Angiographic Anatomy of the Normal Heart Through Axial Angiography

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SUMMARY We sectioned a series of hearts in a manner similar to that seen on angiographic axial views. A correlation with normal anatomic components to identify the anatomic components of the four cardiac chambers showed that the components of the normal cardiac anatomy can be identified accurately through axial angiography in a manner not shown previously.

KNOWLEDGE of the normal appearance and relationships of the different cardiac segments is necessary for diagnosing malformations. The angiographic anatomy of the normal heart has been described as seen by standard frontal and lateral views. With the recent appearance of axial angiography these descriptions are not accurate or complete enough. In this report, we analyze the anatomy of the normal heart using axial angiography and compare these images with actual specimens.

Material and Methods

We studied a series of normal hearts from patients without heart disease during life or cardiac lesions at postmortem examination. The hearts were cut following the orientation of the radiographic axial views. Photographs were taken of the cut surfaces simulating the appearance shown on the projections of axial angiography.

The angiographic material was obtained from the Pediatric Cardiology Division of the University of Alabama in Birmingham and consisted of normal angiograms performed during investigation for possible cardiac malformations. Therefore, the anatomic specimens and angiograms shown in this paper do not correspond to the same patient.

Radiographic pictures are volume images, while sections of fixed hearts represent planes, or tomographs. Therefore, the anatomic pictures do not at times give the full set of findings as seen by x-rays, and a series of them, at different levels, may be necessary.

The projections in axial angiography are: long-axis view (60° left anterior oblique plus 30° craniocaudal angulation), elongated right anterior oblique (20° right anterior oblique plus 30° craniocaudal angulation) and “four-chamber” view (45° left anterior oblique view plus 30° craniocaudal angulation). Different anatomic specimens were sectioned at these angles and each of the four chambers in each view was photographed.

Results

Angiographic Anatomy of the Cardiac Chambers

Right Atrium

Long-axis view. The left border is formed by a straight contour representing the atrial septum in its most anterior portion. The upper septal contour is formed by the superior atrial free wall. The anterolateral wall between superior and inferior vena cavae is seen on the right side. The anterior wall and the atrial appendage are not seen in this view because they overlie the atrial chamber. The annulus of the tricuspid valve is located inferiorly and to the left, somewhat overlying the entrance of the inferior vena cava (fig. 1A). At the beginning of diastole a rapid flow through the annulus is easily seen (fig. 1B). An exact similarity is seen in the anatomic picture (fig. 2).

Elongated right anterior oblique view. The right atrium is shown as a globe-shaped structure. The superior and inferior vena cavae are in continuity with the posterior border seen on the right. The inferior contour is formed by the space between the in-
ferior vena cava and the tricuspid annulus. The tricuspid valve is seen in profile. The right atrial appendage is seen superiorly and to the left (fig. 3). The anatomic counterpart is shown in figure 4.

Four-chamber view. The right atrium in the four-chamber view has a globular appearance, very similar to that in the long-axis projection. The main differences are that the left border is formed by the more posterior aspects of the atrial septum, while the right border is formed by the more anterolateral aspects of the atrium, which overlap the atrial appendage. The superior and inferior venae cavae are seen over the middle portions of the superior and inferior borders. The right atrial contours are smooth. The tricuspid valve forms part of the inferior left contour and its shadow is partially overlain by the atrial border.

Left Atrium

Long-axis view. The left atrium is seen as an oval structure with the right contour formed by the anterior portion of the atrial septum. The superior border, slanting to the left, is formed by the atrial roof in its contact with left main stem bronchus and the pulmonary arteries. The entrance of the right pulmonary veins is seen in the right upper corner. The left vein entrance is not seen. The posterior contour represents the posterior and left portion of the free wall of the atrium. The anterior and posterior right walls are not seen on this view because they overlie the body of the atrium, as does the atrial appendage. The mitral valve forms the inferior contour (fig. 5). The anatomic counterpart is seen in figure 6.

Elongated right anterior oblique view. The left atrium is seen as a quadrangular structure. The upper contour is formed by the roof in its continuation to the entrance of the right pulmonary veins. The anterior lateral border is on the left, showing the left atrial appendage as a prominent structure. The posterior lateral border is formed by the joining of the posterior wall and the septum. The mitral valve forms the inferior and anterior contours (fig. 7).

Four-chamber view. The same oval appearance
described for the long-axis view is seen, except for visualization of the posterior portion of the atrial septum in the vicinity of the inferior vena caval entrance.

Identification of Atrial Appendages. The atrial appendages are clearly visible in the elongated right anterior oblique view. The right atrial appendage is a triangular structure with a broad base and dome-shaped apex (fig. 8). The left atrial appendage is a curved, finger-shaped structure with a short base and a sharp, pointed apex (fig. 9).

Right Ventricle

Long-axis view (fig. 10). The right ventricle is seen as a triangular structure with the base superior and to the right, the apex inferior and to the left and the free border inferior and to the right. The anterior portion of the septum in diastole forms an upper contour on the left. The posterior part of the septum is seen as a sharper line pointing to the apex. The right ventricular outflow tract is seen as a wide channel formed by the crista supraventricularis on the right side and by part of the trabecula septomarginalis on the left. The pulmonary valve is located on top of the infundibulum.

The tricuspid valve is seen in diastole as a negative shadow overlying the right upper contour of the right ventricle. The medial commissure is seen in the left superior angle of the tricuspid shadow. The medial or septal leaflet is almost parallel to the septum. The anterior or mural leaflet is superior and to the right. The posterior or inferior leaflet cannot be identified angiographically. The anterior papillary muscle may be seen as a filling defect in the middle of the ventric-
visualized. The anatomic counterpart is shown in figure 11. The anterior half of the ventricle, including the pulmonary outflow tract, has been resected. Only the posterior half of the specimen is shown. The tricuspid valve, posterior septum and anterior papillary muscle are shown in detail.

_Elongated right anterior oblique view._ The right ventricle is seen as a triangular structure with the base posterior to the right and the apex inferior and to the left. The tricuspid valve is seen profiling the posterior border. The outflow tract of the right ventricle is seen anterior and superior as a channel formed by the crista supraventricularis posteriorly and the free wall of the ventricle anteriorly. The pulmonary valve is separated from the tricuspid by the whole length of the crista. The inferior border represents the posteroinferior wall of the ventricle. The superior border is the free anterior wall of the ventricle with its prominent characteristic trabeculation (fig. 12). The anatomic counterpart is shown in figure 13.

_Four-chamber view._ In the four-chamber view, the morphology of the right ventricle is similar to that in the long axial view; however, there are differences that allow us to visualize another right ventricular structure. The septal leaflet of the tricuspid valve now forms part of the septal aspect of the right ventricle parallel to the posterior septum, indicating that the septum is profiling its more posterior and inferior por-

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**Figure 7.** (A) Selective left atriogram in the elongated right anterior oblique view. (B) Venous phase of pulmonary angiogram. The entrance of the left pulmonary vein is obscured by the body of the atrium. The atrial septum in both views is facing the observer. _LA = left atrium; LAA = left atrial appendage; MV = mitral valve; LV = left ventricle; RPV = right pulmonary veins; clear arrows = posterior wall of atrium; arrowheads = roof of atrium._

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**Figure 8.** Right atrial appendage in the elongated right anterior oblique projection. (A) Angiogram. (B) Anatomy. _RA = right atrium._

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**Figure 9.** Left atrial appendage (LAA) in the elongated right anterior oblique projection. (A) Angiogram. (B) Anatomic specimen. _LA = left atrium._
tions. The outflow tract of the right ventricle is obscured by the ventricular shoulder.

The annulus of the tricuspid valve is also well identified, but more medially than in the long-axis view. The mural leaflet is seen laterally, forming a semicircle surrounding the septal leaflet (fig. 14). The anatomic counterpart is shown in figure 15, where
again only the posterior half of the specimen is represented.

**Left Ventricle**

*Long-axis view.* In the long-axis view (fig. 16), the left ventricle appears as a triangular structure with the base superior and the apex inferior. The right contour of the left ventricle is formed inferiorly by the trabecular septum and only in a short superior segment by the infundibular septum. The posterolateral free wall is seen between the mitral shadow and the apex to the left. The clearly defined outflow tract is bounded by the infundibular septum anteriorly and by the septal mitral leaflet posteriorly. The aortic valve is located on top of the left ventricular outflow tract. The semilunar aortic valve shows its left cusp posteriorly and the noncoronary cusp overlies the right coronary cusp anteriorly.

The mitral valve is seen as a negative shadow during diastole, with its anterior commissure located superiorly and immediately beneath the level of the left coronary cusp. The posterior commissure is seen inferior and medially. The anterior mitral leaflet is

**Figure 15.** Posterior half of the right ventricle as seen in the four-chamber projection. $s$ and $m =$ septal and mural leaflets of the tricuspid valve; $RA =$ right atrium; $RV =$ right ventricle; $S =$ septum.

**Figure 14.** Right ventriculogram in the four-chamber view. (A) Systolic phase. (B) Diastolic phase. $TV =$ tricuspid valve; $m =$ medial commissure; $p =$ posterior commissure; $a =$ anterior commissure; $RV =$ right ventricle; $PA =$ pulmonary artery.

**Figure 16.** Left ventriculogram in the long-axis view. (A) Systolic phase. (B) Diastolic phase. $LV =$ left ventricle; $AO =$ aorta; $s =$ septal mitral valve; $m =$ mural mitral valve; $l =$ left coronary cusp; $r =$ right coronary cusp; $nc =$ noncoronary cusp; white arrows = infundibular septum; arrowheads = trabecular septum; black arrows = mitral commissures.
clearly visualized between the anterior and posterior commissure, displaced closer to the septum. During systole, the anterior leaflet moves posteriorly and superiorly to join the posterior leaflet and open the outflow tract. The annulus of the mitral valve is seen as an oval shape that overlies the inferior contour of the left atrium. The papillary muscles are seen as a negative shadow overlying the middle portion of the left ventricle, the anterior being higher than the posterior. The anatomic counterpart is seen in figure 17. Notice the full length of the septum with the obvious trabecular and infundibular components. The specimen is fixed in a position similar to early diastole.

**Elongated right anterior oblique view.** The elongated right anterior oblique view (fig. 18) is different from the standard right anterior oblique view in that the outflow tract is shown in a more elongated fashion. The left ventricle has a triangular shape, with the base superior and posterior and the apex anterior and to the right. The posterior-superior contour of the left ventricle, to the right, shows a smooth, straight line that extends from the noncoronary aortic cusp to the crux cordis and does not change during the cardiac cycle. This line represents contrast material accumulated under the septal leaflet of the mitral valve in its insertion into the muscular atrioventricular septum. In some hearts, this contour is overpassed by the posterior mitral leaflet in its most inferior portion. From this point downward, the contour of the left ventricle is formed by its inferior free wall. To the left, the short upper segment of the anterior-superior contour of the left ventricle, related to the aortic right and left cusps, is formed by the infundibular septum and by the free wall of the left ventricle. The outflow tract of the left ventricle is therefore bounded by the infundibular septum anteriorly and the atrioventricular septum posteriorly. The aortic valve in this view is located on top of the outflow tract. The noncoronary cusp is posterior and the right and left coronary cusps overlie each other anteriorly.

The mitral valve is seen face-on in the elongated right anterior oblique view. The anterior septal leaflet is usually not visualized. The posterior mural leaflet forms a semicircle around the inlet, overlying the outlet portion of the ventricle. During diastole, the shape of the mitral valve is seen immediately below the aortic valve; during systole this shadow disappears.

The anatomic representation of the elongated right anterior oblique view (fig. 19) is remarkably similar to the angiographic image, even though a great part of the mitral valve has been resected from the specimen. The definition of the outflow tract with its infundibular and atrioventricular boundaries is also easy to appreciate.

**Four-chamber view.** The left ventricle in the four-chamber view (fig. 20) appears as an elongated hemisphere with a medial, relatively straight component and a lateral, rounded component crowned by the aorta. The apex is directed inferiorly and to the right. On the right border of the left ventricle, there are two well-defined consecutive contours. The superior contour extends from the aortic valve to the middle wall portion, marked by the posterior leaflet of the mitral
valve in its proximity to the ventricular septum (crux). This contour is formed by the atrioventricular component of the muscular septum, which separates the right atrium from the left ventricle. From this point downward, there is a well-defined contour that represents the most posterior portion of the interventricular septum. The left contour of the heart is formed by the posterolateral segment of the free wall, which extends from the apex to the aortic left coronary cusp.

The aortic valve in the four-chamber view is represented by two definite shadows, the posterior one being the left coronary cusp and the anterior one the overlying right and noncoronary cusps. The mitral orifice is seen face on in the four-chamber view. The anterior leaflet is horizontally placed toward the observer and is therefore not visualized; however, its implantation is related to the left coronary cusp. The commissures are well demonstrated because the implantation of the mural leaflet is seen throughout its length.

The papillary muscles may be seen on the ventricular cavity as two negative shadows located anteriorly and posteriorly in the ventricular chamber and oriented toward the commissures.

The anatomic counterpart of these images is shown in figures 21 and 22. Figure 21 shows the whole struc-

Figure 20. Left ventriculogram in the four-chamber view. (A) Diastolic phase. (B) Systolic phase. LV = left ventricle; AO = aorta; l = left coronary cusp; r = right coronary cusp; nc = noncoronary cusp; arrows = commissures; arrowheads = atrioventricular septum.

Figure 21. Left ventricle as seen in the four-chamber view. The two white arrows show the position of the atrioventricular septum. RA = right atrium; LA = left atrium; RV = right ventricle; LV = left ventricle; T = tricuspid valve; s = septal mitral leaflet; m = mural mitral leaflet; nc = noncoronary cusp.
tture with the mitral valve intact, the two commissures are easily seen; the fibrous implantation of the anterior leaflet is continuous with the left and non-coronary cusps and will not produce a radiologic interface. The short posterior segment of its implantation in the septum delimits the atrioventricular septum as seen radiographically. When the anterior leaflet is removed, the implantation of the posterior leaflet is easily seen, corresponding to the radiologic picture.

In all these ventricular projections, the characteristic coarse (right) or smooth (left) trabeculations of the main ventricular chambers are visualized as well as with standard radiographic techniques.

Discussion

A detailed knowledge of the normal angiographic appearance of the heart is necessary to recognize possible abnormalities. Previous angiographic studies have made this knowledge readily available for all four heart chambers using standard frontal and lateral views.1

In this report, we describe the important anatomic characteristic of the cardiac chambers as seen by axial angiography. We believe that the information here presented is timely, because axial angiography is rapidly becoming the angiographic method of choice for studying congenital heart disease.

In this study, we focused on the correct angiographic identification of each of the four chambers and their anatomic components, independent of their position, relations or connections. Only by being familiar with these normal images can many of the malformations be properly categorized, such as “wrong” connections, shunts, or malpositions.

Many of the important complex congenital heart malformations, as studied by axial angiography, deserve separate detailed analyses. Some have already been reported,2,3 and other reports are being prepared.

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