Body Surface Potential Mapping: Historical Background, Present Possibilities, Diagnostic Challenges

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EVOLUTION OF ELECTROCARDIOLOGY

For more than 100 years, it has been possible to measure and display the electrical potentials of the heart on the body surface. Since the first attempts of Waller and Einthoven, many researchers helped us to understand better the cardiac electrical events. A hundred years ago, ECG was the only instrument to examine the heart, whereas today, there are many ways to study the heart. Nevertheless, ECG remained the most used method because of its simplicity and its high information content. The aims of electrocardiographic examinations are partly the same as they were a century ago: to measure and display the electrical potentials on the body surface and to interpret the intracardiac electrical events ("inverse problem"). Importantly, the new noninvasive and invasive cardiac investigation techniques provide an opportunity to define further the relationship between the electrical events and the underlying morphologic, functional or hemodynamic findings.

Waller's first publications were based on body surface potential measurements. He presented the distribution of the electrical potentials on the body surface as they were generated by a dipole inside of the thorax and applied to the body surface.¹ Because of this assumption of a dipole source, the aim was to determine the resultant vector for a long time.² There is no question that the multiple activation fronts of the heart cannot be characterized by a single moving dipole. However, body surface

potential mapping (BSPM), as a method, can be suitable to display the nondipolar electric components in addition to the dipolar component.^{3,4}

During the "evolution" of the conventional ECG, researchers tried to identify the most useful leads. Since Wilson's works, the 12-lead ECG has three dipolar leads and three modified unipolar leads in the frontal plane, as well as six unipolar leads on the anterior chest. The information content of those leads is sufficient to diagnose most of the electric abnormalities of the heart. Unipolar electrograms from numerous other sites of the chest (the BSPM) may provide more information about the electric event (Table 1). Some electric information, however, can only be obtained by means of electrophysiologic examinations (intracavitary leads + programmed electrical stimulation). Other useful information content, e.g., late potential, will only appear after a signal averaging process.⁵ In other cases, only long-time monitoring (Holter) provides diagnostic information. Combination of these approaches, along with drug testing or exercise testing⁶ can provide further details.

BODY SURFACE POTENTIAL MAPPING: TECHNICAL DETAILS

Manual evaluation of numerous electrograms recorded at the same time is time consuming and difficult, therefore it requires computer processing. That processing is the technical basis of BSPM, and that is why BSPM became feasible only after the 1960s.⁷

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Table 1. Comparison of ECG and BSPM

	ECG	BSPM
Technical data		
Availability	everywhere	in specialized centers
Acquisition time	2–3 min	10–60 min
Processing	no necessary	only by computer
Display	simultaneously	after processing
Evaluation	by all physicians	only by experts
Automatic evaluation	+	–
Information about the electrical event		
Components	Mainly dipolar	dipolar + multipolar
Modeling the electrical sources	–	+
Localization	+	++
Monitoring	+	–
Diagnostic value		
Myocardial infarction		
Acute	+	– +
old. Q wave	+	++
old non Q wave	–	++
+conduction defect	– +	+
Hypertrophies	+	++
Intraventricular conduction defects	+	++
Supraventricular conduction defects	+	–
Accessory pathway	+	++
Hyperdinam rhythm disturbances	+	–
Localization of ectopic activity	+	++
Measuring the effect of invasive procedure	– +	+

The principle of different BSPM techniques is the same, but the number and location of the leads, the filtering or the display method may be different.⁸ The information content may be converted between the different systems.^{9,10} As an example, following is a description of the technical details of the "Montreal" system that we use currently.¹¹

Body surface potentials are measured using 63 unipolar leads referenced to the Wilson central terminal. Ag-AgCl electrodes are mounted on 12 equidistant adhesive strips with an interelectrode distance of 6 (on the back 12) cms. Forty-three electrodes are mounted on the front of the torso and 20 electrodes on the back. The ECG signals are amplified with programmable-gain amplifiers using a 0.05–200 Hz bandwidth, are sampled at 500 sample/sec and are converted to a 10 bit digital format by a custom made computerized system (Cardiplot). Signal averaging with beat alignment by cross-correlation is performed for a period of 52 seconds to improve the signal-to-noise ratio. Baseline shift is corrected by adjusting the TP segments to a

straight line. Different types of body surface maps are generated (details follow). On these maps, the torso surface is represented by a rolled-out cylinder cut along the right midaxillary line. The left side of the map corresponds to the anterior torso and the right side corresponds to the posterior torso.

MAP TYPES

Different ways to analyze the electric information resulted in various map-types.⁸ Their basis are the *isopotential maps* (Fig. 1b), where, at a given moment, the sites of equal potentials (Fig. 1a) are connected by a line. The zero level is identified by a heavier line and contour lines are drawn at regular intervals (or they are identified by different colors). A plus and a minus sign indicates the location of the maximum and the minimum. It is important to indicate the time-instant of the electrical signal at which point the map is computed (distance from the onset of the investigated interval or a marker in

Figure 1. Presentation of various map-types in a schematic form (old anterior infarction, using the Montreal configuration). (a) potential values on the sites of the electrodes at the 30th ms after QRS onset; and (b) the corresponding isopotential map; (c) isoarea map of the first 30 ms of the QRS from the same patient; (d) averaged isoarea map of the first 30 ms of the QRS in normal group (24 patients) for computation of departure maps; (e) isoarea departure map of the first 30 ms of the QRS (c – d); (f) isoarea departure index map of the first 30 ms of the QRS (like “f” but only those sites are assigned, where the difference is more than 2 SD of the normal group); (g) isochron map during the QRS also from the same patient. (In (b–f), the maximum and minimum values are given and their location is indicated by an A+ or an A– sign on the map. Difference between isopotential lines in (b): 0.5 mV; difference between isoarea lines in (c–f) 2.2 mVms).

a characteristic lead). The value of the maximum, the value of the minimum, as well as the scale of the isopotential lines are also important. Isopotential maps usually are plotted at every 1 or 2 ms during the selected interval. Holographic representation of the maps has

also been proposed.¹² A description of other frequently used map types follows.

Isoarea maps represent the body surface distribution of the time-integral of the potential during the selected time interval (e.g., first third of the QRS complex (Fig. 1c), the entire

QRS complex or the combination of the QRS complex and T wave).

On the *isochron maps*, the isochron lines link the sites that are activated at the same time, i.e., the depolarization wavefront (Fig. 1g).

Departure map, which is not a separate type of map, shows the difference from the normal group, i.e., departure map (Fig. 1e) = map of the particular patient (Fig. 1c) minus the averaged map of the control group (Fig. 1d). *Departure index map* only indicates those parts of the departure map, where the difference from the map of the control group exceeds the 2 standard deviations (Fig. 1f). For example, to calculate an isoarea departure index map, first the mean and standard deviation for the control group has to be computed. In a case of a particular patient, if the variable of the departure maps at a given lead is within the two standard deviations of the mean value at the corresponding lead on the normal group, the map shows a zero value; if the variable exceeds two standard deviations above the mean value, the map shows the difference between the observed value and the mean, plus two standard deviations (positive area). If the variable is at least two standard deviations below the mean value, the map shows the difference between the observed value and the mean, minus two standard deviations (negative area).

Epicardial potential during heart surgery using a multiple electrode "sock" is suitable to determine the borderline of an aneurysmectomy or identify the origin of ventricular arrhythmia for cryoablation purpose.¹³⁻¹⁵ Processing and computing the epicardial map is similar to the processing of a BSPM map.

As in animal and human studies, it is also possible to detect electric potentials intraoperatively and compute maps from the endocardial surface using an inflatable multielectrode balloon introduced to the left ventricle through a left atrial incision.^{13,16}

In some cases, for example in patients with Wolff Parkinson White (WPW) syndrome, determination of the single moving dipole as a mean of interpretation can also be useful. The electric information of the BSPM is suitable to calculate the single moving dipole.^{11,17-21} Furthermore, it is also the source for the calculation of the theoretical "dipolar" body surface map, or a difference map from the measured map and from this theoretical "dipolar" map. That difference map contains the non-dipolar information of the electrical sources.⁴

PRINCIPLES OF THE BSPM EVALUATION

Solution of the Inverse Problem: Localization

The measured electric potential values on the body surface represents the corresponding potentials of the heart in function of the distance of the source (electrical wavefront) from the measuring electrode. Thus, some higher potential amplitudes may significantly influence the measured potentials in the neighboring sites on the body surface. To localize the site of origin of the electric potentials which are measured on the body surface, the heart regions have to be defined more precisely than "anterior" or "posterior" side. In most cases, the "Selvester-division" of the heart seems to be satisfactory: it is based on combinations of four longitudinal regions: anteroseptal, anterosuperior, posterolateral, and inferior; and three transversal regions: basal, middle, and apical.²² The isopotential maps can help to identify these regions as the temporal information partly depends on the activation sequence of the heart.²³ (Fig. 2).

The Role of the Normal Control Group

To diagnose any ECG abnormality, it is important to know the pattern of the normal maps. While the maps of the various mapping systems have minor differences, each mapping system requires its own suitable (number, age) healthy control group which is essential to calculate departure maps.

Map Features that are Suitable for Evaluation

Negativity and Positivity on the Body Surface Isopotential Maps

Positivity of a body surface site means that (1) the activation is occurring in the heart region under the electrode and activation spreads in endo-epicardial direction; or (2) an activation wavefront is moving towards the measuring electrode. The positivity only lasts until the activation front reaches the epicardial surface. Initial positivity indicates the first activation, the maximum positivity at each time instant indicates the direction of the mean activation front.

Initial negativity indicates that the activation of the corresponding region has not begun yet. Nega-

Figure 2. Some "Selvester heart region" in schematic form and their projection sites to the body surface in case of potential loss. (a) anterior-paraseptal part of the anterosuperior basal region; time: 0-14 ms after QRS onset; (b) antero-septal/inferior-middle regions; 10-22 ms after QRS onset; (c) inferior-apical region; 20-24 ms after QRS onset; (d) anterosuperior-middle/basal regions; 24-42 ms after QRS onset; (e) posterolateral-middle/basal regions; 30-40 ms after QRS onset; (f) inferior-basal region; 34-40 ms after QRS onset.

tivity also may indicate an opposite direction of the activation wavefront. It may be normal, if that region will be activated later, or pathological, if that region is not able to get activated because it is a scar tissue. Negativity after an earlier positivity indicates the termination of the depolarization process of that region. In normal cases, it occurs on the front of the chest (approximately at the site of lead V_1), corresponding to the first myocardial region still depolarized (the free wall of the right ventri-

cle). This phenomenon is called to be "right ventricular breakthrough."

Maxima and Minima: Spatial and Temporal Relation

The location of the maxima and minima, and the time interval between their appearance²⁴ provide information about the localization of the maximal activation in each isopotential map or isoarea map. Their "wandering" in consecutive isopotential maps may also be informative.²⁵ The maximum-minimum timecurves, that can be computed, simply represents the amplitude and the temporal relation of the maxima and minima. In normal cases, the maximum curve is the mirror image of the minimum time curve. Due to the eccentric heart position (the anterior wall of the left ventricle is closer to the anterior body surface than the posterior wall to the posterior body surface), anterior necrosis results in a deeper minimum curve, smaller maximum/minimum ratio, while posterior necrosis results in an opposite form: higher maximum curve, higher maximum/minimum ratio (Fig. 3).

In comparison to the map patterns of different abnormalities, well-defined time points help to evaluate the isopotential maps. Such time points are the ones when the minimum appears first in the right anterior chest, the time points of the highest maximum or deepest minimum. The interpretation of the isopotential map series due to the many time points is complex but they provide most of the information. Isoarea maps involve a time interval, therefore their evaluation is easier but consideration of the fine time relation is hardly possible. Departure maps are easy to read, they provide information for experts and nonexperts as well, they may facilitate easily accessible computer-based diagnosis. In spite of that, calculation of departure maps need a suitable chosen control group.

MAPS IN NORMAL CASES

In normal cases, distribution of the electric sources on the body surface, during atrial and ventricular depolarization and repolarization was reported repeatedly.^{8,26-28}

Atrial Activation ("P" Wave)

The first positivity appears on the upper part of the chest representing the site of the sinus node.

Figure 3. Schematic maximum-minimum time curves in normal cases, in anterior and in posterobasal necrosis during the QRS interval. In normal cases, the measure of the maximum and minimum and their appearing time point does not differ from each other but there are characteristic differences between them in anterior and posterobasal necrosis. In anterior necrosis the maximum/minimum ratio is low and the maximum is late. The posterior necrosis shows an opposite shape: high maximum/minimum ratio and the minimum is late.

Later, positivity spreads along the whole right part of the chest, representing the right atrial activation (Fig. 4a). In the second half of the atrial activation the positivity and the maximum (about 0.2 - 0.3 mV) moves to the left and downward—according to the left atrium projection (Fig. 4b). In cases of left atrial enlargement, the positivity moves even more to the left and the reciprocal negativity appears not only on the right side of the chest but also close to the midsternal line, furthermore their values increase, therefore, in these cases, a “P terminal force” appears in lead V_1 .

Ventricular Activation (“QRS” Interval)

The electrical signal coming from the His-Purkinje network usually begins endocardial activa-

tion at four sites: the upper midseptal site, the high anterior paraseptal left ventricular site, the right ventricular apex, and the low posterior paraseptal site. Later the activation spreads to the right and left ventricular free walls. Their representation on the *body surface isopotential maps* is as follows: the first positivity with its first maximum is located on the anterior-superior chest, the initial negativity is located on the back (Fig. 4c). Their values are increasing by time and their peak appears at about 20 to 30 ms after the QRS onset. The minimum appears on the anterior right superior area, always before the highest maximum (Fig. 4e). Before that time, the initially small right superior negativity makes a print in the positive area and then spreads into or seldom even splits it (= right ventricular

Figure 4. Schematic body surface maps in normal case. Isopotential map series from P onset to T end (a-j), isoarea maps of the frequently used intervals (k: first one-third QRS, l: total QRS, m: ST-T, n: QRST) and an isochron map during QRS interval (o). The potential maximum and minimum is indicated by an A+ and an A– sign. Time points and time intervals are displayed and the averaged maximum and minimum values are given. Values between two isopotential lines in (a-j): 0.5 mV, values between two isoarea lines in (k): 2.2; (l): 10; (m): 16; (n): 20 mVms.

breakthrough, indicating the site where the depolarization of the free right ventricle finishes first) (Fig. 4d). Both the maximum and minimum are then "wandering" to the left, and reach their highest value (about 1-2 mV) at about 30 to 40 ms after the QRS onset. The highest maximum is located approximately at the site of lead V_5 of the conventional ECG, while the deepest negativity is approximately located at lead V_2 of the conventional ECG (the depolarization of the left ventricle dominates) (Fig. 4f). Later on, both the maximum and minimum are decreasing in voltage and wandering to the left (Fig. 4g). Finally, there is a small maximum on the back, but it may also appear on the right upper anterior area in youngsters (or in cases of right ventricular overloading), representing the outflow tract of the right ventricle.

Isoarea map: First one-third QRS isoarea map: the positive area is on the anterior chest while the negative area is on the back, values 2 to 20 mVms (Fig. 4k). Total QRS isoarea map: the positive area is on the left lateral region, in the middle, the negative area is situated on the right upper region, values are between 10-30 mVms (Fig. 4l).

Isochron map: The isochrons are gathered around the interventricular septum that is activated first. The 10-40 ms isochrons are located on left side of the chest while the 50-70 ms isochrons are located on the back and on the right thoracic side (Fig. 4o).

Repolarization Time ("ST-T" Interval)

Isopotential Maps During Repolarization

After depolarization, there is a positivity on the right side of the chest and a negativity on the left (Fig. 4h). During the repolarization (T wave), the amplitude of the positivity and the negativity increases to a 0.2-0.6 mV in absolute value. The location of the minimum area moves closer to the right, to the location of the maximum (to the upper mid-chest area) (Fig. 4i). Towards the end of repolarization, the potential values decrease, but their locations do not change significantly (Fig. 4j). **Isoarea maps:** ST-T interval: The positivity and the maximum are located on the left anterior and lateral chest surface with a value of about 50-80 mVms. The negativity and the minimum are located on the right side, with a value of about 10-30 mVms (Fig. 4m).

The whole QRST isoarea map is sometimes referred to as the ventricular gradient map. Its pattern is similar to the QRS isoarea map. Its maxi-

mum and minimum values are about 40-80 mVms. There is also a normal variant, when the anterior chest surface is dominantly negative and the positivity is located on the left side of the back. In these cases, the minimum value exceeds the maximum value (Fig. 4n), otherwise the positive area dominates the left anterior chest surface and the maximum value is higher than the minimum value.

VARIOUS ECG ANOMALIES WITH CHARACTERISTIC BSPM PATTERN

BSPM patterns in various cardiac abnormalities have been described.^{7-8,29,44,47,49,60}

Myocardial Infarction

In the acute and subacute phase of myocardial infarction, repolarization changes may reveal a diagnostic information.³⁰⁻³² ST elevation in anterior or inferior myocardial infarction results in an increase of positivity on the anterior or inferior chest wall, respectively. To the contrary, ST depression or T negativity results in a more significant negativity in the corresponding region. The pathological Q wave of the conventional ECG in old anterior infarction manifests in significant negative area on the anterior chest during the first third of depolarization on the body surface maps (Fig. 5a and Fig. 1).^{8,33} Continuous inferior negativity during the Q interval was described in old inferior infarction (Fig. 5b).^{8,34-35} A considerable negativity persists on the back in old posterobasal infarction (Fig. 5c). Negativity dominates the anterior and inferior chest in combination of old anterior and inferior infarctions (Fig. 5d).

In the second half of the depolarization, the surface pattern does not differ significantly from the pattern of the normal depolarization. Indeed, already the conventional ECG ensures the diagnosis, therefore a significant part of the BSPM information is not used. The BSPM can be useful in detecting the periischemic zone,³⁶ revealing the presence of more than one infarction, identifying the infarct-related coronary artery,³⁷⁻³⁸ or recognizing electrical changes following interventions.³⁹⁻⁴¹

Intraventricular Conduction Defects

The diagnosis, based on the wide QRS and the characteristic features, usually does not mean

Figure 5. Characteristic isopotential map patterns in various abnormalities. (a) old anterior infarction: negativity on the anterior chest; (b) old inferior infarction: negativity over the inferior surface; (c) old posterobasal infarction: persisting posterior negativity; (d) combination of old anterior and inferior infarction: negativity on the anterior and inferior chest; LBBB: maps at three characteristic time periods: initial right ventricular depolarization with an anterior maximum; (e) middle part of the depolarization - septal as well as inferolateral and posterior side of the left ventricle with a posterior maximum; (f) terminal part of the depolarization: anterior positivity because of the terminally activating anterior part of the left ventricle (g); (h) characteristic map in anterior necrosis associated with LBBB during the terminal depolarization: the anterior positivity (see g) is lacking; Maps in RBBB at four characteristic time periods: initial septal activation with anterior positivity (i): isolated left ventricular activation with a left axillary maximum that moves further to the back (j); simultaneous posterior and anterior positivities of the left and right ventricular activation with a negative field in between (k); terminal right ventricular activation with an anterior maximum (l). The potential maximum and minimum is indicated by an A+ and an A- sign. Time points and time intervals are displayed and the averaged maximum and minimum values are given. Values between two isopotential lines: 0.4 mV.

there will be difficulties according to the conventional ECG.

The depolarization time in left bundle branch block (LBBB) can be divided into three phases. The first phase, the normal activation of the right ventricle, results in a right anterior positivity (Fig. 5e). The second phase, the slow septal activation and the activation of the inferolateral and posterior sides of the left ventricle, results in a lateral, left-posterior positivity, that moves slowly from right to left (Fig. 5f). The third phase, the anterior left

ventricular activation, manifests in a positivity on the anterior body surface (Fig. 5g).⁴²

The initial depolarization in right bundle branch block (RBBB) is similar to the normal septal activation (Fig. 5i). Later, but still during the first half of the depolarization, the positivity is located in the antero-lateral area, corresponding to the isolated left ventricular activation (Fig. 5j). During the middle phase of depolarization, that positivity decreases, and another positivity develops on the right side. The two positive areas are separated by

a negative field (Fig. 5k). During the second half of the depolarization, the right-sided positivity first increases then (terminally) decreases, according to the right ventricular activation (Fig. 5l). The terminal right-sided positivity may be separated when one positivity moves to the right axillar line (free wall of the right ventricle), while the other one appears on the upper right anterior area (corresponding to the activation of the outflow tract of the right ventricle).⁴³⁻⁴⁵

The ECG diagnosis of a remote anterior myocardial infarction in the presence of RBBB is feasible using the standard 12-lead ECG, however, an infero-posterior remote infarction can be masked by a concomitant RBBB. In those cases the deficiency of the isolated left ventricular activation on the BSPM indicates the area of necrosis.

There is an eternal problem in electrocardiology: how to diagnose an old infarction in the presence of LBBB. While the terminal depolarization and initial repolarization results in an anterior positivity in LBBB, that positivity is missing in the presence of an anterior necrosis (Fig. 5h).⁴⁶⁻⁴⁷ The corresponding sign on the ECG is the lack of the separation of the "J" point, or even an overshoot of the ST segment and/or a notch during the upslope of the S wave in the anterior precordial leads.⁴⁸

Investigation of the initial positive-negative area of the QRS,⁴⁹⁻⁵¹ or the BSPM of retrograde P waves⁵² may help to localize accessory pathways.

BSPM can also help us in the localization of the origin of ventricular tachycardia directly⁵³ or by ventricular pace stimuli.⁵⁴ Atrial rhythm disturbances can also be analyzed by BSPM records.⁵⁵

NEW POSSIBILITIES: DETECTION OF MINOR POTENTIAL LOSSES

Diagnosis of an old non-Q wave myocardial infarction is a challenge even with the use of BSPM. Until now, authors recommended various features of isopotential and isoarea departure maps for the diagnosis of a non-Q wave myocardial infarction.⁵⁶⁻⁵⁹ Recently, a new isopotential map evaluation method has been suggested, that results not only in the diagnosis of non-Q wave myocardial infarction with a sensitivity of 91%, but it also localizes the potential losses. Interestingly, similar signs of potential loss were also detected in 69% of

the patients with unstable angina.⁶⁰ To localize a minor potential loss, identification of the appearance time (initial, early, normal or late) of the first right-anterior/anterior minimum is the first step. The site and the amplitude of that minimum as well as the appearance of minor negativities and positivities at abnormal sites at the same time also help in the diagnosis. The criteria established by other investigators to describe normal maps,^{8,26-28} maps of Q-wave myocardial infarction,^{33-35,56-58} the cardiac activation sequence in normal,^{14,23} and in Q wave infarction cases,¹⁵ as well as the body surface representation of the heart regions²⁵ were taken into account.

Description of Isopotential Map Features⁶⁰

An initial antero-superior minimum, located slightly to the right of the midfrontal area indicates a potential loss in the midseptal area (Fig. 6a).

An initial antero-superior and left-sided minimum indicates an anterior-paraseptal potential loss (Fig. 6b).

Early and small right-anterior minimum (10-22 ms after QRS onset, absolute value (< 0.22 mV), as well as an infero-right-anterior and infero-mid-posterior negativity at the same time indicates a potential loss in the antero-septal/inferior-middle region (Fig. 6c).

A right-sided inferior negativity with mid-posterior increased positivity at the time of the normal right-anterior minimum (20-24 ms after QRS onset) indicates a potential loss in the antero-septal-apical region (Fig. 6d).

However, a contiguous negativity on the inferior torso (suggesting that the right ventricular breakthrough comes from below) would indicate an inferior-apical potential loss (Fig. 6e).

The first right-anterior/anterior minimum appears on the anterior-superior part of the chest at 24 to 42 ms after QRS onset. At that time, a contiguous negativity over the superior part of the torso would indicate an anterosuperior-middle/basal potential loss (Fig. 6f).

A minimum persisting on the back beyond the timing of the peak of the maximum (approximately 40 ms) indicates a posterolateral-middle/basal potential loss (Fig. 6g).

A late (34-40 ms after QRS onset) and high amplitude minimum (below -0.6 mV) persisting over

Figure 6. Schematic isopotential maps in non-Q wave myocardial infarction. The various locations of the potential losses in the relevant time periods. (a) middle part of the septum (antero-superior initial minimum); (b) anterior-paraseptal part (left-antero-superior initial minimum); © anteroseptal/inferior-middle regions (early, slight, right-sided minimum + infero-right-anterior and infero-mid-posterior negativities; (d) anteroseptal-apical region (infero-right-anterior negativity and elevated, "dome-shaped" mid-posterior positivity at the time of the first right-sided minimum); (e) infero-apical region (contiguous inferior negativity at the time of the first right-sided minimum); (f) anterosuperior-middle/basal regions (the minimum from the back arrives to the superior-anterior chest area with a contiguous superior negativity); (g) posterolateral-middle/basal regions (the minimum persists on the back even after the positivity reaches its maximum); (h) inferior-basal region (the first right-sided minimum appears late, its measure is considerable and it persists on the right-superior area). The potential maximum and minimum is indicated by an A+ and an A- sign. Characteristic time from the QRS onset and the averaged maximum and minimum values for all maps are indicated. Values between two isopotential lines: 0.4 mV.

the superior-right-anterior part of the torso, followed by a short incisura (= smaller minimum) on the minimum time curve (when the minimum moves to the middle-anterior part) indicates an inferior-basal potential loss (Fig. 6h).

FUTURE DIRECTIONS IN THE APPLICATION OF THE BSPM

An intriguing clinical challenge is the reversibility of potential loss ("electrical viability"), one is the

main area that could be used in the noninvasive assessment of CAD. Preliminary observations suggest, that a part of minor potential losses in ischemic heart disease that can be detected by BSPM are reversible as they can regress after revascularization or nitroglycerin administration. The interpretation of this phenomenon could be that minor potential losses can develop not only in the presence of definitive necrosis but also in the case of myocardial hybernation. The location and extent of electrically viable myocardium can orient the clinician in the planning of the revascularization procedure.

An automatic, computerized system for the using of BSPM could highly facilitate its widespread use in cardiologic diagnostics. The main limitation of the present widespread use of the method is the evaluation of the great number of maps required and also the cumbersome evaluation of the positive and negative areas of the maps. The computerized evaluation of isoarea departure maps seems to be easier. However, most of the information is hidden in the isopotential map series. The maximum-minimum curve of the isopotential maps (maximum/minimum ratio, time-shift between maximum and minimum time) appears to be suitable for computation.

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