Axial Cineangiography in Congenital Heart Disease

Section I. Concept, Technical and Anatomic Considerations

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SUMMARY Cineangiographic axial techniques were designed to overcome the limitations of conventional angiography in the diagnosis of congenital heart disease. Two basic patient (or equipment) maneuvers are involved: 1) long axis of the heart is aligned perpendicular to the X-ray beam, and 2) rotation of patient results in the heart being radiographically sectioned at 30° angles. To accomplish this with fixed vertical and horizontal X-ray tubes, three positions were developed: 1) "hepato-clavicular," "4 chamber," 2) "long axial oblique," 3) "anterior-posterior axial." A fourth, the "sitting-up" projection is discussed. The hepato-clavicular position profiles the posterior ventricular septum and atrial septum, separates the A-V valves, places the four cardiac chambers en face, and clarifies mitral valve-semilunar valve and outflow tract relationships. The long axial oblique profiles the anterior ventricular septum, left ventricular outflow tract, aortic valve-anterior mitral valve leaflet. The sitting-up view visualizes the bifurcation of the pulmonary trunk and separates true pulmonary arteries from systemic collaterals.

IMPROVEMENTS IN CARDOVASCULAR SURGICAL TECHNIQUES in the past several years have made it possible to repair many congenital heart lesions which had been considered inoperable because of the complexity of the defect or the age and size of the patient. This improvement in surgical capability has made necessary unprecedented accuracy in the preoperative and angiographic demonstration of the cardiac anatomy.

In an effort to achieve consistent accuracy, we have developed an approach to the anatomical diagnosis of congenital heart disease which we call axial cineangiography. It is the purpose of this paper to present our concept of axial cineangiography, describe the techniques we use to obtain the necessary radiographic projection, and illustrate the normal and abnormal anatomy as seen using these projections. Section II of this paper, which begins on page 1084, will deal with specific lesions.

Axial Cineangiography

Concept

Although the technical aspects of axial cineangiography seem complex when first considered, the principles are simple and are readily understood if the heart is considered to be an inverted cone with the atria as the base and the ventricles forming the apex (fig. 1).

The various anatomic positions described in the text are nothing more than practical methods of properly aligning the long axis of this cone with the long axis of the X-ray table (fig. 1B) and of rotating the cone to attain the desired radiographic section. These particular maneuvers are made necessary by our equipment configuration: two fixed X-ray tubes at 90° angles. With different X-ray systems such as the C or Z arm, the method of aligning and rotating the heart will differ. However, with proper appreciation of the principles involved and a knowledge of the cardiac anatomy, the same radiographic results can be obtained even more easily.

The most important consideration in axial angiography after the axial alignment of the heart is that of sectioning the heart radiographically at 30° angles, much as a pie is sliced into twelve pieces.

Such sectioning is useful because the left ventricle, in cross section, roughly forms a sphere, and the ventricular septum is an arc of the circumference of this sphere, and, in the usual heart, subtends an angle of about 120° (fig. 2A).

The right portion of the septal arc (fig. 2A Y-Z) forms the posterior ventricular septum and is best visualized by an X-ray beam tangent to this section. Since this posterior septum separates the two A-V valves, and since the atrial septum is in roughly the same plane as the posterior ventricular septum, this beam not only shows well the posterior septum and the defects located in this region, but also clearly demonstrates the relationship of the A-V valves to one another and to the septum (fig. 2B, dotted line B). The atria are also well separated from the ventricles and from one another by this view. The four chambers consequently are seen rather like the leaves of a four leaf clover (thus the term four chamber view). This very useful projection is obtained by elevating the patient's thorax at a 45° angle to the table and then elevating the left shoulder 45° and using the vertical X-ray tube (fig. 3).

The left portion of this arc (fig. 2A, X-Y) forms the anterior ventricular septum and is similarly best visualized radiographically when the diagnostic X-ray beam is tangent to it. When fixed biplane equipment is available this is readily accomplished by positioning the patient obliquely 30° on the table, and raising the right shoulder 15–30°, and using the lateral X-ray tube as the primary diagnostic unit (long axial oblique position, fig. 9).

If biplane equipment is not available, the projection giving the silhouette seen with line C, usually filmed with the lateral tube, can still be obtained. Using the AP tube the pa-
tient is placed on the table with the left shoulder rotated to 75–80° and the thorax is elevated from the table 15–20°.

When the hepato-claviclar and axial oblique positions are used in addition to the AP position, and all are filmed in the biplane mode, the heart is sectioned at approximately 30° angles (fig. 2B).

We often utilize a fourth patient position in which the patient is sitting up at 45°. Although not an integral part of axial angiography, it is often necessary for viewing extra cardiac structures, especially the pulmonary trunk up to and beyond its bifurcation.

It should be realized that such complete sectioning is seldom needed for adequate diagnosis, nor is a specific combination of views always indicated for a specific lesion. The selection of position and mode (single or biplane) must be made at the discretion of the physician as he proceeds through the examination.

Hepato-Claviclar (4 Chamber) Technique

Method of Positioning

We believe this to be the most useful projection (fig. 3). The patient's thorax is elevated to a sitting position of approximately 45°, the left shoulder is rotated up and to the left approximately 45°, and the body is slanted to the right in the horizontal plane 10–15°. The positioning itself is achieved by various sized and angled foam plastic wedges (fig. 3).

Since in this position the X-ray beam of the vertical X-ray tube transverses the liver upon entering the body and the
clavicle upon leaving it (fig. 3), the term hepatoclavicular view seemed descriptive. Initially this projection was filmed only in a single plane mode but recently the biplane technique has been found to add considerably to the information obtained.

When first analyzing the films obtained with axial angiography, one must adapt to the somewhat altered radiographic anatomy. Therefore, we will first discuss the normal anatomy as seen in each of the various projections.

Hepato-Clavicular Position Filmed with the Vertical Tube

Left Ventricle and Ventricular Septum. Raising the body 45° places the X-ray beam of the vertical image intensifier perpendicular to the long axis of the heart. The 45° upward portion of the left shoulder roughly aligns the atrial septum and the posterior portion of the ventricular septum parallel to the X-ray beam (fig. 2B). Therefore, in the initial phases of the ventriculogram the posterior portion of the septum is first visualized (figs. 4 and 5). This portion is not usually well seen in conventional left ventriculography. In the initial phases of the left ventriculogram, contrast media fills the sinus and the attachment of the posterior leaflet of the mitral valve is seen en face (fig. 5A). An anatomic landmark usually well seen is the junction between the attachment of the anterior and posterior mitral valve leaflets, and the junction of the left ventricular free wall and the posterior ventricular septum (figs. 4 and 5). During ventricular systole, the free wall area shows a slight localized bulge which is characteristic of the projection. Distinctive ventricular septal defects (defects of the persistent A-V canal type) occur in this area and can be localized best in this projection (fig. 4 and 5, Section II).

Following this initial phase of opacification of the sinus portion of the left ventricle, the left ventricular outflow tract opacifies. Ventricular septal defects in this area are well visualized, but are seen in more detail in the long axial oblique view to be discussed.

Atrial Septum. This is an excellent view for analysis of the entire atrial septum. The septum is best visualized by injecting through the tip of the catheter into the proximal portion of the right upper pulmonary vein (fig. 6). Defects occurring anywhere along the septum are then visualized, since contrast material streams along the septum in order to reach the mitral valve (fig. 6). Injections into the body of the left atrium or its appendage are less satisfactory since the streaming effect is lost and the septal wall is not as well outlined.

Additional Left Sided Structures and Relationships. A number of other structures are usually nicely seen in this projection with appropriate injections.

The anterior leaflet of the mitral valve can be seen to be either normal or cleft. The latter often occurs in the partial form of persistent common A-V canal and will be discussed in detail in Section II.
The distinction between mitral valve incompetence and left ventricular-right atrial shunting can usually be made, and is especially helpful in the diagnosis of the A-V canal spectrum of the lesion.

Mitral valve-semilunar valve relationships are well seen in conditions with double outlet right ventricle and/or bilateral coni.

Abnormal attachments of the mitral valve to the left ventricular outflow tract can be appreciated, especially in complete transposition of the great arteries.

Pulmonary valve, pulmonary trunk, and the origin of the left pulmonary artery from the pulmonary trunk in transposition complexes are outlined with the same injection.

Aortic valve cusps are usually well outlined.

The major bifurcation of the left coronary artery into the anterior descending and proximal circumflex is vividly demonstrated, as are the septal arteries coursing to the right and the diagonal ones to the left.

The transverse aortic arch and ductus region are opened up so that a patent ductus arteriosus can be distinguished easily from an upper lobe pulmonary artery crossing the ductal region, a phenomenon that may cause confusion following conventional left ventriculography in patients with a large ventricular septal defect.

Right Ventricle and Pulmonary Trunk. From the right ventricular side, the ventricular septum is seen in profile (fig. 7). The tricuspid valve and inflow portion of the right ventricle are seen to the right of the septum and are not superimposed over the left ventricle (fig. 7A). When the right-to-left shunting is present, this results in excellent visualization of the ventricular septum and any lesion along its length from the apex to the base.

Figure 5. A) Left ventriculogram in diastole. The large arrow shows the crucial junction of the posterior mitral valve and the anterior mitral valve commissure with the posterior and free wall of the ventricular septum. The small arrows depict the posterior mitral valve attachment. The left ventricular outflow tract is opacified, and is seen between the mitral valve (MV) and the aortic valve. R = right cusp and L = left cusp. The left atrium (LA) is opacified because of catheter-induced mitral valve incompetence. Note how the left atrium is completely separated from the right atrium. This is a great help in diagnosing mitral valve incompetence and left ventricular-right atrial shunting. B) Left ventriculogram in systole. The mitral valve — posterior ventricular and free wall septal junction (arrow) is usually characterized by a localized bulge during systole. The entire length of the muscular septum is also well seen. The arrowheads show the relationship of the atrial septum to the ventricular septum.

Figure 6. Analysis of the atrial septum. The patient is in the hepato-clavicular view and the catheter tip in the right upper pulmonary vein (RUPV). The atrial septum is in profile. The right atrium (RA) opacifies via an ostium primum defect in the most inferior aspect of the atrial septum. LA = left atrium.
Figure 7. Normal right ventricle (RV) in the hepato-clavicular view as viewed with the vertical X-ray tube — image intensifier. A) Ventricular diastole. This view gives a clear visualization of the entire tricuspid valve ring (arrows), the pulmonary valve, pulmonary trunk (P) and bifurcation and course of the left pulmonary artery (LPA). B) Ventricular systole. This view also shows accurately the location and size of the ventricular septal defect in conditions with systemic pressures in the right ventricle, especially in the transposition and double outlet right ventricle complexes.

Figure 8. Right ventricular cineangiogram with hepato-clavicular view in a tetralogy of Fallot. A and B show the right ventricle as viewed by the horizontal image intensifier; the vertical view is not shown. A) Ventricular systole. The tricuspid valve is in profile and the sinus and inflow portions are well seen. The infundibular stenosis (I) created by the anteriorly deviated conus is vividly demonstrated. B) Ventricular diastole. The pulmonary valve, anulus, trunk (P) and origin and full length of the right pulmonary artery (RPA) are well seen.
The pulmonary valve and its anulus, the pulmonary trunk and the origin of the left pulmonary artery are well demonstrated in this view (fig. 7). This information is especially valuable in tetralogy of Fallot.

Hepato-Clavicular Position with Horizontal X-ray Tube

This is the view at 90° from that obtained with the vertical tube and the patient in this same position (Fig. 2b). It is not always needed but often gives much additional information. The slanting of the body 10–15° away from the horizontal image intensifier places the long axis of the heart perpendicular to the X-ray beam. The 45° sitting position and the 45° rotation of the shoulder to the left allows the horizontal image intensifier to view the heart in an elongated and tilted right anterior oblique view.

Left Ventricle. Left ventriculography yields a tilted right anterior oblique view with excellent visualization of the mitral valve, posterior papillary muscle, left ventricular outflow tract and the number of cusps of the aortic valve. This is also a good projection for visualizing the supracristal ventricular septal defect.

Right Ventricle and Pulmonary Trunk. The horizontal tube produces an excellent view of the ostium of the right ventricular infundibulum, the musculature comprising the infundibulum itself, as well as the sinus and inflow portions of the right ventricle (fig. 8). This is important since in patients with a large ventricular septal defect, the musculature comprising the posterior wall of the right ventricular infundibulum is poorly visualized with the vertical image intensifier (fig. 10A, Section II). We believe this may be an excellent view for Ebstein's malformation of the tricuspid valve and the anomalous muscle bundles of the right ventricle, but have not yet documented this impression.

The pulmonary valve anulus and pulmonary trunk are well seen (fig. 8) and the origin of the right pulmonary artery and its entire length is in profile (fig. 8B). This is especially important, since the origin of the right pulmonary artery may be obscured when elevating the bifurcation of the pulmonary trunk with the vertical X-ray tube-image intensifier combination.

The anastomosis of the ascending aorta to the right pulmonary artery (Waterston shunt) is often seen in profile in this view.

Long Axial Oblique Views

Method of Positioning

The technique of positioning is as follows (fig. 9). The entire torso or long axis of the patient's body is slanted 20–30° away from the horizontal image intensifier or, in this instance, with the feet to the right side of the table, and then the patient's right shoulder is elevated 15–20° (fig. 9).
Angi cardiographic Aspects as Filmed with the Horizontal Tube

Of the two planes of viewing, the horizontal is usually the most useful. Slanting the body on the table places the long axis of the heart perpendicular to the X-ray beam. The second maneuver, rotation of the right shoulder, places the anterior portion of the ventricular septum and the left ventricular outflow tract in profile (figs. 2, B-C, and 10).

When the long axial oblique technique with the horizontal tube is compared with the heptavo-clavicular technique using the vertical X-ray tube, a 20–30° steeper left anterior oblique view of the ventricular septum is obtained with the former (compare fig. 4 with fig. 10). This results in the anterior ventricular septum being in profile rather than the posterior ventricular septum as in the heptavo-clavicular view.

Figure 10 shows an artist's rendition of an actual necropsy specimen as seen angi cardiographically in this view. Note how the left ventricular outflow tract and the subaortic valve region are emphasized. The free edge of the anterior leaflet of the mitral valve is also seen in profile.

Figure 11 shows a left ventriculogram in the long axial oblique view (horizontal tube). It is strikingly similar to the drawing (fig. 10). In diastole (fig. 11A), the anterior leaflet of the mitral valve is seen in profile. The left ventriculogram vividly depicts the anterior portion of the ventricular septum in the area of the left ventricular outflow tract and the muscular septum below this. The relationship of the mitral valve to the left ventricular outflow tract itself can also be nicely appreciated. This is a particularly informative view in patients with asymmetrical septal hypertrophy, as well as in patients with prolapse of the anterior leaflet of the mitral valve.

Angi cardiographic Aspects of the Long Axial Oblique View Filmed with the Vertical Tube

With the vertical X-ray tube, these maneuvers have placed the left and right ventricles in a right anterior oblique view, and offer little advantage over most conventional single plane right anterior oblique views. There are, however, certain anatomic features worth emphasizing.

Left Ventricle and Thoracic Aorta. The atroventricular part of the cardiac septum (fig. 12) is well shown in this projection. Since this structure is usually absent in persistent A-V canal, this projection is of particular importance in the diagnosis of this lesion. This view, when correlated with the findings derived from the horizontal tube, depicts well the variations in mitral valve movement and often the site of mitral valve incompetence.

Mitral Valve-Left Atrial Relationship. This view, when correlated with the findings of the horizontal tube, yields considerable information regarding which leaflets are involved in the various forms of mitral valve disease, especially in the prolapsing mitral valve.

Right ventriculography using the long axial oblique technique in tetralogy of Fallot gives about the same information as the right ventricular injection in the AP projection. This is an excellent view for the trabecula septal marginis region of the right ventricle.

Anterior-Posterior Axial Technique

This is a biplane mode of filming in which the patient's shoulders are elevated approximately 10–15°. It closely approximates the position used in the conventional AP and lateral technique.

We use this patient positioning for an initial injection

Figure 11. Normal left ventricular cineangiogram utilizing the biplane long axial technique as viewed with the horizontal X-ray tube-image intensifier. A) ventricular diastole. This left ventriculogram can be considered a virtual cast of the left ventricle shown in figure 10. B) Ventricular systole. Both phases (A and B) depict vividly the anterior portion of the ventricular septum, the left ventricular outflow tract, and the entire muscular septum below. Arrows show the anterior leaflet of the mitral valve. The left coronary artery (LCA) and its bifurcation are well laid out.
Figure 12. Normal left ventricular (LV) cineangiogram utilizing the biplane long axial technique as viewed with the vertical X-ray tube image intensifier. A) Ventricular diastole. B) Ventricular systole. The black arrows show the region of the atrioventricular septum and the white arrows the mitral valve commissure. This view is especially useful in the supracristal form of VSD, A-V canal entities, ASH, etc.

Figure 13. Schematic representation of the straight sitting-up view (45°–60°) as shown in relation to the vertical image intensifier. (The under-table X-ray tube is not shown.)

Figure 14. Cine right ventriculogram, sitting-up view, in a patient with tetralogy of Fallot. This particular view gives superb visualization of the bifurcation of the pulmonary trunk, pulmonary trunk (P) itself and the pulmonary valve and its anulus. This occurs because this maneuver places the pulmonary trunk perpendicular to the X-ray beam. RV = right ventricle.
when the chamber position is unknown or when the case is complex and the diagnosis uncertain.

**Sitting-Up View**

In 1970, Kattan described a technique of caudal angulation of the X-ray tube at the time of pulmonary arteriography to visualize better the pulmonary trunk and its bifurcation. The same results can be obtained if the patient is elevated 45–60° in a straight sitting up position (fig. 13). As the head is brought back there is a tendency for the chest to rise upward and flatten, thereby decreasing the angle in relation to the table. If this occurs, it should be corrected.

This view is optimal for visualization of the bifurcation of the right and left pulmonary arteries, the pulmonary valve, anulus and pulmonary trunk (fig. 14). The sitting maneuver places the pulmonary trunk and its bifurcation almost perpendicular to the X-ray beam. With conventional angiographic techniques, the pulmonary trunk is foreshortened and is superimposed over the bifurcation of the pulmonary trunk. This view or a modification of it is always utilized in the angiography of the patients with tetralogy of Fallot, pulmonary atresia with a common arterial trunk and other conotruncal abnormalities. In lesions with a common arterial trunk, this view is especially important since it allows accurate detection and separation of systemic or bronchial arteries from true pulmonary arteries.

The sitting maneuver projects the true pulmonary arteries inferior to the labyrinth of systemic bronchial arteries and serves as a “poor man’s” subtraction technique.

**Radiation Dose**

In most of the angled radiographic projections used in axial angiography the heart shadow is at least in part superimposed on that of rather dense tissue, usually the liver. Optimal radiographic technique under such circumstances requires a significant increase in both MAS and KV and consequently in the radiation dose received by the patient. In our opinion, this increase in patient dose is well justified by the very great increase in diagnostic information made possible by the change.

In a well disciplined laboratory the increase in radiation should not be reflected fully in the radiation dose received by the laboratory personnel. The catheter is manipulated with the patient in the usual AP position and the angled views are employed only during the cine runs. During this period laboratory personnel should be protected by screening devices and distance. Continuous dose monitoring of our personnel during the three years these techniques have been employed attest to their relative safety and acceptability.

**References**

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