Abnormalities of atrial depolarization in infradiaphragmatic interruption of inferior vena cava¹

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The P wave of the electrocardiogram was analysed in 8 patients who had infradiaphragmatic interruption of the inferior vena cava with azygous continuation. If regard was taken of atrial situs, one patient had normal sinus rhythm, one had a P wave vector which was a mirror image of normal, four had coronary sinus rhythm, and two had left atrial rhythm. There was no simple relation between the P wave vector and abnormalities of the interatrial septum, systemic, or pulmonary venous drainage. The defect of depolarization may be due to aberrant or bilateral development of the sinoatrial tissue, or may be a result of an escape mechanism which occurs in the absence of normal sinoatrial tissue.

In a patient with congenital heart disease, coronary sinus or left atrial rhythm should suggest this abnormality of the inferior vena cava.

Interruption of the inferior vena cava with azygous continuation is an uncommon congenital abnormality and clinical identification of this syndrome is difficult. It should be suspected in any patient with visceral heterotaxis or in a patient who shows, on the chest x-ray, an unusual bulge of the right cardiac border at the junction of the superior vena cava and the right atrium (Anderson, Adams, and Burke, 1961; Campbell and Deuchar, 1967). Coexistent abnormalities of atrial depolarization are often present (Momma and Linde, 1970).

In nearly all normal patients and those with congenital abnormalities of the heart, atrial depolarization starts in the sinoatrial node so that the direction of electrical activation of the atrium is determined by the position, location, and relation of the two atria. In situs solitus of the atria with the heart in the normal position in the chest (laevocardia), atrial activation and depolarization are responsible for a P wave vector which is directed caudally from right to left and posteriorly: this inscribes a P wave which is upright in leads I, II, III, and V6 and which is inverted in aVR. The P wave vector which occurs in patients with atrial inversion travels inferiorly, pos-

teriorly, and to the right, inscribing a P wave which is inverted in leads I and V6 but which is upright in leads II, III, and aVR. These statements are true if it is possible to be certain of the atrial situs, but this can be confusing if there is visceroatrial discordance, anomalously situated sinoatrial tissue, or an ectopic atrial pacemaker (Neill and Mirowski, 1966).

The abnormality of atrial depolarization in patients with interruption of the inferior vena cava has been regarded as diagnostic (Momma and Linde, 1970). We studied a series of 8 consecutive patients with this lesion to determine the nature of the P wave aberration, to find a possible cause for the abnormality, and to see whether it was possible to predict the spatial relation of the respective atria.

Patients and methods

Eight patients were studied. Left and right heart catheterization and multiple selective angiocardiograms were made to establish a complete anatomical and physiological diagnosis in each patient. Details of the individual patients are shown in Table 1. Chest x-rays and angiocardiograms were reviewed to determine the spatial position of the heart and abdominal viscera. The electrocardiograms from each patient were reviewed and the P wave analysed.

Coronary sinus rhythm was considered to be present if the P wave vector was directed from

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TABLE I Summary of clinical features in each patient with details of associated visceral positions and cardiac malformations

Case No.	Age (yr)	Sex	Race	Superior vena cava		Atrial septal defect	Ventric. septal defect	Great vessels	PS	Associated cardiac malformations	Position of heart	Side of stomach	Side of liver
				R	L								
1	10	M	African	+	-	+	+	N	+	Endocardial cushion defect with atrial and ventricular septal defect, mitral regurgitation, and severe pulmonary stenosis	Left	Right	Central
2	3	M	African	+		-	+	N	+	Single ventricle, pulmonary atresia	Central	Left	Central
3a	12	F	African	+	+	+	-	N	-	Single atrium with swan neck abnormality of left ventricle	Left	Right	Central
3b	3	M	Indian	+	+	+	+	N	-	Large atrial, small ventricular septal defect of endocardial cushion type with severe pulmonary hypertension	Central	Left	Central
3c	11/12	M	Indian	+	+	-	+	Complete transposition of great vessels	+	Single ventricle with pulmonary stenosis and complete transposition of great vessels	Left	Right	Central
3d	6/12	M	White	+		-	-	N	-	Persistent ductus arteriosus	Central	Right	Central
4a	2½	M	African	+	+	-	+	N	+	Single ventricle, pulmonary stenosis	Right	Right	Central
4b	4	F	African	+		-	+	[N]	+	Ventricular inversion, inverted and non-transposed great vessels + ventricular septal defect + pulmonary stenosis	Left	Right	Central

R, right; L, left; N, normal relation; [N], normal but inverted; PS=pulmonary stenosis.

right to left in a cephalad direction, if the PR interval was normal, and if the patient was in atrial situs solitus. In left atrial rhythm, with the atria in solitus position, the impulse arises in automatic tissue in the left atrium and the consequent vector is cephalad, to the right, and usually anteriorly directed.

Abnormalities of spatial position of the viscera, cardiac chambers, and great vessels were defined according to the nomenclature of Daves and Pryor (1970). Evidence of asplenia, polysplenia, pulmonary lobation, and the presence of a gall bladder were also identified where possible.

Results

The electrocardiograms are shown in Fig. 1a and 1b. An analysis of the P wave relation is shown in Fig. 2 and Table 2.

The position and relation of the right and left atria were determined from the angiocardigrams. If all the pulmonary veins drained into an atrial chamber this was regarded as the left atrium and if the only, or if

present, both superior venae cavae and the hepatic veins drained into the other atrium, this was regarded as the right atrium. The orifice of the coronary sinus enters the right atrium, and its location was determined by the course of the catheter at catheterization or

TABLE 2 Analysis of P wave in standard leads and V6 of electrocardiogram

Case No.	Pr	P2	P3	PV6	P vector in frontal plane
1	+	+	+	+	↘
2	-	+	+	+	↘
3a	+	-	-	Flat	↗
3b	+	-	-	Flat	↗
3c	+	Flat	-	+	↗
3d	+	-	-	+	↗
4a	-	-	+	-	↘
4b	-	-	-	-	↘

FIG. 1A Standard and extremity leads of the electrocardiogram in respective patients.
FIG. 1B Precordial leads of the electrocardiogram in each patient.

from selective angiocardiograms made into the azygous vein if this drained into the coronary sinus. One patient had a single atrium with pulmonary veins connected anomalously: in this patient the atrial situs is uncertain. Two patients had a left-to-right shunt at atrial level but neither had evidence of partial

anomalous pulmonary venous drainage. In 5 patients the atrial septum was intact, and in each instance the azygous and superior venae cavae drained into the systemic venous atrium.

The patients could be divided into 4 groups. This was based on an analysis of the configuration of the P wave in relation to the spatial disposition of the atria.

Group 1: normal One patient with an endocardial cushion defect of the complete variety had a normal P wave vector.

Group 2: mirror image of normal One patient had pulmonary atresia and a common ventricle, the right atrium was situated on the right. There was no evidence of an interatrial shunt or of a left superior vena cava draining into the left atrium. The P wave vector was directed caudally and to the right, the mirror image of normal.

TABLE 3 Findings supporting a diagnosis of bilateral left 'sidedness'

Case No.	Howell-Jolly bodies	Gall bladder	Bronchographic anatomy
1	Negative	—	Bilateral left lungs
2	Negative	Absent	—
3a	Negative	—	Bilateral left lungs
4a	Negative	—	Bilateral left lungs
4b	Negative	On left	—

FIG. 2 Analysis of the mean P wave vector in the frontal plane.

Group 3: coronary sinus rhythm Four patients had this abnormality, 3 had bilateral superior vena cavae. Patient 3A had laevocardia with a common atrium. The right atrium was probably on the right as the azygous vein ascended on the left of the spine to enter the coronary vein and passed into the coronary sinus on the right of the spine. The site of the orifice of the coronary sinus was assessed from the position of the catheter, and

by inference the P wave abnormality was interpreted as indicative of coronary sinus rhythm. In the other 3 patients, the ‘sidedness’ of the azygous vein and its drainage into the coronary sinus of the superior vena cava and hence into the right atrium was different in each case (Fig. 3), but each patient had coronary sinus rhythm.

Group 4: left atrial rhythm Two patients had this abnormality. One had a bilateral superior vena cava, neither had shunts at atrial level, and there was no evidence of a left superior vena cava draining into the left atrium.

Discussion

Difficulties of interpretation The analysis was made in a group of living patients. There are several problems relating to the analysis of the information and the conclusions must be interpreted in the light of these difficulties.

The patients had heterotaxia and, though the position of the stomach bubble could be identified, the liver occupied a midline position. The heart, in 3 patients, appeared to be centrally situated, but the position and direction of the apex was often uncertain even after a careful examination of the chest x-ray and angiocardiograms. The site and side of the azygous vein was determined from the route of passage of the catheter through the vessel

FIG. 3 The site and side of the azygous vein in each patient. Each diagram also indicates the right atrial situs (in black), the superior vena cavae, and the side of the stomach bubble (s).

and by its subsequent pathway of drainage into the right atrium (Fig. 2). The spatial relation of the right and left atria was an inference based on information obtained by catheterization and angiocardiology. In contrast to morphological studies which are obtained at necropsy, there is no radiological method of distinguishing between right and left atria (Daves and Pryor, 1970). We have inferred atrial 'sidedness' from the drainage patterns of the systemic and pulmonary veins. The atria were explored carefully to exclude bilateral superior vena cavae, but as they were catheterized from the leg, failure of the catheter to enter and demonstrate a second superior vena cava did not exclude its presence.

Is interruption of inferior vena cava with azygous continuation a defect of 'sidedness'? The lesion rarely occurs in a heart that is otherwise normal: other congenital cardiac abnormalities are commonly associated and these include defects of the atrial septum, pulmonary veins, and coronary sinus. It implies an early embryological maldevelopment of the sinus venosus and cardinal venous system. Complete or partial heterotaxia is usually accompanied by asplenia (Ruttenberg *et al.*, 1964), rudimentary spleen (Layman *et al.*, 1967), or the presence of multiple small spleens (polysplenia) (Moller *et al.*, 1967). This implies a difficulty in distinguishing between the right and left sides of the body: certain structural and functionally specific cells fail to shift to one side or the other, remain central in situation, or may be duplicated. Polysplenia is a developmental complex of bilateral 'left-sidedness' with a tendency for duplication of left-sided structures and absence of structures normally situated on the right side of the body. Patients with polysplenia have no demonstrable Howell-Jolly bodies, bilateral bilobed ('left') lungs, absence of the gall bladder, interruption of the inferior vena cava, and a centrally situated liver. We looked for these additional visceral malformations; the relevant abnormalities are indicated in Table 3, and support the hypothesis of bilateral 'left-sidedness'.

P wave aberrations In the cardiac malposition complexes, particularly when there is interruption of the inferior vena cava, abnormalities of the P wave vector are common. Only two groups have regarded the abnormality as a specific diagnostic feature (Hastreiter and Rodrigues-Coronel, 1968; Momma and Linde, 1970). Momma and Linde (1970), in a review of the P wave vector in 40 patients with dextrocardia, found it to

be a reliable method of determining the side of the right and left atrium, unless the patient had associated anomalies of the venae cavae, or the asplenia or polysplenia syndrome. Left atrial rhythm was associated with bilateral superior venae cavae particularly if one drained into the left atrium. Coronary sinus rhythm was present in all their patients with interruption of the inferior vena cava. Hastreiter and Rodrigues-Coronel (1968) described 3 patients with this anomaly, a high sinus venosus atrial septal defect, and mild cardiac and visceral heterotaxia: 2 of them had left atrial rhythm while the other had sinus arrest or sinoatrial block with a slow ectopic left atrial rhythm and intermittent atrioventricular dissociation. Leachman and Slovis (1964) described 2 patients with this syndrome: they also had P wave abnormalities, in one the P wave axis was 0° and the other had a wandering pacemaker, the morphology of which suggested coronary sinus rhythm. Neill and Mirowski (1966) analysed a group of patients with dextrocardia and showed many to have a left atrial origin of the atrial impulse. They also showed that alternating sinus and left atrial rhythm occurred frequently in the same patient.

Sino-atrial node: a unilateral or paired structure? Patten (1956) suggested that in the early embryo the sinoatrial node was a paired structure. Van Mierop and Gessner (1970) were unable to find bilateral sinoatrial nodal tissue in young mouse embryos. It is possible that right-sidedness of the embryo had already differentiated and that if they had studied the heart at an earlier stage of development it might have revealed a central sinus venosus with paired bilateral vessels and pacemaker tissue. In contrast, Van Mierop, Patterson, and Reynolds (1964) described 2 patients with congenital asplenia and isomerism of the cardiac atria, the sinoatrial nodes, and the artery to the sinoatrial node, confirming that bilateral structures can exist.

Both anterior cardinal veins arise from the sinus venosus. The sinus venosus shifts to the right, and becomes incorporated in the right atrium; the right superior vena cava drains directly into the right atrium and the remnant of the left anterior cardinal vein forms the left superior vena cava, the great vein of Marshall, and the coronary sinus. Later the upper remnant of the left superior vena cava disappears. If the sinoatrial node is a paired structure, then the right sinoatrial node should be located in its usual position at the junction of the right atrium and superior vena cava, while the anlage of the left sino-

atrial node should lie at the junction of the coronary sinus and the right atrium. If the left superior vena cava drains into the left atrium, the coronary sinus is absent and sinoatrial tissue can be expected at the junction of the left superior vena cava and left atrium. If interruption of the inferior vena cava is associated with a lack of differentiation between 'sidedness', then a sinoatrial node in relation to the route of drainage of the left superior vena cava is acceptable. This hypothesis would explain all the findings of Momma and Linde.

Does the patient have alternative or bilateral sinoatrial tissue or is normal sinoatrial node absent? Van Mierop *et al.* (1964) have described the only patients with bilateral sinoatrial nodes. We, therefore, have no histological evidence to prove or disprove bilateral or alternative sinoatrial nodal tissue.

One patient had a P wave vector which was normal, indicating that the node was located in its normal position. In another patient, the P wave vector was a mirror image of normal, there was no evidence that the left superior vena cava drained into the left atrium: he had either ectopic sinoatrial tissue in the left atrium, a mirror image of normal, or this was a result of an ectopic rhythm arising at this site. Four patients had coronary sinus rhythm; in 3, a bilateral superior vena cava with a coronary sinus was demonstrated and it was not excluded in the fourth. Additional ectopic or reduplication of sinoatrial node tissue in the region of the coronary sinus is therefore a strong possibility. Two patients had left atrial rhythm: one had a variation in the origin of the site of depolarization. One patient had a bilateral superior vena cava but there was no evidence of drainage into the left atrium. Thus, in these patients, sinoatrial tissue could have been present in the left atrium or, alternatively, the normal sinoatrial node could have been absent.

The reported presence of multiple atrial arrhythmias, and the observation in 2 of our own cases, suggests a possible alternative hypothesis. It is possible that the normal sinoatrial tissue is absent, and that the pacemaker of the heart shifts to the next subsidiary area of automaticity, located either in the region of the coronary sinus or in the left atrium. The presence of numerous ectopic rhythms

and sinoatrial bradycardias tends to support such a hypothesis, but careful review of our own data and of the published data suggests that it is more likely that ectopic sinoatrial tissue is present.

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