ESTIMATION OF THE RIGHT VENTRICULAR VOLUME OVERLOAD IN CHILDREN WITH ATRIAL SEPTAL DEFECT BY BODY SURFACE MAPPING

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To investigate the possibility of estimating the right ventricular volume overload in atrial septal defect (ASD) by body surface mapping (BSM), 45 children with ASD were included in the present study.

The breakthrough minimum (BTM) appeared later and more leftward in ASD subjects than in the normal controls. Neither the length of the delay in the appearance of the BTM nor the extent of its leftward deviation was significantly correlated with the pulmonary and systemic flow volume ratio (Qp/Qs), obtained by cardiac catheterization. Therefore neither could be used as the parameter of the right ventricular volume overload.

ΣR , R_{max} ($D3+D4$) + $|S| \max(H4+H5)$ and "T dep", the sum of the absolute values of the departure indices (DIs) in the G4, G5, H4 and H5 leads, and the DIs in the J5, J6, K5, and K6 leads in T departure Map, correlated with the Qp/Qs significantly ($r=0.62$, 0.68 , 0.69 , respectively). Accordingly, they might be useful for estimating the right ventricular volume overload.

The subjects were divided into 3 groups according to their Qp/Qs. Discriminant analysis between these 3 groups was then performed, using R_{max} ($D3$), $|S| \max(H4)$, and T dep as the variables. The accuracy of this discrimination was 82.2%. The result suggests the possibility of estimating the severity of ASD by BSM.

BODY surface mapping (BSM) has more advantages for investigating the abnormal electrical events of the right ventricle than either conventional electrocardiography or vectorcardiography, for there are many lead points on the right anterior chest!

There are several reports on BSM in relation to atrial septal defect (ASD);²⁻⁹ but many of them have depicted the conduction delay in ASD. On the other hand, there are only a few reports on the estimation of right

ventricular volume overload in ASD.^{10,11}

The present study was designed to obtain partial answers for two questions: (1) How is the right ventricular volume overload in ASD reflected in BSM? and (2) Can the degree of the right ventricular volume overload, in other words the severity of ASD, be estimated by BSM?

MATERIALS

Forty-five children (16 males and 29 females) with ASD, aged 4 to 14 years (mean=8.8 years, standard deviation=3.8 years), were included in this study. All of

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them had been diagnosed as secundum ASD by physical examination, ECG, chest X-ray, and echocardiography. They were admitted for cardiac evaluation. During their stay in the hospital, BSMs were recorded. They also underwent cardiac catheterization, by which the pulmonary and systemic flow

volume ratio (Q_p/Q_s) and the pulmonary arterial pressure were obtained.

In all cases the pulmonary arterial systolic pressure was 40 mmHg or below, so cases with right ventricular pressure overload were excluded in this study.

One hundred and thirty-five healthy children, judged to have normal hearts on the basis of physical examination, ECG, and chest X-ray, were selected as the normal controls. They were divided into the following 6 groups according to age and sex: (1) 31 males, aged 4 to 8 years, (2) 24 females, aged 4 to 8 years, (3) 20 males, aged 9 to 12 years, (4) 21 females, aged 9 to 12 years, (5) 20 males, aged 13 to 15 years, and (6) 19 females, aged 13 to 15 years.

Fig.1. The arrangement of 87 lead points. They consisted of 59 leads on the anterior chest and 28 leads on the back.

METHODS

BSMs were recorded by either HPM 5100 (Chunichi Denshi Co. Ltd.) or VCM 3000

Fig.2. The time of the appearance of the BTM in ASD (●) and the normal controls (○).

On the right, the means $\pm$ SD of ASD cases and the controls are shown for comparison.

The BTM appeared significantly later in ASD cases than in the controls: in the group of males aged 4 to 8, females aged 4 to 8, and females aged 9 to 12.

Fig.3. The location of the appearance of the BTM in ASD (●) and the normal controls (○).

The means $\pm$ SD of ASD cases are compared with that of the controls.

In ASD, the BTM appeared significantly more leftward than that it did in the control, except in the males aged 9 to 12, and 13 to 15.

(Fukuda Denshi Co. Ltd.), following the method described by Yamada et al.¹² In summary, a unipolar lead ECG recording was made at 87 leads, 59 on the anterior chest surface and 28 on the back using Wilson's central terminal as the reference points (Fig. 1). The sampling interval was 1 or 2 msec. The subjects were supine for recording of their BSMs. The data was analyzed by VCM 3000 with regard to the following points.

First, with regard to the QRS isopotential Map, the correlation between the Qp/Qs and the following 3 parameters was studied: (1) The time and the location of the appearance of the breakthrough minimum (BTM), (2) ΣR , the sum of maximum potentials of each of the 33 leads on the right anterior chest (Fig. 1, a part of screen tone), and (3) Rmax

$(D3+D4)+|S|\max(H4+H5)$. This is the sum of the maximum potentials of the R wave in the D3 and D4 leads, and the absolute value of the potentials of the S wave in the H4 and H5 leads on the same point from the beginning of the QRS.

Second, 45 subjects were divided into 6 groups in the same way as the normal controls. The departure index (DI) was calculated, following the method described by Tonooka et al.¹³ in 87 leads as follows: $DI=(\chi-M)/SD$; χ =the potential in each lead, M =the mean potential in each lead in the normal controls, SD =standard deviation in each lead in the normal controls, and the T departure map, the distribution on the body surface of DI during the T period, was constructed. T dep was calculated for each

Fig.4. The correlation between the ΣR and Qp/Qs. Fig.5. The correlation between $R_{\max}(D_3+D_4)+|S|\max(H_4+H_5)$ and Qp/Qs.

subject. It is the maximum value of the sum of the absolute value of the DIs in the G4, G5, H4, and H5 leads, and the DIs in the J5, J6, K5 and K6 leads. Finally, the correlation between the Qp/Qs and T dep was studied.

The statistical analysis was performed using the unpaired t-test for two groups and linear correlation between the Qp/Qs and ΣR , $R_{\max}(D_3+D_4)+|S|\max(H_4+H_5)$, and T dep.

Third, to investigate the possibility of judging the severity of ASD, the subjects were divided into the following 3 groups according to their Qp/Qs: (1) Group A, more than 2.5, (2) Group B, less than 2.5

and more than 2.0, and (3) Group C, less than 2.0. The reliability of grouping was analyzed using the discriminant function¹⁴ with a personal computer (PC-286VE EPSON). The variables for this discriminant analysis were selected by the backward elimination method, in which the variable, a statistic value (F value) of which was below the limit value (F_{out} value), was eliminated from this analysis.¹⁴

RESULTS

1. QRS Isopotential Map

(1) The time and the location of the appearance of the BTM

In each ASD group, the BTM appeared later than it did in the normal controls, significantly ($p<0.01$) in the group of males aged 4 to 8 years, females aged 4 to 8 years and females aged 9 to 12 years (Fig. 2). Moreover, the location where the BTM appeared shifted significantly ($p<0.01$) more leftward in ASD than in the normal controls, except in the groups of males aged 9 to 12 years and the males aged 13 to 15 years (Fig. 3). Apparently, the BTM appeared later and more leftward in cases of ASD with larger Qp/Qs. But neither the length of the delay in the appearance of the BTM nor the extent of its leftward deviation was significantly correlated with Qp/Qs ($r=0.23, 0.28$).

(2) ΣR (Fig. 4)

The ΣR and the Qp/Qs were significantly

Fig.6. An example of a T isopotential map (the upper panel), and that of a T departure map (the lower panel) of a girl with ASD (Qp/Qs 3.8). In the isopotential map, there is a negative area in the vicinity of the G4 lead like a “niche”. On the other hand, in the departure map, there are negative DIs in the surroundings of the minimum in the G4 lead, and positive DIs in the surroundings of the maximum in the J5 lead.

Fig.7. The correlation between T dep. and Qp/Qs.

correlated ($r=0.62$, $p<0.001$).

(3) $R_{\max} (D3+D4) + |S| \max (H4+H5)$ (Fig. 5)

$R_{\max} (D3+D4) + |S| \max (H4+H5)$ and the Qp/Qs were significantly correlated ($r=0.68$, $p<0.001$).

2. T departure map

An example of T isopotential map of a female aged 10 years with ASD is presented in the upper panel of Fig. 6. In this isopotential map, there is a negative area in the vicinity of the G4 lead like a “niche”. In the departure map of the same patients, shown in the lower panel, there are negative DIs in the surroundings of the minimum in the G4 lead, and positive DIs in the surroundings of the maximum in the J5 lead.

T dep and Qp/Qs, as shown in Fig. 7, were significantly correlated ($r=0.69$, $p<0.001$).

TABLE I DISCRIMINANT ANALYSIS

*Linear Discriminant Function**Equation*

$$u(x) = 9.7839 Rmax(D3) + 7.0326 |S| max(H4) + 0.9554 T dep - 11.9051$$

$$v(x) = 8.9839 Rmax(D3) + 5.3886 |S| max(H4) + 0.4184 T dep - 5.4548$$

$$w(x) = 3.8131 Rmax(D3) + 4.5340 |S| max(H4) + 0.3349 T dep - 2.3598$$

Discrimination

If $u(x) > v(x)$ and $u(x) > w(x)$, then classified in Group A.

If $v(x) > u(x)$ and $v(x) > w(x)$, then classified in Group B.

If $w(x) > u(x)$ and $w(x) > v(x)$, then classified in Group C.

Result of Discrimination

Group	No. of Cases	No. Correct	Percent Correct	No. of Cases Classified		
				A	B	C
A	21	18	85.7%	18	2	1
B	11	7	63.6%	1	7	3
C	13	12	92.3%	1	0	12

QRS Isopotential Map

Fig.8. An example of a QRS isopotential Map in ASD.

The BTM appeared in the G4 lead, 37 msec from the beginning of QRS. After this point, a maximum shifted from the F2 lead to the D3 lead, and, in the terminal stage, to the D6 lead.

3. Linear discriminant analysis

The subjects were divided into 3 groups, according to their Qp/Qs. Group A comprised 21 cases. Groups B and C consisted of 11 and 13 cases respectively.

The discriminant analysis of these 3 groups was conducted using Rmax (D3), $|S|_{\max}$ (H4), and T dep as the variables. The discriminant functions shown on the upper panel of Table I were calculated. By this method, as shown on the middle panel of Table I, all of the subjects were discriminated. The accuracy of discrimination, the lower panel, was 85.7% in group A, 63.6% in group B, and 92.3% in group C (total 82.2%).

DISCUSSION

The fact that the BTM appears later and more leftward in ASD patients than in the controls has often been reported, and there are some reports of this with regard to children. In many of these earlier studies, the comparisons were made between age-matched ASD cases and normal controls.⁵⁻⁸ In children the time and the location of the appearance of the BTM may be influenced more by age or sex than it is in adults.¹⁵⁻¹⁸ So we separated both the patients and the normal controls into 6 groups according to age and sex, then the time and the location of the appearance of the BTM were compared within each group between the ASD cases and the normal controls. The BTM in the ASD cases tended to appear later and more leftward than in the controls, but neither the length of the delay of the appearance of the BTM nor the extent of its left deviation was significantly correlated with Qp/Qs. Yoshida et al⁴ and Aiba et al⁶ reported results similar to ours. These findings show that the delay and the left deviation of the appearance of the BTM are not caused by the right ventricular volume overload only, and that they cannot be the parameters for its estimation.

ΣR was calculated to determine more precisely the electrical events in the right ventricle. Yoshida et al¹⁰ reported that ΣR was significantly correlated with the Qp/Qs in adult patients with ASD (including ECD). But in 6 cases among their 45 subjects, the right ventricular systolic pressures were over 50 mmHg. ΣR is also influenced by press-

ure overload in the right ventricle!¹⁹ Accordingly, we selected patients whose right ventricular systolic pressure was under 40 mmHg, in order to exclude this effect. Even without right ventricular pressure overload, ΣR was still significantly correlated with Qp/Qs.

In many ASD cases, after the BTM appeared the positive potentials with a maximum shifted from the left anterior chest to the lower part of the mid anterior, slightly right-shifted, chest (Fig. 8). In the terminal stage these potentials shifted to the upper part of the right anterior chest. In the remaining cases soon after the BTM appeared, the BSM pattern resembled the pattern above, but in the terminal stage the positive potentials occurred in the lower part of the right anterior chest. Several reports have stated that in the latter half of the the QRS in ASD, the ventricular excitation occurred in the right ventricular free wall, unlike that in a normal control.^{2,20-25} We speculated that the BSM pattern shown in Fig. 8 occurred because the excitation of the right ventricle was delayed by the volume overload, so it could be detected without the influence of the excitation of the left ventricle. Thus a variety of sums of R wave potentials in the leads of the right anterior chest and the absolute values of S wave potentials in those of the left and lateral chest were investigated with regard to the correlation with the Qp/Qs. Rmax (D3+D4)+ $|S|_{\max}$ (H4+H5) was the best combination from the viewpoint of the correlation coefficient and the ease of calculation, for the fewer the leads involved, the easier the calculation becomes.

It has been reported that the T isopotential map for ASD patients differs from that of normal controls.^{11,26} T-wave abnormalities may be related to the right ventricular volume overload. However, these abnormalities are variegated: inverted, biphasical, or flat. So the sum of the potentials of the T isopotential map cannot be a parameter for the right ventricular volume overload. Then we constructed a T departure map. We had the impression that in cases with larger Qp/Qs ratios the DIs of the G and H columns decreased and those of the J and K columns increased in the T departure map. So a variety of sums of the absolute values of

the DIs of the G and H columns and the DIs of the J and K columns were investigated with regard to the correlation with Qp/Qs. We found that the maximum value of the sum of the absolute values of the DIs in the G4, G5, H4 and H5 leads and those in the J5, J6, K5 and K6 leads was significantly correlated with Qp/Qs. We named that sum "T dep".

Although the right ventricular volume overload in ASD patients could be estimated by such parameters as ΣR , $R_{\max}(D3+D4) + |S|_{\max}(H4+H5)$, or T dep, none of them was a satisfactory indicator of the severity of ASD, for none of their ratio of correlation coefficients with Qp/Qs was above 0.7. So we attempted to estimate the severity of the ASD using the discriminant function, one of the methods for multivariate statistical analysis.²⁷ Imataki et al²⁸ and Yoshida et al²⁹ used this analytical method to discriminate between various types of right ventricular overload: volume overload, pressure overload, and combined volume-pressure overload.

At first we attempted the discriminant analysis using ΣR , $R_{\max}(D3+D4) + |S|_{\max}(H4+H5)$, T dep as the variables. But ΣR could not contribute to the discrimination and the accuracy was 73.7%. Then we selected the variables from among $R_{\max}(D3)$, $R_{\max}(D4) + |S|_{\max}(H4)$, $|S|_{\max}(H5)$, T dep by using the backward elimination method. The accuracy was best (82.3%) when $R_{\max}(D3)$, $|S|_{\max}(H4)$, and T dep, all of which could contribute to the discrimination, were selected as the variables. Although there is no firm proof that external samples can be discriminated by this method, this result suggests the possibility of estimating the severity of ASD by BSM.

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