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Echocardiographic and anatomical correlates in the fetus*

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SUMMARY Fetal cardiac anatomy was studied in 200 pregnancies between 14 weeks' gestation and term using real time two-dimensional echocardiography. Eight scan planes were chosen as contributing valuable and distinct information on the establishment of cardiac normality. To confirm the echocardiographic interpretation, 25 fetal specimens between 12 and 28 weeks' gestational age were sectioned to imitate echocardiographic scan planes and the echocardiographic and anatomical pictures obtained were correlated with each other. The number of patients in whom each plane was recognised was tabulated in the first and second hundred, the second hundred having been studied after the anatomical studies were made. One longitudinal and one transverse plane could be seen in nearly all patients and considerable improvement in the frequency of recognition of other planes was made in the second hundred patients with increasing experience and anatomical understanding. The tricuspid-pulmonary and four-chamber planes alone, however, showed four cardiac chambers, two atrioventricular valves, and two arterial valves within their respective outflow tracts.

Because of the improved resolution and penetration of modern real time cross-sectional ultrasound scanners it has become possible to study cardiac anatomy during intrauterine life. This has important diagnostic and therapeutic implications for the future prenatal detection of congenital cardiac malformations. Because the fetal heart is surrounded by fluid-filled and airless lungs, which do not obstruct ultrasound, the heart is visualised in planes unobtainable in the neonate. The anatomy thus displayed is therefore different from that obtained with standard neonatal echocardiographic views, and that difference could allow misinterpretation of normal findings. In this study we have correlated anatomical and echocardiographic sections to confirm the echocardiographic interpretation and provide the basis for the detection of cardiac abnormalities.

Patients and methods

Two hundred pregnancies were scanned using a Kretz Combison 100 sector scanner or an ATL mark 3 sector scanner. The pictures were recorded on a Sanyo VTC 7100 videocassette recorder and subsequently analysed. The fetal position was established initially by visualising the spine longitudinally from the head to the sacrum (a sagittal section). Having established the fetal spine as the reference point, it was found that each of four planes in the longitudinal axis of the fetus provided slightly different information about the cardiac structures to be identified (Fig. 1). By turning the transducer through 90° from the longitudinal plane the fetus was then examined in the transverse axis (Fig. 2). Scanning in four transverse planes again augmented information about cardiac anatomy.

ANATOMICAL STUDIES

Twenty-five abortuses between 12 and 28 weeks' gestation were sectioned to imitate the postulated echocardiographic planes. The specimens were taken from a museum collection of spontaneous abortions which had been fixed in formalin. In several instances more than one section was required before the correct orientation was discovered.

Results

The first observation was that the fetal heart lies

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in a more horizontal plane than the neonatal heart (Fig. 3). This is because of the size of the liver, which in the fetus extends to the left side of the abdominal wall. Thus, the apex of the heart is displaced cranially and the long axis of the left ventricle is more horizontal than in the adult.

LONGITUDINAL PLANES

The most consistently obtained plane echocardiographically in the longitudinal axis (Fig. 4) shows that the pulmonary valve is anterior and cranial to the aortic root. The aortic valve is easily visualised cranial to the tricuspid valve as the latter enters the right ventricle from the right atrium. The right atrium is recognised by identifying its connection to the superior and inferior vena cavae. It was found that this plane of anatomy, termed the tricuspid-pulmonary plane, was produced by cutting the abortus parallel to the spinal cord with about 20° obliquity to the coronal plane, the plane being well anterior relative to the thoracic cavity (Fig. 1). The tricuspid-pulmonary plane was identified in 90 per cent of the first and 96 per cent of the second hundred patients studied. Having obtained this standard view, the angle of the transducer was then altered to obtain further longitudinal planes. By increasing the obliquity from the sagittal plane the pulmonary trunk can be shown sweeping posteriorly and connecting via the ductus arteriosus with the descending aorta (Fig. 5).

The aortic root is seen as a circle with the aortic valve closing at its centre and the right atrioventricular junction is well visualised. This plane is called the ductus plane. If instead of following the pulmonary trunk back to the ductus the angulation of the transducer to the sagittal plane is increased, the aortic arch can be traced

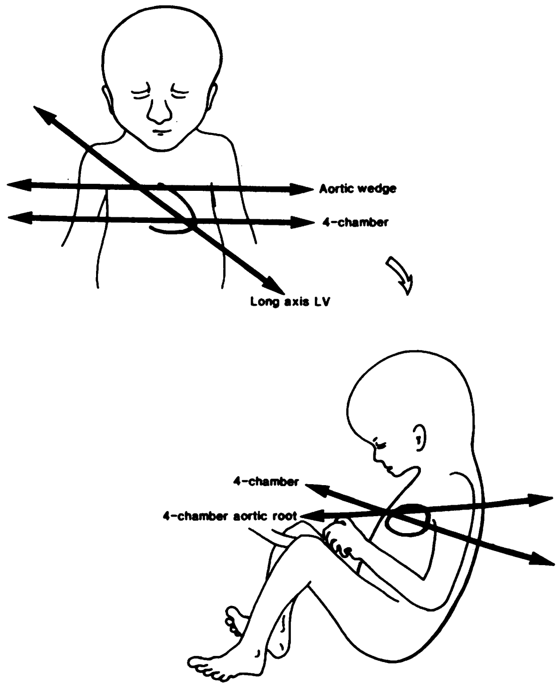


Fig. 2 *Diagram showing the four different planes in the transverse plane of the fetus. The aortic wedge and the four-chamber planes are direct transverse cuts. The four-chamber aortic root plane is obtained in the same transverse plane as the four-chamber but with cephalic angulation of the beam as shown in the lower right-hand diagram. The long axis of the left ventricle is obtained as an oblique plane as shown in the upper left-hand diagram.*

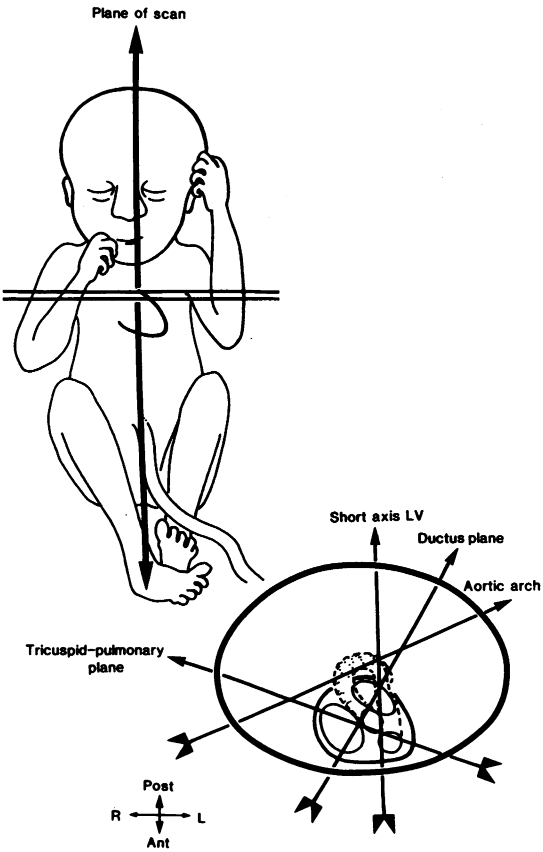


Fig. 1 *Diagram showing the four different planes all taken in the longitudinal axis of the fetus. The inset is a transverse section of the thorax showing the approximate orientation needed to produce the four different planes.*

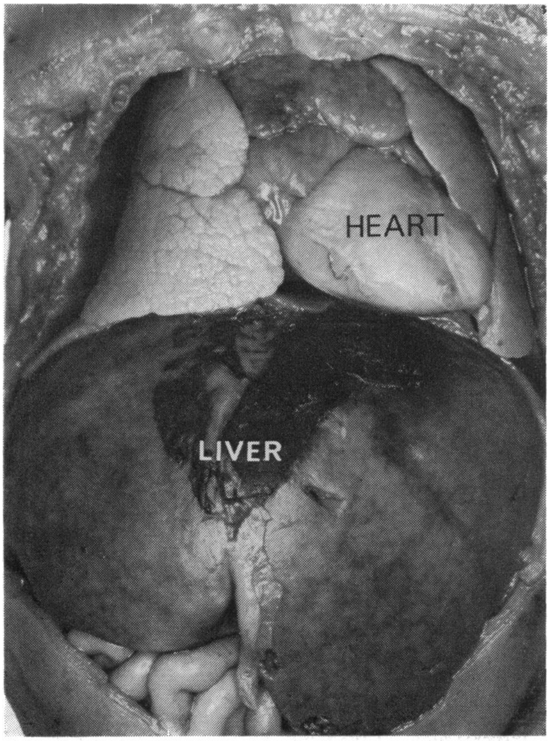


Fig. 3 *The thorax and abdomen of an 18-week human abortus dissected to show the orientation of the heart in relation to the remaining organs.*

into the descending aorta. The head and neck arteries are seen ascending from the arch and the relation to the oesophagus is seen (Fig. 6). This is the aortic arch plane. By then cutting the thorax in a sagittal plane taken to the left of the sternum with a slight degree of obliquity towards the left shoulder, the left ventricle is seen in its short axis with the right ventricular infundibulum ascending anterosuperiorly. The pulmonary valve is visualised in this plane (Fig. 7). We have called this the left ventricular short axis plane. The degree of success in obtaining these three additional longitudinal planes in the first and second hundred patients studied is shown in Tables 1 and 2.

TRANSVERSE PLANES

When the fetus is scanned in its transverse axis (Fig. 2) the view most consistently obtained shows the four-chamber view of the heart (Fig. 8). The right ventricle is seen anterior to the left ventricle, and its thinner wall and coarser trabecular pattern are often distinguishable. The anatomical cut to produce this plane was found to be completely transverse at the level of the junction of the sternum and the fifth costal cartilage. A similar transverse cut at the level of the manubrio-sternal junction (Fig. 2) shows the aorta wedged between the right and left atria and hence is termed the aortic wedge plane. The right and left ventricle are seen considerably foreshortened anterior to the aorta

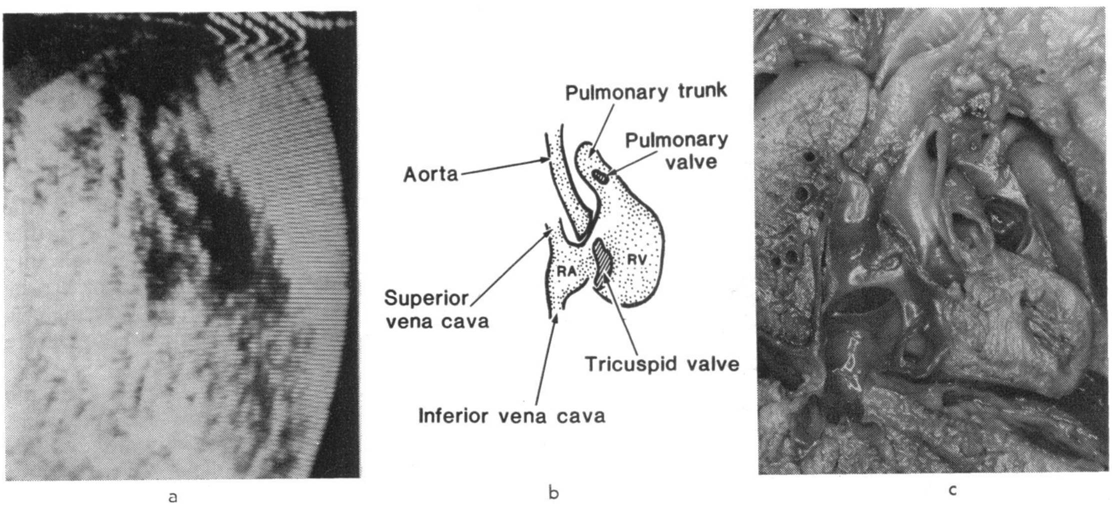


Fig. 4 *The longitudinal echocardiographic findings* (a) *in the tricuspid-pulmonary plane shown in Fig. 1. The drawing* (b) *shows the structures visualised, and* 4c *shows the simulated plane in a dissected human abortus.*

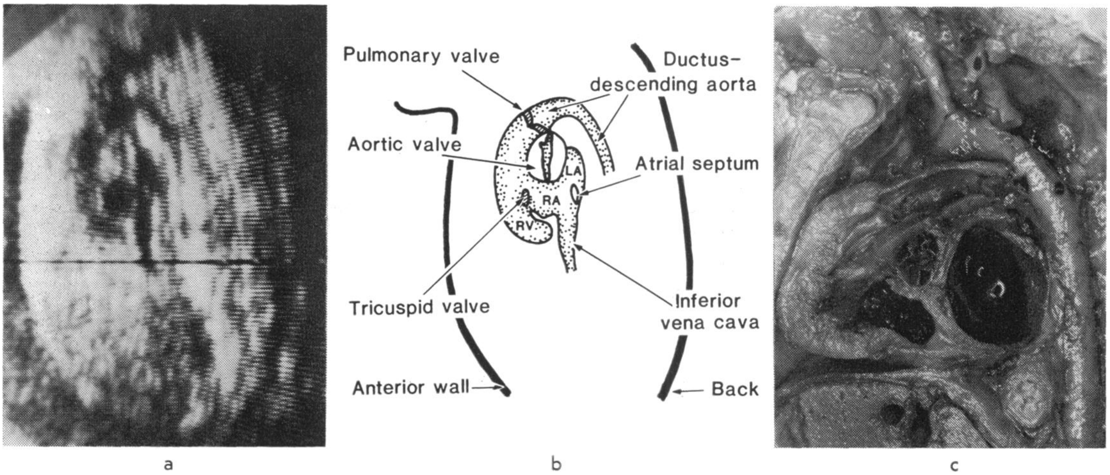


Fig. 5 *A similar composite of echocardiographic findings* (a), *drawing* (b), *and anatomical dissection* (c) *illustrating the ductus longitudinal plane as shown in Fig. 1.*

(Fig. 9). By adding cranial obliquity to the transverse plane at the level of the fifth costal cartilage the aortic root is seen in four chamber projection originating from the left ventricle, giving the four-chamber aortic root plane (Fig. 10). Finally, by taking a transverse plane with some obliquity away from the horizontal (Fig. 2) towards the right shoulder it is possible to cut the left ventricle in its long axis, giving the left ventricular long axis plane. The infundibulum of the right ventricle is then seen anteriorly, and the origin of the aortic root from the left ventricle, with aortic-mitral continuity, is visualised (Fig. 11). The success rate of obtaining these transverse planes is shown in Tables 1 and 2. The four-chamber plane was obtained in all of the first 100 patients studied and all of the subsequent patients. The left ventricular long axis plane showing its outflow tract was found only five times in the first 100 but in 41 per cent of the second 100 patients examined.

It may be seen from the Tables that some scan planes were easier to obtain at different gestational

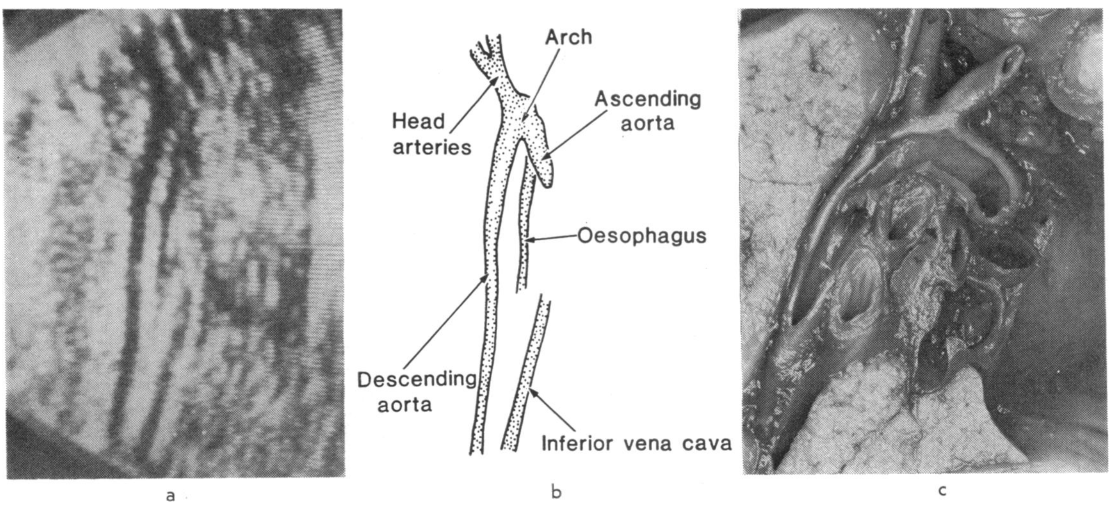


Fig. 6 *A similar composite as shown in Fig. 4 and 5, this time illustrating the aortic arch plane shown in Fig. 1.*

Table 1 *Plane recognition throughout pregnancy in first 100 patients*

Gestational age (wk)		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Number of patients		2	2	11	3	11	4	10	5	5	3	6	2	1	1	3
	(%)	100	100	82	100	91	100	80	100	100	100	83	100	100	100	100
Tricuspid-pulmonary plane		2	2	9	3	10	4	8	5	5	3	5	2	1	1	3
	(%)	—	—	27	33	36	25	50	80	40	66	83	50	—	100	100
Ductus plane		—	—	3	1	4	1	5	4	2	2	5	1	—	1	3
	(%)	—	—	—	—	9	—	30	—	—	—	17	—	100	—	—
Aortic arch plane		—	—	—	—	1	—	3	—	—	—	1	—	1	—	—
	(%)	—	—	—	—	—	25	10	20	20	33	17	50	—	—	—
Short axis left ventricle		—	—	—	—	—	1	1	1	1	1	1	1	—	—	—
	(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Four-chamber plane		2	2	11	3	11	4	10	5	5	3	6	2	1	1	3
	(%)	—	—	27	66	91	25	60	80	40	100	50	—	100	100	66
Aortic wedge plane		—	—	3	2	10	1	6	4	2	3	3	—	1	1	2
	(%)	—	—	9	—	18	50	30	40	20	33	50	50	100	100	30
Four-chamber aortic root plane		—	—	1	—	2	2	3	2	1	1	3	1	1	1	1
	(%)	—	—	—	—	—	—	—	—	—	—	17	—	—	—	—
Long axis of left ventricle		—	—	—	—	—	—	—	—	—	—	1	—	—	—	—

Table 2 *Plane recognition throughout pregnancy in second 100 patients*

Gestational age (wk)		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Number of patients		3	1	5	11	11	4	6	4	4	6	4	2	2	—	4
	(%)	100	100	100	100	100	100	100	100	100	100	100	50	100	—	100
Tricuspid-pulmonary plane		3	1	5	11	11	4	6	4	4	6	4	1	2	—	4
	(%)	33	100	80	82	91	100	66	75	100	83	100	50	100	—	100
Ductus plane		1	1	4	9	10	4	4	3	4	5	4	1	2	—	4
	(%)	33	—	20	55	73	50	50	50	100	33	75	0	0	—	100
Aortic arch plane		1	—	1	6	8	2	3	2	4	2	3	—	—	—	4
	(%)	33	—	40	36	45	50	33	100	75	66	50	100	50	—	75
Short axis left ventricle		1	—	2	4	5	2	2	4	3	4	2	2	1	—	3
	(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	—	100
Four-chamber plane		3	1	5	11	11	4	6	4	4	6	4	2	2	—	4
	(%)	100	100	40	82	82	75	83	75	50	83	75	—	100	—	50
Aortic wedge plane		3	1	2	9	9	3	5	3	2	5	3	—	2	—	2
	(%)	66	100	60	82	91	100	100	100	100	100	100	100	100	—	100
Four-chamber aortic root plane		2	1	3	9	10	4	6	4	4	6	4	2	2	—	4
	(%)	0	0	20	27	18	25	66	25	50	83	50	0	0	—	50
Long axis of left ventricle		—	—	1	3	2	1	4	1	2	5	2	—	—	—	2

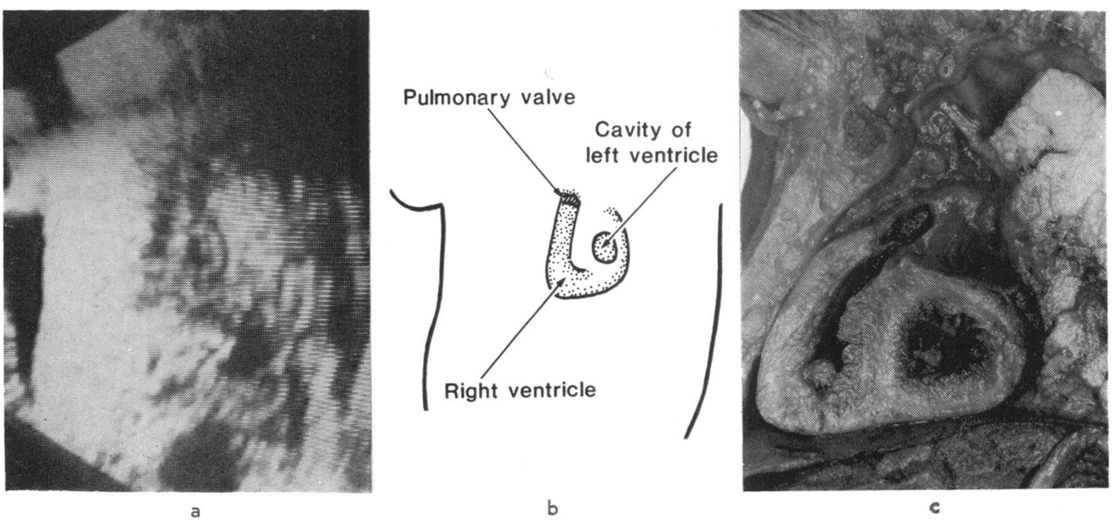


Fig. 7 *A composite showing the left ventricular short axis plane. See Fig. 1 for orientation.*

29	30	31	32	33	34	35	36	37	38	39	40	
5	2	2	3	—	8	5	2	1	2	1	—	100
100	100	100	66	—	75	100	100	100	50	100		
5	2	2	2	—	6	5	2	1	1	1	—	90
60	100	100	66	—	38	80	—	100	—	100	—	
3	2	2	2	—	3	4	—	1	—	1	—	50
40	50	50	66	—	25	40	50	—	—	100	—	
2	1	1	2	—	2	2	1	—	—	1	—	18
—	—	—	—	—	—	40	—	—	—	—	—	
—	—	—	—	—	—	2	—	—	—	—	—	92
100	100	100	100	—	100	100	100	100	100	100	—	
5	2	2	3	—	8	5	2	1	2	1	—	100
60	50	100	33	—	75	40	—	—	50	100		
3	1	2	1	—	6	2	—	—	1	1	—	55
100	100	100	100	—	63	80	100	100	50	100	—	
5	2	2	3	—	5	4	2	1	1	1		45
20	—	—	—	—	12·5	20	—	100	—	—	—	
1	—	—	—	—	1	1	—	1	—	—	—	5

29	30	31	32	33	34	35	36	37	38	39	40	
4	2	3	4	2	10	2	2	3	1	—	—	100
100	100	100	100	100	80	50	100	100	100	—	—	
4	2	3	4	2	8	1	2	3	1	—	—	96
75	100	33	50	100	70	50	100	66	100			
3	2	1	2	2	7	1	2	2	1	—	—	79
50	50	33	75	100	50	50	50	33	—	—	—	
2	1	1	3	2	5	1	1	1	—	—	—	53
75	100	66	75		40	100	50	66				
3	2	2	3	—	4	2	1	2	—	—	—	54
100	100	100	100	100	100	100	100	100	100	—	—	
4	2	3	4	2	10	2	2	3	1	—	—	100
75	50	100	75	100	60	50	100	33	100	—	—	
3	1	3	3	2	6	1	2	1	1	—	—	72
100	100	33	100	100	90	100	100	100	100			
4	2	1	4	2	9	2	2	3	1	—	—	91
50	50	33	50	100	70	100	0	33	0	—	—	
2	1	1	2	2	7	2	—	1	—	—	—	41

ages—for example, the short axis left ventricular plane after 20 weeks' gestation. It should be pointed out that the frequency of plane recognition reflects the speed and ease of their identification, and a higher detection rate could have been achieved if unlimited time had been available or if a repeat study had been performed in individuals. This is because fetal position or fetal movement may limit the number of planes identified at one particular time. In addition, scan plane identification is really an artificial way of dividing up what is a continuous scan sweep, which, with experience, allows each view to follow on from one another.

Discussion

The ability to recognise with accuracy normal cardiac anatomy by fetal echocardiography is a prerequisite for the successful antenatal diagnosis of congenital cardiac malformations. We have shown that this anatomy is displayed in a significantly different fashion in the fetus as compared with standard paediatric and adult echocardiographic sections. The reasons for this are twofold. First the heart is surrounded by fluid-filled lungs which, unlike the situation in extrauterine life, do not obstruct ultrasound. Second, the orientation of the heart is different, particularly in the middle trimester, because of the relatively large size of the liver, the major haemopoietic organ of the fetus. This tilts the apex of the heart cephalad and produces a more horizontal long axis of the left ventricle than is usually seen in the neonate.

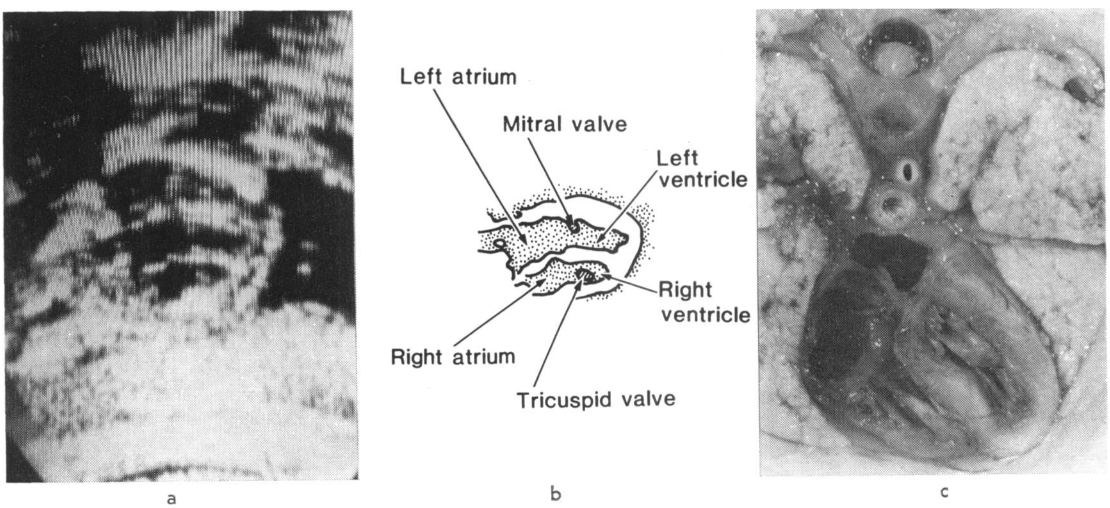


Fig. 8 *A composite of echocardiogram* (a), *drawing* (b), *and dissection* (c) *illustrating the findings in the four-chamber transverse plane (see Fig. 2). The left ventricle is dissected anterior to the annulus of the mitral valve.*

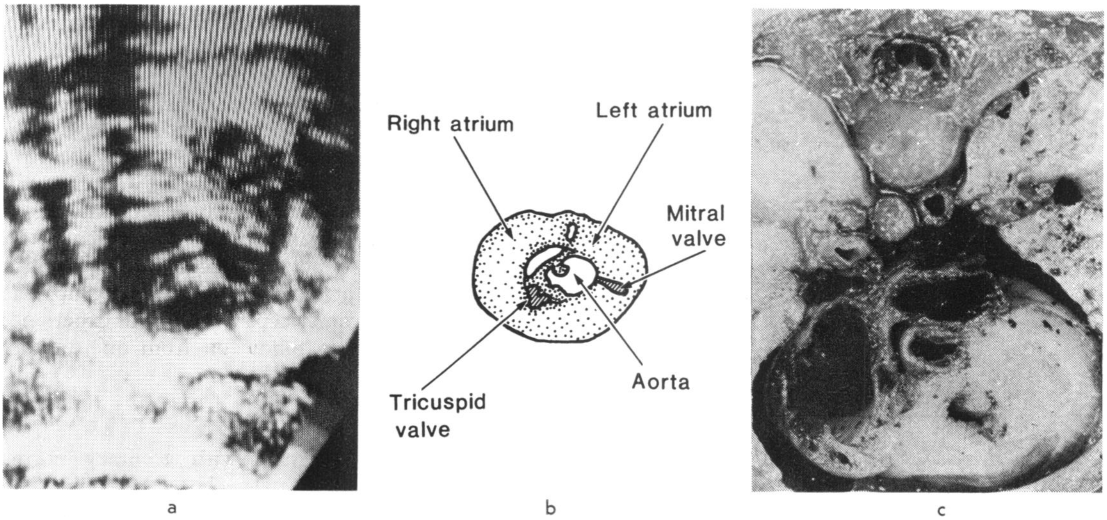


Fig. 9 *A composite showing the findings in the transverse plane which gives the aortic wedge echocardiographic cut (see Fig. 2).*

Perhaps because of this, the most easily obtained view in extrauterine life, namely the long axis section of the left ventricle, was the view most difficult to obtain during fetal life. The most consistently obtained longitudinal view showed the relation of tricuspid and pulmonary valves relative to the aortic valve while the most easily obtained transverse section disclosed the four-chamber arrangement of the right and left sides of the heart. By angulation of the ultrasound beam from these readily obtained scan planes, it was then possible to show with a high degree of accuracy the connection of the aorta to the left ventricle and the pulmonary trunk to the right ventricle. Thus, in all the patients studied, by using combinations of our described scan planes, it was possible to determine unequivocally the normality of the cardiac connections. Cardiac morphology can, we believe, be assessed with a high degree of accuracy though minor degrees of stenosis or obstruction

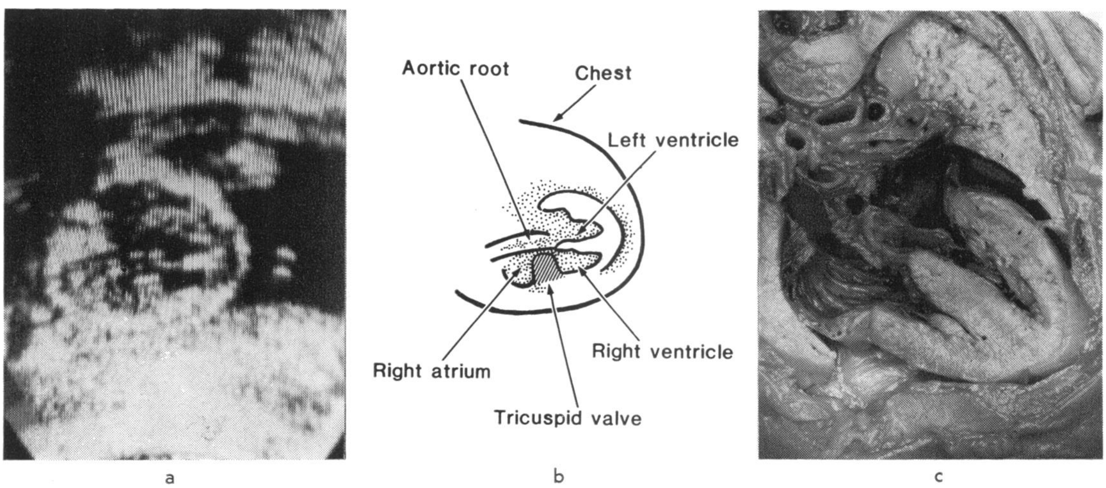
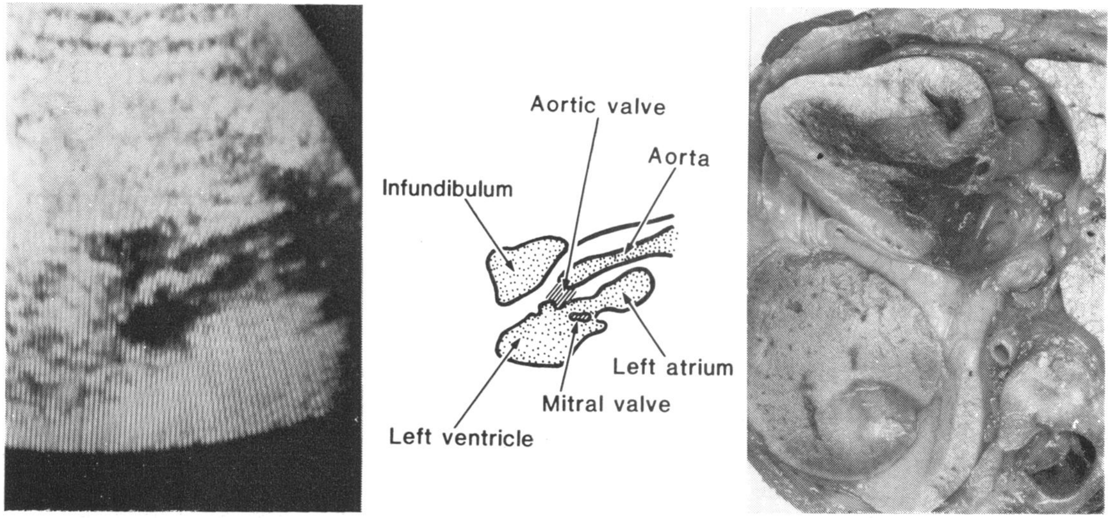


Fig. 10 *By angling the echo beam cranially in a transverse plane at the level of the fifth costal cartilage (see Fig. 2) the four-chamber aortic root plane is obtained, as shown in this composite.*



a b c

Fig. 11 *An oblique cut in the transverse plane as illustrated in Fig. 2 gives the long axis plane of the left ventricle, as shown in this composite.*

to ventricular outflow tracts may not be detected.

Despite these minor limitations concerning precise morphology, our findings show that many congenital lesions should be detectable between 20 and 30 weeks' gestation. A four-chamber scan alone should exclude hypoplasia of the right or left ventricles, univentricular heart with double inlet or absent connection, and the various forms of atrioventricular defects.

Normal scan planes showing the aortic root and pulmonary trunk ductus axis should exclude aortic and pulmonary atresia and truncus arteriosus. The four-chamber plane with the aortic root and the long axis plane of the left ventricle showed aortic-mitral and aortic-septal continuity with the attendant implications of these positive findings. Combinations of all the planes should allow the demonstration of normal intracardiac anatomy while the views obtained of the aortic and pulmonary artery may exclude anomalies of these vessels such as hypoplasia of the aortic isthmus.

Tables 1 and 2 show clearly the progress obtained with practice. In part the greater success obtained in the study of the second 100 patients was related to increased scanning experience, but also to the increased knowledge of fetal cardiac anatomy. These findings show that it is possible to establish cardiac normality in the fetus and should make it possible to diagnose major congenital cardiac malformations.

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