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Clinical Use of Body Surface Potential Mapping in Cardiac Arrhythmias

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Summary

Body surface potential maps have and certainly will have a very important role in the field of clinical arrhythmology, specifically for the localization of accessory pathways, for the detection of the origin of ventricular arrhythmias and for the identification of patients at risk of sudden death. In this particular setting, surface maps are certainly more useful than other more costly and sophisticated imaging techniques.

Key words

Cardiac arrhythmias – Body surface potentials – Mapping

Introduction

In the diagnostic field of cardiac arrhythmias traditional electrocardiographic techniques, such as Holter monitoring, intracardiac electrophysiological study, are of unquestionable importance. Nevertheless, among the non-invasive methods, body surface potential maps (BSM) have been demonstrated to be of great value for the localization of ventricular preexcitation areas in the Wolff-Parkinson-White (WPW) syndrome, for the identification of arrhythmogenic foci in ventricular tachycardias and for detecting a cardiac state of vulnerability to malignant ventricular arrhythmias.

WPW syndrome

Many years ago, several authors have shown that BSM provide much more information on the localization of a pre-excited area than can be obtained from traditional ECG and VCG (Yamada *et al.* 1975, De Ambroggi *et al.* 1976, Iwa and Magara 1981).

An extensive description of BSM in 42 cases of the WPW syndrome was reported by De Ambroggi *et al.* (1976). Taking into consideration the position of the potential maximum and minimum on the thorax during the delta wave and the following sequence of the potential distribution during ventricular activation, we were able to classify the BSM into six types. For each of them we suggested the most likely localization of the pre-excited area. The following six localizations of pre-excitation were proposed:

Type 1: posterior portion of the atrioventricular (AV) ring;

Type 2: right infero-lateral portion of the AV ring;

Type 3: right antero-superior portion of the AV ring;

Type 4: left anterior portion of the AV ring;

Type 5: left antero-lateral portion of the AV ring;

Type 6: right side of the ventricular septum (Mahaim fibres).

At that time we did not have the possibility to correlate BSM with intracardiac electrophysiological data or epicardial maps in all cases. Thus, our classification was rather arbitrary, incomplete and still approximate. Indeed, it is an oversimplification to distinguish only a limited number of types (6, 8 or more). In fact, the accessory AV pathways can be everywhere along the AV ring, giving rise to many different potential patterns gradually changing from one to the other. Subsequently, our findings were to a great extent confirmed by other investigators, who also proposed new criteria for a more precise localization of the accessory AV connections (Benson *et al.* 1982, Kamakura *et al.* 1986, Giorgi *et al.* 1991, Liebman *et al.* 1991). Recently, Liebman *et al.* (1991) demonstrated that BSM using QRS analysis accurately predicts the

ventricular insertion site of an accessory AV pathway in a series of patients who were examined by intracardiac electrophysiological methods during cardiac surgery. They found that the location of accessory AV connections identified by BSM and by electrophysiological recording during surgery were identical or differed by less than 1.5 cm (i.e. one position of the Guiraudon grid used as reference by the authors).

An accurate localization of the accessory AV pathway is very important today in view of the radio-frequency catheter ablation of the pathway (Jackman *et al.* 1991). Precise knowledge of the pathway location before the ablation procedure makes it possible to shorten the duration of the procedure and, specifically, of the radiation exposure.

Origin of ectopic ventricular activation

The ability of BSM to localize the site of origin of ectopic ventricular activation was assessed by Sippens-Groenewegen *et al.* (1990) using body surface QRS integral maps during right and left ventricular pacing at many different endocardial points. They demonstrated that the QRS pattern allows discrimination among 38 different left and right ventricular sites of ectopic endocardial stimulation in patients with normal cardiac anatomy (Sippens-Groenewegen *et al.* 1990).

Recently, Dubuc *et al.* (1992) were able to identify and ablate the site of origin of idiopathic ventricular tachycardia in two patients, using body surface pace-mapping technique. They recorded BSM of the QRS during ventricular tachycardia presumably originating from the right ventricular outflow tract. By pacing at different points of the outflow tract, a map very similar to that obtained during tachycardia was found. Then, radio-frequency ablation was successfully performed in the pacing point which had generated this map.

Vulnerability to ventricular arrhythmias

Evidence for the relation between vulnerability to arrhythmias and disparities of ventricular recovery times has been provided by experimental studies (Han *et al.* 1966a,b). Abildskov *et al.* (1977) proposed that local repolarization disparities can be detected on the body surface from an analysis of QRST integral distribution. Specifically, the non-dipolar components of QRST integral distribution were considered as an index of repolarization disparity (Abildskov *et al.* 1985).

According to this, we analyzed BSM in different groups of patients with malignant ventricular arrhythmias in order to detect possible signs of ventricular repolarization disparities. We studied two groups of patients with an old myocardial infarction, one (62 patients) without and the other (11 patients) with episodes of ventricular tachycardia (Bertoni *et al.* 1988). A clear-cut multipolar distribution of QRST integral values, which is probably related to gross disparities of repolarization, was infrequently observed in both groups. Thus, a simple inspection of QRST maps does not seem to be useful in predicting the occurrence of ventricular arrhythmias. On the other hand, by applying the eigenvector analysis proposed by Lux *et al.* (1981), we were able to detect and quantitate a high non-dipolar content in many QRST maps showing apparent dipolar distribution.

In this kind of analysis, each individual map is represented as a weighed sum of a limited number of fundamental patterns (eigenvectors), common to both control subjects and patients. The first three eigenvectors generally have a dipolar distribution, whereas those beyond the third are multipolar. Thus the cumulative contribution of eigenvectors beyond the third to an individual map (expressed as percentage contribution of the total map content) will be considered as the "non-dipolar" content of that map. On average, the contribution of non-dipolar components to the individual QRST map was significantly greater in patients with myocardial infarction than in the control population (8.3 ± 6.4 % vs 4.1 ± 2.2 %, $p < 0.001$) and, among patients, with ventricular tachycardia (7.2 ± 5.3 % vs 14.6 ± 8.5 %, $p < 0.001$) (Bertoni *et al.* 1988). Thus, the high non-dipolar content of QRST maps in patients with episodes of ventricular tachycardia suggests the presence of local disparities in recovery duration and it might be considered an useful marker of susceptibility to malignant arrhythmias.

We analyzed BSM in a group of 40 patients affected by the idiopathic long QT syndrome (LQTS) in order to detect signs of dispersion of ventricular repolarization (De Ambroggi *et al.* 1991). A multipolar distribution of QRST integral maps was observed in a few cases (10 %). To detect minor regional disparities of ventricular recovery, all ST-T waveforms were analyzed in each subject. The ST-T wave was divided into successive 20 ms intervals and the mean potential value of each interval was considered. Thus, each ST-T wave is represented by a discrete series of 15–25 values. We performed a "principal component analysis" of the original 117 sets of values (117 thoracic leads) in each subject. This analysis allowed the identification of one set of values, corresponding to the first principal component, which provides better representation, by means of appropriate multiplication factors, of the majority of the 117 sets of values recorded in that subject. We have therefore introduced a "similarity index" (SI), which expresses the ratio between the information content of the first principal component and the total information of the original data in percentage. Actually, a high SI value indicates a great similarity of all waveforms to one fundamental waveform, i.e. a great similarity of all waves to each

other. On the contrary, a low SI value indicates a large variety of ST-T waves, and this is considered a sign of repolarization disparities.

The mean SI value was significantly lower in patients with LQTS than in control subjects (49±10 % vs 77±8 %; $p<0.0001$). A value of 61 % (2 S.D. below the mean value for the controls) was found in 35 out of 40 patients and only in one control subject.

Thus, the SI is a more sensitive marker than the multipolar distribution of QRST maps in revealing electrical disparities of ventricular recovery. The low value of the SI found in LQTS patients indicates a large variety of ST-T waves, suggesting a high degree of dispersion of ventricular recovery times, which is a condition of vulnerability to malignant ventricular arrhythmias.

We recently reported preliminary results from a group of patients affected by arrhythmogenic right ventricular dysplasia (ARVD). As in LQTS patients, we considered the QRST integral maps and the similarity index. The mean SI value was significantly lower in 9 patients with ARVD than in control subjects (60±10 % vs 77±8 %; $p<0.001$). Considering as cut-off level, a value of 69 %, equal to the mean value for the control group minus 1 S.D., we found that 7 out of the 9 patients (78 %) had a lower value, whereas only 3 of the 30 controls had a value below this threshold. As far as the QRST integral maps are concerned, in 7 of the 9 patients the distribution of the values was within normal limits. In 5 of these the SI was abnormally low. In two patients QRST maps showed a larger than normal area of negativity in the anterior thorax and the SI was lower than normal. In one of these cases the distribution was more complex: two minima were present and the location of the maximum on the anterior thorax was higher than normal; the SI was also definitely low (47 %). The "multipolarity" of the QRST integral map and the low value of SI could be considered as an expression of repolarization disparities.

References

ABILDSKOV J.A., BURGESS M.J., URIE P.M., LUX R.L., WYATT R.F.: The unidentified information content of the electrocardiogram. *Circ. Res.* **40:** 3–7, 1977.

ABILDSKOV J.A., GREEN L.S., LUX R.L.: Detection of disparate ventricular repolarization by means of the body surface electrocardiogram. In: *Cardiac Electrophysiology and Arrhythmias*. ZIPES D.P., JALIFE J. (eds), Grune-Stratton, New York, 1985, pp. 495–499.

BENSON W.D., STERBA R., GALLAGHER J.J., WALSTON A, SPACH M.S.: Localization of the site of ventricular pre-excitation with body surface potential maps in patients with Wolff-Parkinson-White syndrome. *Circulation* **65:** 1259–1268, 1982.

BERTONI T., BREGHI M.L., MARCONI M., BONIFACCIO G., DE AMBROGGI L.: Usefulness of the QRST integral maps to detect vulnerability to malignant arrhythmias in patients with old myocardial infarction. In: *Electrocardiology '87*. SCHUBERT E. (ed), Akademie-Verlag, Berlin, 1988, pp. 247–250.

DE AMBROGGI L., TACCARDI B., MACCHI E.: Body surface maps of heart potentials; tentative localization of pre-excited areas in forty-two Wolff-Parkinson-White patients. *Circulation* **54:** 251–263, 1976.

DE AMBROGGI L., NEGONI M.S., MONZA E., BERONI T., SCHWARTZ P.J.: Dispersion of ventricular repolarization in the long QT syndrome. *Am. J. Cardiol.* **68:** 614–620, 1991.

DE AMBROGGI L., NEGRONI M.S., SANTAMBROGIO C., ROVIDA M.: Surface ECG mapping in patients with right ventricular dysplasia. *Eur. Heart J.* **13:** 386, 1992.

DUBUC M., HATALA R., KUS T., TREMBLAY G., SAVARD P., NADEAU R: Radiofrequency ablation of idiopathic ventricular tachycardia guided by on-line body surface mapping. *Eur. Heart J.* **13:** 3, 1992.

GIORGI C., NADEAU R., SAVARD P., SHENASA M., PAGÉ P., CARDINAL R., DEROME D., ACKAOUI A.: Body surface isopotential mapping of the entire QRST in the Wolff-Parkinson-White syndrome. Correlation with the localization of the accessory pathway. *Am. Heart J.* **121:** 1445–1453, 1991.

HAN J., MILLET D., CHIZZONITTI G., MOE G.K.: Temporal dispersion of recovery of excitability in atrium and ventricle as a function of heart rate. *Am. Heart J.* **71:** 481–487, 1966a.

HAN J., GARCIA-DEJALON P.D., MOE G.K.: Fibrillation threshold of premature ventricular responses. *Circ. Res.* **18:** 18–25, 1966b.

IWA T., MAGARA T.: Correlation between localization of accessory conduction pathway and body surface maps in the Wolff-Parkinson-White syndrome. *Jpn. Circ. J.* **45:** 1192–1198, 1981.

JACKMAN W.M., WANG X., FRIAY K. ROMAN C.A., MOULTON K.P., BECKMAN K.J., McCLELLAND J.H., TWIDALE N., HAZLITT H.A.; PRIOR M.I., MARGOLIS P.D., CALAME J.D., OVERHOLT E.D., LAZZARA R.: Catheter ablation of accessory atrioventricular pathways (Wolff-Parkinson-White syndrome) by radiofrequency current. *N. Engl. J. Med.* **324:** 1605–1611, 1991.

KAMAKURA S., SHIMOMURA K., OHE T., MATSUHISA M., YOYOSHIMA H.: The role of initial minimum potentials on body surface maps in predicting the site of accessory pathways in patients with Wolff-Parkinson-White syndrome. *Circulation* **74**: 89–96, 1986.

LIEBMAN J., ZENO J.A., OLSHANSKY B., GEHA A.S., THOMAS C.W., RUDY Y., HENTHORN R.W., COHEN M., WALDO A.L.: Electrocardiographic body surface potential mapping in the Wolff-Parkinson-White syndrome. Noninvasive determination of ventricular insertion sites of accessory atrioventricular connection. *Circulation* **83**: 886–901, 1991.

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.

SIPPENS-GROENEWEGEN A., SPEKHORST H., VAN HEMEL N.M., KINGMA J., HAUER R., JANSE M., DUNNING A.: Body surface mapping of ectopic left and right ventricular activation. *Circulation* **82**: 879–896, 1990.

YAMADA T., TOYAMA J., WADA M., SUGIYAMA S., SUGENOYA J., TOYOSHIMA H., MIZUNO Y., SOTOHATA I., KOBAYASHI T., OKAJIMA M.: Body surface isopotential mapping in Wolff-Parkinson-White syndrome: non-invasive method to determine the localization of the accessory atrioventricular pathway. *Am. Heart J.* **90**: 721–734, 1975.

Reprint Requests

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