aged 10—67 years) using a 80 electrode set. Relative frequencies of positivity and of negativity were ascertained for different levels of the QRST integral values.
Two fuzzy subsets: that of positive and that of negative QRST values were defined on the set of electrode placements. The values of membership functions of their elements were derived from relative frequencies obtained in the reference group of subjects, separately for all levels of QRST integral values. Statistics of these values characterize the reference reliefs of the positive and of the negative QRST values and are used to test their resemblance to a given individual distribution.
In conclusion, the representation of isopotential, or isointegral body surface potential maps as reliefs of their positive and negative values, based on the theory of fuzzy sets, enables a quantitative evaluation of their resemblance to a given individual distribution. ***(Fig. 6, Ref. 18.)***
Key words: cardiac electric field, isointegral QRST distribution, fuzzy subsets.

An analysis of the pertinent literature, published in the sixties of the last century (Rijlant and Ruttkay-Nedecký, 1969) has shown that computers were introduced in medicine earliest and to the greatest extent in electrocardiology. They have been gradually utilized also in our country for electrocardiographic data acquisition and evaluation in preventive population surveys (Bachárová et al., 1988), for recording, visualization, and evaluation of body surface potential distributions (Filipová and Cagáň, 1986; Kozlíková et al., 1988; Kneppo et al., 1988; Slavkovský and Hulín, 1989), as well as for simulation of myocardial activation propagation in studies of the normal variability and pathologic changes of electrocardiograms and vectorcardiograms (Szathmáry, 1989).

The body surface representation of the cardiac electric field provides also input data for solving the inverse problem of electrocardiology, i.e. the model of its source. On the other hand, potential maps provided by computer simulation of such a source are a criterion of their adequacy.

In the course of a cardiac revolution, the three dimensional visualization of areas of positive and negative potential distributions shows elevations and depressions of irregular ad changing shape. An optimal method for quantitative evaluation of normal variability, as well as of pathologic changes of such complex shapes is not available. Problems arise also due to inconsistency in number and localization of recording sites, as well as in differences of characteristics of data acquisition systems. In earlier papers (Ruttkay-Nedecký, 1988, 1991), a fuzzy set based method was proposed for evaluation of the similarity between images of ventricular activation surfaces, obtained by dipolar electrocardiotopography (Titomir and Ruttkay-Nedecký, 1987). In the present study, it was adapted for appraisal of the similarity between body surface potential maps and applied in a study of the distri-

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This work is dedicated to RNDr. Vavrinec Szathmary.

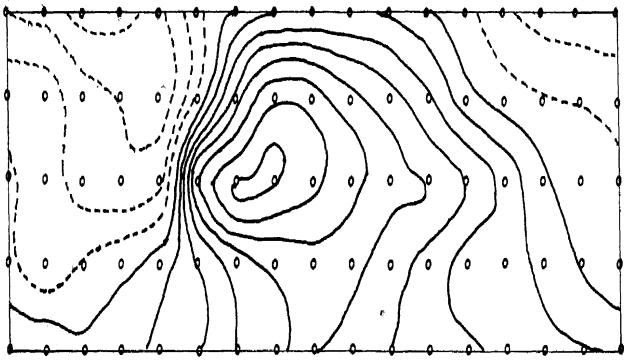

Fig. 1. Izointegral map from a normal subject. Both the left and right margins indicate the right midaxillary line, the small circles the placement of electrodes. The solid lines indicate positive time-integral values of QRST, the dashed lines negative values. Separation by 10 μVs intervals.

bution of isointegral QRST values, that are considered to be a potential marker of ventricular repolarization inhomogeneity (Abildskov et al., 1983; Abildskov and Green, 1987; De Ambroggi, 1997).

Material and methods

The reference group consisted of 45 subjects (35 males, 10 females) aged 10—67 years (median 59), with no history and signs of cardiovascular disorders, and a normal McFee-Parungao vectorcardiogram (Vectorcardiograph system 1520A, Hewlett-Packard). The potential maps were obtained by a computer based electrocardiologic system (CARDIAG 128.1, METE, Prague) using a set of 80 unipolar leads, distributed regularly at the intersections of 5 rows and 16 columns on the chest surface. Isointegral contour maps, delineating areas with identical positive, or negative values of the QRST time integral, in μVs, were printed at the output of the recording system (Fig. 1). The ordinary set of the electrode sites of unipolar leads was treated as consisting of two fuzzy subsets: one with positive and one with negative values of the QRST integrals. The membership characteristic functions of their elements were derived from the respective relative frequencies obtained in the reference group of normal subjects. This procedure was repeated for the ordinary subsets of those electrode sites, where the absolute value of the QRST integral attained, or surpassed the values of 10, 20, 30, 40 and 50 μVs, respectively.

Results

The relative frequencies of positive and negative QRST values, obtained in our reference sample, at the intersections of rows A—E and columns 1—16, are shown on Figure 2 for the total thoracic surface, on Figs 3—6 for those parts of the surface, where the QRST integral value attained 10, 20, 30, or 40 μVs.

Since the course of separating lines between positive and negative QRST values on the body surface exhibits interindividual variability, a given electrode site may be a member of both the positive and the negative fuzzy subsets with different values of membership functions, so that they have intersections. As shown on Figure 2, in our reference sample, the absence of positive QRST values could be expected only on a small circumscribed area under the right clavicle, and the absence of negative QRST values in the left axillary region. However, this image was changed after taking into consideration not only the sign of the QRST integral, but also its value in μVs. Then the fuzzy subsets were defined exclusively on the sets of electrode sites where the QRST integral reached, or surpassed, a predetermined value. The area of intersection became much smaller at the 10 μVs level, and this tendency continued toward higher μVs levels (Fig. 3—6).

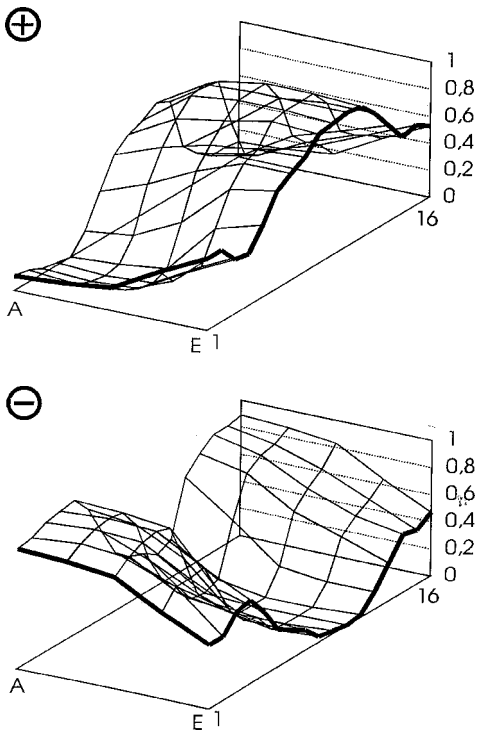

Fig. 2. Distribution of positive (+) and negative (-) values of relative frequencies (vertical axis) of QRST integrals from the reference set. A—E represents the right midaxillary line, A is at clavicular level. Recording electrodes were placed at intersections of A—E rows and 1—16 columns.

Qualitative, as well as quantitative criteria may be used to compare an individual distribution with a reference one. An important qualitative criterion is the absence of positivity, or negativity of a QRST value at electrode sites, which are not elements of an intersection of fuzzy subsets. In such a case, lack of similarity is supposed between the individual and the reference relief. Quantitative criteria are based on relations between the arithmetic means of membership function values at different levels of μVs, as well as of the sum of all membership functions of the given subject on one side, and the statistics (mean±standard er-

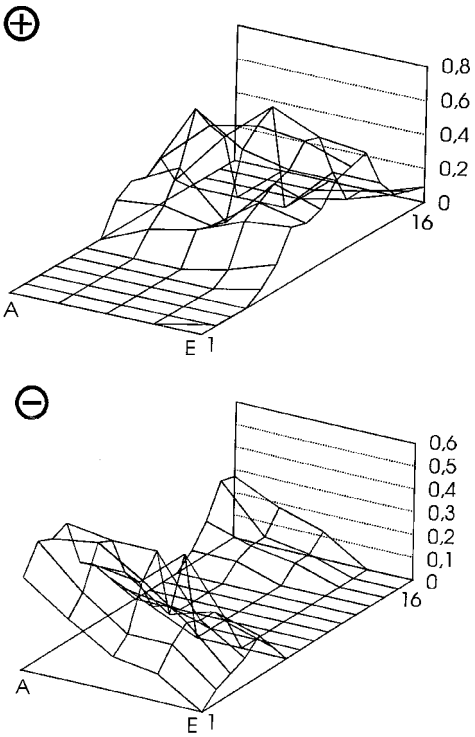

Fig. 3. Distribution of relative frequencies of positive and negative values of QRST integrals •10 μVsec. For further explication see Fig. 2.

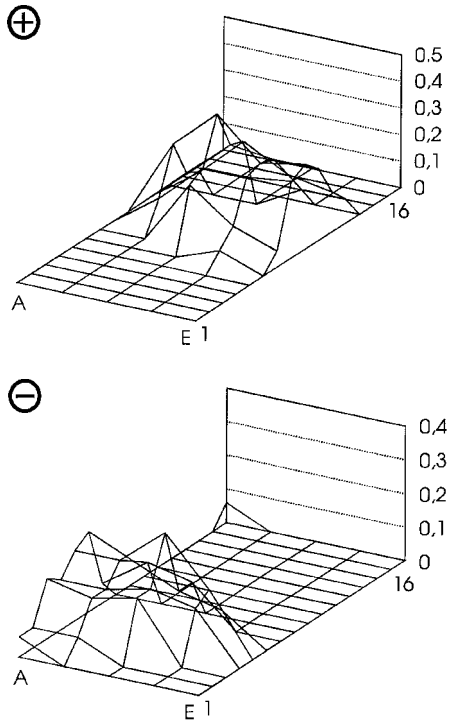

Fig. 4. Distribution of relative frequencies of QRST integrals •20 μVsec.

ror of the mean) of the respective values obtained from the reference sample. An individual distribution of data (or its computer simulation) is deemed to be similar to a reference distribution, if the arithmetic means of membership function values of all fuzzy subsets are within the intervals±2 times standard error of the mean obtained from the respective characteristics of the reference set. If any of them lies between±2 SE and ±3 SE, the similarity is only marginal, if outside of ±3 SE, it is nonexistent.

Discussion

Elements of fuzzy sets are considered to be intrinsically imprecise. On the other hand, randomness involves uncertainty about occurrence of an event precisely described. However, in real life, it could often be the case that both fuzziness and randomness are present (Negoita and Ralescu, 1975). This is relevant also to the topics of the present study. The body surface potential distribution of a given subject is related to the distribution of potentials on the surface of its heart, but this relationship is confounded by the electrical properties of the extracardiac space. When counting the relative frequencies of positivity, or negativity of QRST integral values at electrode sites, we are dealing with precisely described events. When characterizing the 3D reliefs of positivity and negativity, we are imprecise, because they are evaluated only at predetermined levels of μVs. The transformation of relative frequencies into characteristical membership functions of fuzzy elements, as used in this study, may be consi-

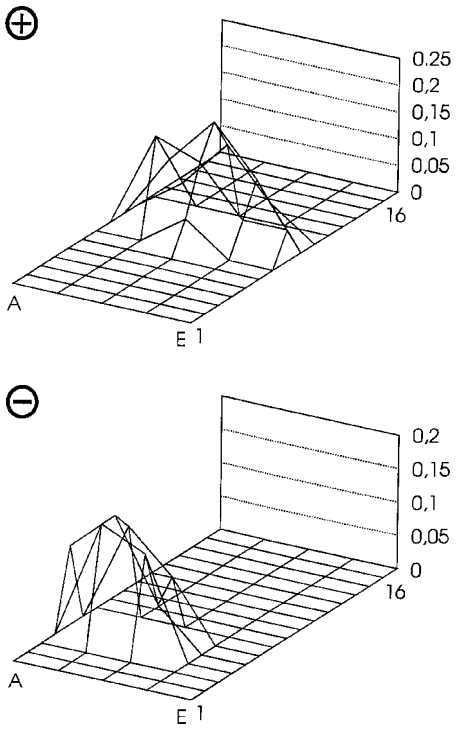

Fig. 5. Distribution of relative frequencies of QRST integrals •30 μVsec.

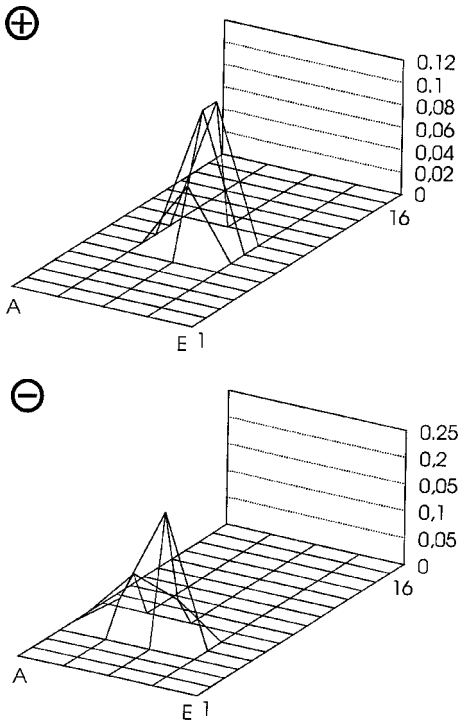

Fig. 6. Distribution of relative frequencies of QRST integrals •40 μVsec.

dered as a first approximation and the values may be corrected if necessary, e.g. in experimental work, or simulation studies using a computer model of the source of the cardiac electric field.

In earlier works, the reliefs were characterized by statistics of maxima and minima of QRST integral distributions (Montague et al., 1981), or their peak-to-trough amplitudes (Ruttkay-Nedecký and Regecová, 1999). The normal distribution of QRST was studied also by mathematical data compression in the reference set, where the QRST complex was represented by 216 Karhuenen-Loeve coefficients (Kozman et al., 1999).

The body surface distribution of QRST integral values is in fact a distribution of Wilson's „ventricular gradient" (Wilson et al., 1934). Since it reflects mainly the inhomogeneity of ventricular repolarization, due to differences in action potential shape and duration, its source has a distributed character and its interpretation in terms of a dipole, a multipole, or a multidipole is of no physiological meaning. Its quantitative characteristic has therefore to be focused on the localization and the shape of reliefs of positive and negative QRST distributions. According to De Ambroggi, negative QRST integrals should be recorded from areas facing myocardial regions with longer recovery durations, whereas positive values are recorded from the thoracic surface facing cardiac regions with shorter recovery durations (De Ambroggi, 1997). Also differences in the variability of their peak values were reported, e.g. the age-related decrease of the minimum is greater than that of the maximum, and in held deep inspiration, the maximum decreases more than the minimum (Ruttkay-Nedecký and Regecová, 1999).

The presented method of evaluation does not take into account the absolute values of QRST integrals, but only the occurrence of their positivity, or negativity at the electrode sites, as well as at predetermined levels of the reliefs. Its accurateness depends also on the density of such levels. The method makes it possible to deal with conventionally printed isointegral maps (Fig. 1), where the QRST values are not indicated at the individual electrode sites. Since in the reference set the QRST values are not averaged, the reliefs of positivity and negativity, including their intersections, are evaluated and may be visualized separately. The method permits not only to assess a global similarity between the individual and the reference relief, but also the degree of eventual differences at predetermined levels of the relief.

References

Abildskov JA, Green LS, Lux RL: The body surface distribution of QRS, ST-T and QRST deflection areas. P. 169. In: Yamada K, Harumi K, Musha T (Eds.): Advances in Body Surface Potential Mapping. The University of Nagoya Press, Nagoya 1983.

Abildskov JA, Green LS: The recognition of arrhythmia vulnerability by body surface electrocardiographic mapping. Circulation 1987; 75-III: 79—83.

Bachárová L, Melotová J, Horský I: Automated evaluation of orthogonal electrocardiogram in prevention (in Slovak, English abstract). Bratisl Lek Listy 1988; 89: 673—677.

De Ambroggi L: Body surface potential mapping as a tool for detecting arrhythmia vulnerability. P. 489. In: Liebman J (Ed.): Electrocardiology '96. Singapore—New Jersey—London—Hong Kong, World Scientific Publishing Co 1997.

Filipová S, Cagáň S: Evaluation of localization and extent of myocardial infarction by means of ECG mapping (in Slovak, English summary). Bratisl Lek Listy 1986; 86: 639—653.

Kneppo P, Titomir LI, Zrubec V, Tyšler M, Turzová M, Popperová E, Hatala R: Possibilities of applying topographic measurements and imaging of the electromagnetic field of the heart in diagnostics of its functional state (in Slovak, English summary). Bratisl Lek Listy 1988; 89*:* 641--646.

Kozlíková K, Turzová M, Tyšler M, Popperová E, Sabolová K, Petrášová H, Michalík D: Body surface integral mapping of ventricular activation in boys during puberty (in Slovak, English summary). Bratisl Lek Listy 1988; 89*:* 694--705.

Kozmann Gy, Farkas N, Sándor Gy: Statistical characterization of QRST integral maps of normal subjects. P. 95. In: Préda I (Ed.): Electrocardiology '98. Singapore—New Jersey—London—Hong Kong, World Scientific Publishing Co 1999.

Montague TJ, Smith ER, Cameron DA, Rautaharju PM, Klassen GA, Felmington CS, Horacek BM: Isointegral analysis of body surface maps. Surface distribution and temporal variability in normal subjects. Circulation 1981; 63: 1166—1172.

Negoita CV, Ralescu DA: Applications of fuzzy sets to systems analysis. Basel—Stuttgart, Birkäuser Verlag 1975, 186 p.

Rijlant P, Ruttkay-Nedecký I: Computers in electrocardiology (in Slovak, English summary). Bratisl Lek Listy 1969; 51: 101—123.

Ruttkay-Nedecký I: Application of fuzzy subsets in quantification of normality of the QRS complex of orthogonal electrocardiograms (in Slovak, English summary). Bratisl Lek Listy 1988; 89: 627—630.

Ruttkay-Nedecký I: Decision making in boundary problems of computerized electrocardiology using fuzzy sets. P. 557. In: Werner R (Ed.): Computers in Cardiology. Washington—Brussels—Tokyo, IEEE Computer Society Press 1991.

Ruttkay-Nedecký I, Regecová V: Normal variability of the gradient between maximum and minimum of the QRST area distribution. P. 36. In: Préda I (Ed.): Electrocardiology '98. Singapore—New Jersey—London—Hong Kong, World Scientific Publishing Co 1999.

Slavkovský P, Hulín I: Graphic representation of deviations of the cardiac electric field (in Slovak, English summary). Bratisl Lek Listy 1989; 90: 81—91.

Szathmáry V: New results of computer simulation of the spread of excitation in the myocardium (in Slovak, English summary). Bratisl Lek Listy 1989; 90: 129—134.

Titomir LI, Ruttkay-Nedecký I: Chronotopography: A new method for presentation of orthogonal electrocardiograms and vectorcardiograms. Int J Bio-Med Comp 1987; 20: 275—182.

Wilson FN, Macleod AG, Barker PS, Johnston FD: The determination and significance of the area of the ventricular deflections on the electrocardiogram. Amer Heart J 1934; 10: 46—61.

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