THE VECTORCARDIOGRAM IN ATRIAL SEPTAL DEFECT

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The right ventricular hypertrophy in uncomplicated atrial septal defect results from an increase in stroke output. The electrocardiogram in these circumstances differs from that when there is a raised right ventricular pressure (Cabrera and Monroy, 1952). The right bundle-branch-block pattern is frequent, and was found in 95 per cent of the patients with uncomplicated atrial septal defect studied by Barber *et al.* (1950). Vectorcardiography shows that the RSR' in lead V1 in these cases is produced by moderate right ventricular hypertrophy (Lasser *et al.*, 1951) (Fig. 1).

FIG. 1.—(From Grishman and Scherlis). Diagrams of the horizontal projection of the QRS loop of the vectorcardiogram with the derived precordial ECC leads V1 and V6. In the normal subject and in R.B.B.B. the loop is counter-clockwise in sense, while in both types of R.V. hypertrophy it is clockwise. An RSR' pattern in lead V1 is found in both R.B.B.B. and R.V. hypertrophy, though the vectorcardiograms differ considerably.

A series of patients with atrial septal defect were studied to see if there were any distinctive features of the vectorcardiogram in right ventricular hypertrophy with an increased stroke output. Evidence of additional left ventricular hypertrophy was also sought. This may be due to a ventricular septal defect or to mitral incompetence, indicating that the atrial septal defect is part of a defect of the atrio-ventricular cushions. Present techniques do not allow safe repair of this type of defect, so detection before operation is important.

MATERIAL AND METHODS

Forty patients were studied. The presence of an atrial septal defect was established by cardiac catheterization in all, and was confirmed in 12 at subsequent operation. Cases with pulmonary hypertension or pulmonary stenosis were excluded.

Cardiac Catheterization. The technique followed was that described by Wood (1956). The pulmonary blood flow was expressed as a ratio to the systemic flow. In calculating these flows it was assumed that the oxygen saturation of the superior vena caval sample was representative of the whole venous return, and that the pulmonary venous blood was 95 per cent saturated.

The presence of a left-to-right shunt at ventricular as well as atrial level, with the passage of the catheter to the left ventricle and aorta without sharp angulation, was regarded as evidence of an atrio-ventricular cushion defect.

Electrocardiography. A Cambridge photographic machine was used. The electrocardiograms were classified from the appearance in lead V1 which showed an RSR', RR', or QR pattern in most cases. Complete right bundle-branch block was diagnosed when the QRS complex was 0.12 sec. wide or more. If the QRS complex was narrower than this, but showed a secondary R wave in lead V1, it was classified as incomplete right bundle-branch block.

In the absence of bundle-branch block, right ventricular hypertrophy was diagnosed when R in V1 was 7 mm. or more in height (Sokolow and Lyon, 1949). An R' of 10 mm. or more was taken to indicate right ventricular hypertrophy in addition to right bundle-branch block when the QRS width was between 0.10 and 0.12 sec. (Barker and Valencia, 1949). In complete bundle-branch block, additional right ventricular hypertrophy was diagnosed when R' was 15 mm. or more (Booth *et al.*, 1956).

Vectorcardiography. The apparatus described by Dower and Moore (1955) was used. The lead system was that recommended by Grishman *et al.* (1951): four electrodes are placed on the thorax at the corners of an imaginary cube, and are connected to give three bipolar leads with a common electrode on the right lower back. The leads are combined in pairs, one on each axis of the oscilloscope, to produce vectorcardiograms in the horizontal, frontal, and sagittal planes, which are recorded photographically.

The Einthoven system of polarity was used, in which directions are indicated from the point of view of the subject. Forces directed forwards, downwards, or to the left are regarded as positive.

The oscilloscope beam was interrupted 80 times per second. The rate of inscription of the vectorcardiogram is indicated by the distance between these interruptions. As each break is abrupt, and the next segment has a pointed origin, the direction of inscription is easily detected.

RESULTS

Atrial Septal Defect. In 35 patients there was no evidence of an atrio-ventricular cushion defect. The only complications present were anomalous pulmonary venous drainage (4), mitral stenosis (2), pulmonary regurgitation (1), and tricuspid regurgitation (1). These complications tend to increase the stroke output of the right ventricle.

The electrocardiogram showed complete right bundle-branch block in 18 with right ventricular hypertrophy in 1, incomplete right bundle-branch block in 16 with right ventricular hypertrophy in 5, and was normal in 1 patient. Atrial fibrillation was present in 5 patients.

The pulmonary blood flow varied from 1.4 to 6.7 times the systemic flow. The pulmonary vascular resistance was less than 3 units (240 dynes sec. cm.⁻⁵) and the arterial oxygen saturation more than 90 per cent in every case. Some patients had a systolic pressure gradient at the pulmonary valve, but this was never more than 20 mm. Hg.

The vectorcardiograms of these patients were classified as follows:

Right ventricular hypertrophy	..	..	..	..	..	..	..	24
Right ventricular hypertrophy with R.B.B.B.	..	..	..	..	..	..	..	1
Normal with some delay in R.V. activation	..	..	..	..	..	..	..	8
Normal	..	..	..	..	..	..	..	2

In 24 patients the vectorcardiogram showed right ventricular hypertrophy (Fig. 2). The QRS vector was directed anteriorly and inferiorly forming a clockwise loop in the horizontal plane but remaining close to the transverse axis. A small initial deflection representing septal activation was usually present. The remainder of the loop consisted of a narrow left deflection followed by a

FIG. 2.—The vectorcardiogram and electrocardiogram in a patient with atrial septal defect, showing right ventricular hypertrophy of moderate degree. Diagrams of the horizontal and frontal projections of the vectorcardiogram are shown alongside the corresponding photographic records. In the diagrams the axial leads V1, V6, and aVF are shown. The QRS loop is narrow, and the vector remains close to the transverse axis.

wider right deflection with slowing of part of the returning limb. In three patients the slow segment involved some of the outgoing limb also. The T loop was directed to the left. The variations in the vectorcardiogram within this group could not be correlated with the pulmonary blood flow.

18 patients with pulmonary hypertension or stenosis were studied for comparison. In 6

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with high right ventricular pressures, the QRS vector passed further forwards and downwards than in atrial septal defect, to form a more circular loop (Fig. 3). The 9 subjects with moderate right ventricular hypertension had QRS loops similar to those found in atrial septal defect. However, 13 of the patients with atrial septal defect had narrower QRS loops than any in the group with a raised right ventricular pressure. Three patients with mild pulmonary stenosis had normal vectorcardiograms.

FIG. 3.—Diagram of the vectorcardiogram in the horizontal plane and the electrocardiogram in a patient with severe pulmonary stenosis, showing right ventricular hypertrophy of severe degree. The QRS loop is nearly circular in this plane.

One patient with atrial septal defect had tricuspid regurgitation. The right deflection of the QRS loop was more anterior than usual in this case, and was counterclockwise in the horizontal plane (Fig. 4). The T loop was directed posteriorly. This pattern indicates right bundle-branch block in addition to right ventricular hypertrophy.

In 8 patients with atrial septal defect the QRS loop was close to the transverse axis, as in the group showing right ventricular hypertrophy, but differed in sense. The left deflection was counterclockwise in the horizontal plane as in normal subjects. The right deflection varied, and the outgoing and returning limbs often crossed (Fig. 5). The electrocardiogram and the findings at cardiac catheterization were in no way unusual in these patients.

FIG. 4.—Diagram of the vectorcardiogram in the horizontal plane and the electrocardiogram in a patient with R.V. hypertrophy and R.B.B.B. The clockwise initial part of the loop indicates R.V. hypertrophy, while the late anterior counterclockwise component indicates R.B.B.B. This pattern was found in only one patient with atrial septal defect.

FIG. 5.—Diagram of the vectorcardiogram in the horizontal plane and the electrocardiogram in a patient with atrial septal defect, showing a counterclockwise left deflection. The later right deflection is clockwise in sense. This pattern was interpreted as normal L.V. dominance with some delay in R.V. activation.

A normal vectorcardiogram was found in two subjects with atrial septal defect. One had a normal electrocardiogram, but in the other patient an embryonic R' was present in lead V₁.

Artio-ventricular Cushion Defect. There was evidence of an atrio-ventricular cushion defect in 5 patients (Table). In four mitral incompetence was detected clinically. The electrocardiogram showed left ventricular hypertrophy in two (R in V₆ 32 and 28 mm.), and the P-R interval was prolonged in the 4 patients with sinus rhythm.

The vectorcardiograms fall into three groups. In two subjects the pattern was similar to that found in atrial septal defect. The other three showed left axis deviation in the electrocardiogram. This was reflected in the vectorcardiogram as a QRS loop directed superiorly (Fig. 6). There was an unusual degree of terminal slowing of the loop in two patients.

FIG. 6.—Diagram of the vectorcardiogram in the frontal plane in a patient with an atrio-ventricular cushion defect. The standard and unipolar limb leads with their corresponding axes are shown in the diagram. The QRS loop is directed superiorly, and the electrocardiogram shows left axis deviation in the standard leads.

TABLE
ATRIO-VENTRICULAR CUSHION DEFECTS

Sex	Age	Clinical evidence of mitral re-gurgitation	Evidence of A-V cushion defect at catheteri-zation	Electrocardiogram			Vectorcardiogram		
				P-R interval	L.A.D.	QRS pattern	Right anterior appendix	Unusual terminal slowing	Ventricular dominance
♀	28	+	O	0.26	O	RBBB inc.	O	O	Right
♂	59	+	O	AF	O	RBBB	O	O	Right
♂	18	+	+	0.24	++	RBBB +LVH	O	O	Combined
♀	39	O	+	0.21	++	RBBB	O	+	Combined
♂	27	+	O	0.28	+	RBBB +LVH	+	+	Left

Cardiac catheterization showed evidence of an atrio-ventricular cushion defect in two subjects. In both the QRS loop in the horizontal plane had a counterclockwise left deflection indicating left ventricular dominance. This was followed by a clockwise right deflection interpreted as evidence of right ventricular hypertrophy (Fig. 7). The remaining patient had a similar counterclockwise left deflection which continued into a right anterior terminal appendix indicating right bundle-branch block.

FIG. 7.—Diagram of the vectorcardiogram in the horizontal plane and the electrocardiogram in a patient with an atrio-ventricular cushion defect. The counterclockwise left deflection indicates L.V. dominance, but the later clockwise right deflection suggests some R.V. hypertrophy.

DISCUSSION

Right bundle-branch block in normal subjects or ischaemic heart disease produces a characteristic vectorcardiogram. The QRS loop has a terminal appendix directed anteriorly and to the right (Lasser *et al.*, 1951) (Fig. 1). Braunwald *et al.* (1956) found that the onset of right ventricular systole was delayed in subjects showing this pattern. The right anterior appendix may therefore be regarded as definite evidence of right bundle-branch block. It was found in two patients in the present series.

Braunwald *et al.* (1956) also found delay in right ventricular systole in some subjects with lesions producing right ventricular hypertrophy. The vectorcardiogram in these patients shows an unusual degree of terminal slowing of the QRS loop. In 9 atrial septal defects with this slowing reported by Silverblatt *et al.* (1957) the QRS loop was directed superiorly. An upwardly directed QRS loop in atrial septal defect suggests a defect of the atrioventricular cushions. The terminal slowing may represent a modification of the right bundle-branch block vector in the presence of left ventricular hypertrophy. Two patients in this series showed unusual terminal slowing of an upwardly directed QRS loop, but in both there was other evidence of left ventricular hypertrophy (Fig. 7).

The vectorcardiogram in the 24 patients showing right ventricular hypertrophy is similar to that described by Richman and Wolff (1955) and Silverblatt *et al.* (1957) in atrial septal defect. Wolff *et al.* (1953) regard the right deflection of the QRS loop in these cases as evidence of impaired conduction in the hypertrophied right ventricle. The T loop axis is directed away from these late

QRS forces as it is in right bundle-branch block. The unusual degree of terminal slowing found in some subjects may also indicate defective conduction. The delay in activation must be confined to part of the right ventricle as the onset of mechanical systole is normal in this group (Braunwald *et al.*, 1956).

The narrow QRS loop probably reflects the distribution of the right ventricular muscle in atrial septal defect. The ventricle is dilated to accommodate the increased stroke output, and the hypertrophy is mainly evident in the muscle bands of the crista supraventricularis and the trabeculae (Kjellberg *et al.*, 1955). The thick free wall of right ventricular hypertension is not found, so no large anterior forces are produced by right ventricular activation. The late right deflection may arise from the region of the crista supraventricularis (Walker *et al.*, 1956).

A normal left deflection of the QRS loop was found in 8 patients. The right ventricular forces have failed to overcome the normal dominance of the left ventricle in these cases. The right deflection shows a similar conduction disturbance to that found in the group with right ventricular hypertrophy. This abnormality of conduction is not a constant feature of atrial septal defect as it was absent in the two patients with normal vectorcardiograms.

Five patients showed features suggesting *atrio-ventricular cushion defect*. The left ventricular hypertrophy in two was apparently not sufficient to affect the vectorcardiogram. In the remaining three the QRS loop was directed upwards. This is probably the result of left ventricular hypertrophy, which is also evident as a counterclockwise left deflection in the horizontal plane. Toscano-Barbosa *et al.* (1956), however, suggest that there is a specific abnormality of conduction in this condition, as this vectorcardiographic pattern is found in patients with the ostium-primum type of defect without mitral incompetence or ventricular septal defect. These authors report 16 patients with atrio-ventricular cushion defects and classify the vectorcardiograms in three groups, each with a characteristic frontal QRS axis. One consists of cases with pulmonary hypertension which were excluded from this series. Two of the present cases fall in the group with balanced ventricular hypertrophy, and the other shows left ventricular dominance.

A prolonged P-R interval is a frequent finding (Milnor and Bertrand, 1957).

CONCLUSIONS

Of 35 patients with uncomplicated atrial septal defect, 25 had vectorcardiograms showing moderate right ventricular hypertrophy with some impairment of conduction. 13 of these had a narrower QRS loop than any found in a series of patients with pulmonary hypertension or stenosis. Three subjects showed unusual terminal slowing of the loop. In 10 patients the vectorcardiogram did not show right ventricular hypertrophy, but in 8 of these there was evidence of a conduction disturbance in the right ventricle. In all, 22 patients with atrial septal defect showed distinctive vectorcardiographic features.

The vectorcardiogram is helpful in differential diagnosis, as it does not show right ventricular hypertrophy in normal subjects with right bundle-branch block or in mild pulmonary stenosis. These may be confused with atrial septal defect clinically.

Three of the five patients in whom an atrio-ventricular cushion defect was suspected showed characteristic vectorcardiograms that can be recognized in the electrocardiogram as left axis deviation.

Vector analysis is helpful in revealing the fundamental changes in the electrocardiogram in atrial septal defect, but many problems of interpretation remain.

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Fig. 1 is reproduced from *Spatial Vectorcardiography* by A. Grishman, and L. Scherlis, (1952) by permission of the publisher, W. B. Saunders Company.

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