★ *Symposium on Electrocardiogram*

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A Study on Direct Epicardial Electrocardiogram

CONCERNING QRS PATTERNS

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Direct epicardial electrocardiograms were recorded in 97 cases of normal hearts and various heart diseases, and the patterns of the QRS complex of the chest lead electrocardiograms were analysed with normal heart, left or right ventricular hypertrophy, combined ventricular hypertrophy, and right bundle branch block.

In the case of the left ventricular hypertrophy the left chest ECG agreed well with the direct epicardial ECG. In the case of right ventricular hypertrophy the right chest ECG may be a mere reflection of the potential variations at the base of the right ventricle or conus arteriosus. The right bundle branch block of the mitral stenosis appears to be not due to a genuine conduction disturbance but to represent the potential variations in the base of the right ventricle.

STUDIES ON the direct epicardial ECGs give an important clue to the interpretation of routine ECGs, and reports are accumulating on this subject along with the development of heart surgery. However, this problem is far from being completely understood. As an approach to this problem the author studied the relationship between the direct epicardial ECGs and the chest ECGs, and some of the results are presented in this paper.

MATERIALS AND METHODS

Materials used were 97 subjects, including various patients operated on at this department together with 4 control subjects. In all cases the pericardium was opened and the heart was exposed; the lead-points were then accurately located. Wilson's terminal served as the indifferent electrode and the different electrode consisted of a silver disc of 5 mm diameter, wrapped in cotton and soaked with a saturated saline solution. For

recording, Twin-Viso and Poly-Viso electrocardiographs of Sanborne type were used, and the paper-speed was usually adjusted at 10 cm per second.

Recordings were obtained from the following points: over the right ventricle, 1) the area close to the sulcus coronarius (S.C.), 2) middle of the free wall (F.W.), 3) near the sulcus interventricularis ventralis (S.I.V.), 4) apical area (AP.), 5) conus arteriosus (C.A.); over the left ventricle, 1') middle of the free wall (F.W.), 2') apical area (AP.). In addition to these regularly explored areas, several other areas were also explored arbitrarily. When deemed necessary, the continuous recordings were obtained from one regularly explored point to the other. As a rule the simultaneous recordings were made from lead II and V₁ (or V₂); whenever necessary, the intracavity lead was also employed simultaneously. For the measurement of impulse arrival time, the peak of R wave or nadir of S wave were employed.

TABLE I

NORMAL (13 CASES)											
	Area	Cases	$rsR'(s')$	rR'	Rs	RS	rS	R/S	$\frac{r}{\text{Time}}$	$\frac{R'}{\text{Time}}$	Height
RV	S. C.	6	6						.024	.061	27.4
	C. A.	13	7	1	1	1	3		.020	.059	52.4
	F.W.	13	1		1	7	4	0.81		.025	55.7
	S.I.V.	8			1	5	2	0.84		.027	62.0
	AP.	6			3	2	1	2.0		.031	41.3
	Area	Cases	$qR(s)$	qRS	QRS	RS	Rs		$\frac{q}{\text{Time}}$	$\frac{R}{\text{Time}}$	Height
LV	F.W.	12	10		1	1			.019	.044	88.4
	AP.	9	3	1		3	2		.017	.033	75.1

LEFT VENTRICULAR HYPERTROPHY (9 CASES)											
	Area	Cases	$rsR'(s')$	rR'	Rs	RS	rS	R/S		$\frac{R'}{\text{Time}}$	Height
RV	S. C.	5	1			1	3			.051	71.3
	C. A.	9	3	1	1	2	2			.042	61.3
	F.W.	9			1	2	6	0.64		.019	68.3
	S.I.V.	5				4	1	0.85		.021	78.6
	AP.	2					2	0.45		.027	50.0
	Area	Cases	$qR(s)$	RS	$rsr'S'$				$\frac{q}{\text{Time}}$	$\frac{R}{\text{Time}}$	Height
LV	F.W.	9	8		1				.016	.046	95.4
	AP.	6	4	2					.015	.041	92.5

RESULTS

(1) Normal heart :

Materials, 13 cases in total, consisted of 4 cases of non-cardiac disease, 4 cases of slight patent ductus arteriosus, 5 cases of slight mitral stenosis, and all cases showed normal ECGs. The QRS patterns recorded at different areas of the heart are shown in Table I. Over the right ventricle, 1) S.C. and 5) C.A. mostly gave $[rsR'(s')]$, and 2) F.W. and 3) S.I.V. gave $[RS]$ $[rS]$; 4) AP. mostly gave $[Rs]$. Over the left ventricle, 1') F.W. gave $[qR(s)]$ in the majority of the cases and 2') AP. gave no q in many cases. Fig. 1 illustrates the recordings in one of such subjects. According to Barbato⁴⁾ the conus arteriosus and areas close to the sulcus coronarius generally give $[rS]$ and this is often associated with notching and slurring. In the author's cases the conus gave $[rS]$ pattern only in a small number of cases, and in the majority of cases the pattern was

Fig. 1. K. M., 32 years old, female, Pulsless Disease.

[rsR' (s')]. Of course, as compared with the cases of right ventricular hypertrophy, the S wave tended to be deep and R wave low, and the pattern was rather close to [rSR'] or [rSr']. At any rate it appears that, in the normal ECG, the right chest ECG reflects the potential variations over the free wall of the right ventricle, and the left chest ECG reflects the potential variations over the free wall of the left ventricle.

(2) Left ventricular hypertrophy:

As shown in Table I, the observed tendency was about the same as in the normal heart. The base of the right ventricle and conus often gave deep S and the middle of left ventricle gave [qR] [qRs], the pattern being the same with what is recorded from the left chest. As shown in Fig. 2, the initial r over the conus coincides with r in V₁, and middle of the right ventricle gave R 0.006 seconds later than this, and with this agrees the q of the left ventricle. On the left ventricular side R wave measured about 9.5 mV and this value was little larger than in the normal heart, but the difference was not so marked here as in the chest lead.

Fig. 2. M. T., 6 years old, boy, Ventricular Septal Defect.

It appears that the high R recordable over the chest is due, not only to an increased electro-motive force of the heart, but also to the approach of the heart to the thoracic wall.

(3) Right ventricular hypertrophy:

Materials consisted of 23 cases of Fallot's tetralogy, 12 cases of mitral stenosis and 3 other cases, Fig. 3 shows the recordings from consecutive spots over the surface of the right ventricle in a case of the VSD associated with the combined ventricular hypertrophy. Along line A the [rsR'] pattern distal to Sulcus coronarius gradually increased its R which covered r, and merged into [Rs] at conus arteriosus, further into [RS] left to the conus. Along line B the pattern of [rsR'] changed into [RS] in the middle of right ventricle and the impulse arrival time was correspondingly shortened. Along line C [Rs] pattern over the conus changed into [RS] at the middle of the right ventricle, but again into [Rs] in the apex. Such trend like this was universally

Fig. 3. T. K., 6 years old, girl, Ventricular Septal Defect. right ventricular pressure 81/0 mm Hg, shunt ratio 78%.

TABLE II
RIGHT VENTRICULAR HYPERTROPHY (38 CASES)

	Area	Cases	$rsR'(s')$	rR'	R	$(q)Rs$	$(q)RS$	rS	R/S	r		R'	
										Time	Height	Time	Height
RV	S. C.	28	1	3	2	12	10						
	C. A.	38	7	3	5	6	10	7		.012	19.3	.042	80.0
	F. W.	37				4	26	7	0.74			.027	68.8
	S. I. V.	30				2	11	17	0.61			.026	55.0
	AP.	19			1	3	11	4	0.88			.026	53.2
	Area	Cases	$qR(s)$	qRS	qrS	Rs	RS	rS	R	q		R	
										Time	Depth	Time	Height
LV	F. W.	36	23	4	6	2		1		.019	34.7	.038	80.6
	AP.	22	4	7	2		5	4				.026	50.5

COMBINED VENTRICULAR HYPERTROPHY (8 CASES)

	Area	Cases	$rsR'(s')$	R	Rs	RS	rS	R/S	R'	
									Time	Height
RV	S. C.	4	2		1	1			.035	76.0
	C. A.	8	2		3	2	1		.038	102.6
	F. W.	8				7	1	0.87	.025	85.5
	S. I. V.	6				6		0.82	.025	80.0
	AP.	3		1		2		1.32	.032	140.0
	Area	Cases	$qR(s)$	qRS	rsR'	R	q	R	$Time$	$Height$
LV	F. W.	8	6	1	1		.017	.049		114.0

noted in those who had hypertrophy of the right ventricle.

As shown Table II 1) S.C. and 5) C.A. gave $[rsR']$, $[rR']$, $[Rs]$ in most cases, and 2) F.W. gave $[RS]$; 3) S.I.V. often gave $[RS]$, $[rS]$, and 4) AP. gave $[Rs]$ rather frequently. Over the left ventricle 1') F.W. gave $[qRs']$ in the majority of the cases and 2') AP. gave deep S, and q was absent in many cases. Fig. 4 shows the recordings in one of such cases. In the presence of right ventricular hypertrophy, it appears, the high R recordable over the right chest probably reflects the potential variations at the base of the right heart or the region of the conus; potential changes in the middle of the right ventricle will be represented to lead V_2 - V_4 . It also appears that $[RS]$ $[qRS]$ recordable over the left chest may reflect the wave of potential occurring in the right ventricle close to the interventricular sulcus or the apex of the left ventricle. Fig. 5 illustrates the simultaneous recordings from these leads points. It will be noted

that the recordings simulate one another among V_1 , conus and areas close to the sulcus

Fig. 4. T. S., 17 years old, male, Tetralogy of Fallot.

Fig. 5. M. M., 7 years old, boy, Tetralogy of Fallot.

Fig. 6. S. F., 11 years old, boy, Tetralogy of Fallot.

coronarius in term of the timing and form; the middle of right ventricle gave [rS] and the peak of r occurred a little behind the initial r of the conus; the left ventricle gave q almost simultaneously with r of the middle of right ventricle.

Mc Gregor¹⁾ recorded [rS] from the surface of the right ventricle in cases of right ventricular hypertrophy and deduced

that the high R recordable over the right chest was due to the electrical activity of the rotated left ventricle. On the contrary, Caruso³⁾ found a good accord between the right epicardial lead and right chest lead. They reached such conflicting conclusions simply because the areas explored were narrow. Thus the subsequent studies by Barboto⁵⁾, Wasserburger⁷⁾ and Brusca⁸⁾ all reveal-

Fig. 7. F.F., 11 years old, boy, Atrial Septal Defect.

ed that a high R appeared at the base of the right ventricle and conus, suggesting that the R recordable over the right chest was due to this high R. This observation agrees with the present author's finding.

In 4 cases of Fallot's tetralogy qV_1 was noted. These cases gave q at the base and middle of the right ventricle, and, in 3 of 4 cases, also over the conus. In this case, the left ventricle gave [qRs]. Fig. 6 shows the simultaneous recordings from different areas. Inspection of this figure will show that qV_1 agreed well with the epicardial q of the right heart, and this coincided with the beginning of the initial r recordable over the conus; it is definitely ahead of q of the left ventricle.

Opinions are divergent as to the genesis of qV_1 , and some authors regard this as an initial r buried within the isoelectric line⁷. In such a case the right intracavity lead also gave r, as shown Fig. 7, and qV_1 started behind this; it was also behind q of the left ventricle.

Fig. 8 also illustrate the recordings where qV_1 is seen. In this case V_5, V_6 gave [rsR'], and the direct epicardial lead gave [qRs] over the right ventricle and [rsR'] over the

left ventricle. This is probably due to the incomplete left bundle branch block.

Behaviors of qV_1 is quite different from what was mentioned above in Fallot's tetra-

Fig. 8. T.K., 7 years old, boy, Ventricular Septal Defect.

logy. According to Zuckermann¹¹⁾ who studied the problem of acute cor pulmonale experimentally, the initial negativity over the conus was due to an enlargement of the right ventricle and the consequent enlargement of the angle subtended by the conus and septum. The author wishes to differ from Zuckermann in opinion, since the author could not record *r* from within the right ventricle. Kert¹²⁾ also maintains the same opinion. The initial negativity at the base of the right heart may be due to one or more of the following reasons: 1) because the wave of excitation sweeps from right to left during the early stage of the septal activation, 2) because, as Kert¹²⁾ maintains, some of the papillary muscles may be thrown in full excitation far earlier than others, 3) because, as Brusca⁸⁾ contends, the base of the heart may function as a common cavity in Fallot's tetralogy in term of both function and structure, and this area may be subject to the influence of the negative charge over the cavity of the left ventricle. At any rate in Fallot's tetralogy the *q* wave recorded over the right chest is

identical with the *q* wave recorded directly from the base of the right heart. However; its precise genesis still remains to be decided.

(4) *Combined ventricular hypertrophy*:

As shown in Table II the problem was analysed in 8 cases. It was found that the recordings had characteristics of both left ventricular hypertrophy and right ventricular hypertrophy; the chest recordings over the right and left chest agreed well with the direct recordings from the right and left ventricle, respectively.

(5) *Right Bundle Branch Block (R.B.B.B.)*:

Materials studied were 3 cases of complete RBBB and 26 cases of incomplete RBBB. In the case of complete RBBB the impulse arrival time was considerably delayed in all areas of the right ventricle; the left heart gave deep *S*. Table III gives the data from 16 cases of ASD and 7 cases of mitral stenosis associated with incomplete RBBB. In cases of ASD the base of right heart gave [*rsR'*] [*rR'*], and the middle of right heart gave [*RS*], and the majority of such cases showed notching; impulse arrival time was

TABLE III INCOMPLETE RIGHT BUNDLE BRANCH BLOCK
ASD (16 CASES)

	Area	Cases	<i>rsR'</i> (<i>s'</i>)	<i>rR'</i> (<i>s</i>)	<i>R</i>	<i>Rs</i>	<i>RS</i>	<i>rS</i>	$\frac{r}{\text{Time}}$	$\frac{R'}{\text{Time}}$
RV	S. C.	12	7	4				1	.017	.061
	C. A.	16	9	4	1	1		1	.017	.061
	F.W.	14	3	3			6	2	.019	.042
	S.I.V.	7					3	4	.019	.038
	AP.	13		8		3	1	1	.021	.041
	Area	Cases	<i>qRs</i>	<i>qRS</i>	<i>qrSr'S</i>	<i>RS</i>	<i>rS</i>		$\frac{q}{\text{Time}}$	$\frac{R}{\text{Time}}$
LV	F.W.	12	2	6	2	1	1		.020	.033
MS (7 CASES)										
	Area	Cases	<i>rsR'</i> (<i>s'</i>)	<i>rR'</i> (<i>s</i>)	<i>Rs</i>	<i>RS</i>	<i>rS</i>		$\frac{r}{\text{Time}}$	$\frac{R'}{\text{Time}}$
RV	S. C.	5	2	3					.015	.057
	C. A.	7	3		2	2			.022	.054
	F.W.	7	1		1	2	3		.024	.049
	S.I.V.	4				2	2		.021	.041
	AP.	1					1		.023	.042
	Area	Cases	<i>qR</i> (<i>s</i>)	<i>qRS</i>	<i>Rs</i>	<i>RS</i>	<i>rS</i>		$\frac{q}{\text{Time}}$	$\frac{R}{\text{Time}}$
LV	F.W.	7	5	1	1				.018	.042
	AP.	4		1	1	1	1			.028

considerably delayed beyond the normal value. Over the left ventricle, deep S was found in half of the cases, and this coincided with the late R recordable over the chest and base of the right heart. Fig. 9 illustrates such a case, and Fig. 10 shows the simultaneous recordings from the interior of

Fig. 9. S.O., 9 years old, girl, Atrial Septal Defect.

Fig. 10. S.O., 9 years old, girl, Atrial Septal Defect.

the right ventricle. The intracavity lead gave a split r wave, the first summit coinciding with the initial r and the second summit coinciding with the ascending limb of late R¹⁸⁾. From these observations a possibility suggests itself that, in the case of ASD, the incomplete RBBB represents a genuine conduction disturbance involving the right bundle branch.

The situation is different with the mitral stenosis; when this is associated with an incomplete RBBB as shown in Table III and Fig. 11, [RS] [rS] patterns recordable at the middle of right heart were scarcely associated with notching. Therefore it is possible, though not quite certain, that the ECG recorded over the right chest actually represents potential variations over the conus or base of the right ventricle in this case, as it was the case with the right ventricular hypertrophy.

CONCLUSIONS

In 97 cases of normal and diseased heart, the direct epicardial ECGs were recorded and

Fig. 11. S.I., 27 years old, male, Mitral Stenosis. right ventricular pressure 58/0 mmHg, cardiac index 4.9l/min/m².

analysed.

(1) In the normal heart the base of right ventricle and conus gave [rsR'], the middle of right ventricle [RS] [rS], the middle of left ventricle [qR(s)]. Electrocardiograms recorded over the right and left chest represented the potential variations at the middle of the right heart and at the middle of left ventricle, respectively.

(2) In cases of left ventricular hypertrophy, ECGs recorded over the chest coincided with the direct recordings. The high R wave recordable over the left chest appears to be due, not only to an increased electromotive force of the heart, but to the approach of the heart to thoracic wall.

(3) In cases of right ventricular hypertrophy the recordings over the right chest represented the potential variations at the base of the right ventricle or the conus. When qV_1 was present, the epicardial recordings also gave q wave. The genesis of q waves was discussed.

(4) The sign of RBBB may be due to a

genuine conduction disturbance in cases of ASD; however, this sign may be a mere reflection of the potential variations at the base of the right heart or conus in cases of mitral stenosis.

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