Angiography

Lee Benson and Haverj Mikailian

Introduction

Accurate anatomic and physiologic diagnosis is the foundation of a successful catheter based therapeutic procedure. As such, a number of complementary imaging modalities have been developed to define, in real time, specific aspects of the heart and circulation for interventional applications. In the evolution of our understanding of the cardiovascular system, angiography with fluoroscopy was the first to be developed, and the angiography suite remains the cornerstone around which the interventional suite is built.

This chapter will include a discussion of standard angiographic approaches and how to achieve them. Emphasis will be placed on the application of these projections as applied to interventional procedures. A detailed description of the physical principles of image formation is beyond the scope of this chapter and the interested reader is referred to other sources for more detailed information.1

Angiographic projections

In the therapeutic management of the child with a congenital heart lesion, the spatial orientation and detailed morphology of the heart and great vessels are of critical importance. As the operator enters the laboratory, an overall understanding of the anatomy should have been synthesized, based upon information from other imaging modalities such as chest roentgenography, echocardiography, and computed tomographic and magnetic resonance imaging. As such, the angiographic projections used in the procedure will be tailored to outline the lesion to allow appropriate measurements and guide the intervention.2

In most children, the heart is oriented obliquely, with the left ventricular apex being leftward, anterior and inferior, then the heart base (Figure 2.1). The interventricular septum is a complex geometric three-dimensional structure that takes an ‘S’ curve from apex to base (Figure 2.2), the so-called sigmoid septum. From caudal to cranial the interventricular septum curves through an arc of 100° to 120°. The right ventricle appears as an appliqué to the left. To address this unique topology, today’s angiographic equipment allows a wide range of projections, incorporating caudocranial or cranio-caudal angulations to outline or profile specific structures. The up-to-date laboratory of today consists of independent biplane imaging chains which, with the proper selection of views, minimizes overlapping and foreshortening of structures.

Terminology

Angiographic projections are designated either according to the position of the recording detector (image intensifier or flat panel detector) or the direction of the X-ray beam toward the recording device. Generally speaking, in cardiology, the convention is the former, and all terminology discussed henceforth will be using that convention. For example, when the detector is directly above a supine patient, the X-ray beam travels from posterior to anterior and the angiographic projection is designated postero-anterior (PA), but based upon detector position it is called frontal, and the position of the detector is by convention at 0°. Similarly, when the detector is moved through 90°, to a position besides and to the left of the patient, a lateral (LAT) projection results. Between 0° and 90° there are a multitude of projections termed left anterior oblique (LAO), and when the detector is moved to the right of the patient, a right anterior oblique projection (RAO) is achieved. As in the LAO projection, there are numerous RAO projections depending on the final angle from the midline. When the detector is posterior to the patient (the X-ray tube is anterior), then a right (RPO) or left (LPO) posterior oblique projection occurs (Figure 2.3).

Standard detectors mounted on a C-arm or parallelogram not only allow the above positions, but the detectors can be rotated around the transverse axis, toward the feet or head, caudal or cranial (Figure 2.4).

In summary, the conventional terms RAO, LAO, PA, and left-LAT designate the position of the recording detector. The LAT position usually will have the detector to the left of the patient by convention, and will be so implied throughout this chapter. Finally, for clarification, while the
Figure 2.1
The typical lie of the heart in the chest. (a) Frontal and (b) lateral projections of a left ventriculogram demonstrate the axis of the heart. The apex points anteriorly, inferiorly, and leftward. Panel (c) is a diagram of how a standard mid-RAO and a standard mid-LAO profile images of the axes of the heart. The RAO profiles the atrioventricular groove, and presents the ventricular septum en face. The mid-LAO view profiles the intraventricular septum, and separates the left and right ventricular and atrial chambers. (Modified from Culham1 with permission.)

Figure 2.2
The sigmoid septum. A venous catheter is in the apex of the left ventricle through the mitral valve, in the long axis oblique projection. The sigmoid configuration of the septum is well seen (white arrows). Aortic–mitral continuity is noted (black arrow). Contrast is seen mixing across a ventricular defect (asterisk). (Modified from Culham1 with permission.)

Figure 2.3
Naming the standard projections with the X-ray tube under the table. This diagram illustrates the various positions of the detector/X-ray tube. The patient is supine, and the view is from the patient’s feet, looking toward the head. (Modified from Culham1 with permission.)
term projection refers to the path of the X-ray beam, to be consistent with cardiologic practice, projection or view will refer to the position of the detector.

Biplane angiography

As outlined in an earlier chapter discussing the ideal catheterization suite, dedicated interventional catheterization laboratories addressing congenital heart defects require biplane facilities. Biplane angiography has the advantage of limiting contrast exposure and of facilitating the assessment of cardiac structures in real time in two projections simultaneously. However, this is at a cost, as these facilities are expensive, and with existing image intensifiers and newer flat panel detectors, extreme simultaneous angulations can be compromised. The choice of a set of projections will depend upon the information required, equipment capabilities, and the physical constraints to patient access. Standard biplane configurations include RAO/LAO, and frontal or lateral projections, with additional cranial or caudal tilt. The possible combinations are endless (Table 2.1 and Figure 2.5).

Cranial-LAO projections

A clear working understanding of these projections is of critical importance in developing a flexible approach to congenital heart defect angiography, and intervention. The practice of using 'cookbook' projections for each case may

Table 2.1 Summary of projections

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<td>Cranially tilted frontal (Sitting up view)</td>
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<td>Cranially tilted shallow LAO</td>
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<td><strong>Biplane combinations</strong></td>
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<td>A plane</td>
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<td>LPA long axis (single plane)</td>
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<td>ASD</td>
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<td>PA bifurcation and branches</td>
<td>30° caudal + 10° RAO</td>
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<td>20° caudal</td>
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Primary projections are in italics. RAO, right anterior oblique; LAO, left anterior oblique; AP, antero-posterior; LAT, lateral; RVOT, right ventricular outflow tract; MPA, main pulmonary artery; LXO, long axis oblique; LPA, left pulmonary artery; ASD, atria septal defect; PA, pulmonary artery.
allow acceptable diagnostic studies, but will fall short of the
detail required to accomplish an interventional procedure.
However, a comprehensive understanding of normal car-
diac anatomy, especially the interventricular septum, allows
the operator to adjust the projection to optimize profiling
the region of interest.

There are a number of ‘rules of thumb’ that allow the
operator to judge the steepness or shallowness of an LAO
projection. Of importance is the relationship of the cardiac
silhouette to the spine, the ventricular catheter, and the ven-
tricular apex.

To optimize the profile of the mid-point of the
membranous ventricular septum (and thus the majority
of perimembranous defects), two-thirds of the cardiac
silhouette should be to the right of the vertebral bodies
(Figures 2.6 and 2.7). This will result in a cranially tilted left
ventriculogram showing the left ventricular septal wall, the
apex (denoted by the ventricular catheter) pointing toward
the bottom of the image. A shallower projection will have
more of the cardiac silhouette over towards the left of the
spine and profile more the infero-basal component of the
septum, ideal for inlet type ventricular defects. This projec-
tion allows for evaluation of atrioventricular valve relation-
ships, inlet extension of perimembranous defects, and
posterior muscular defects. A steeper LAO projection can be
used to profile the outlet extension of a perimembranous

Figure 2.5
Standard projections. (a) Frontal (PA), (b) Lateral (LAT), (c) RAO, and (d) mid-LAO with cranial tilt. (e) Cranially tilted frontal (sitting up);
(f) caudally tilted frontal. (Modified from Culham1 with permission.)
defect, and anterior muscular and apical defects. As noted in Figure 2.6, the ventricular catheter in the cardiac apex can be used to help guide the projection, but only if it enters the chamber through the mitral valve. If catheter entry is through the ventricular defect or retrograde, it tends to be more basal and left lateral.

Modification of the cranial LAO projection will have to be made if there is a discrepancy in chamber sizes, and the septum rotated, such that a steeper or shallower projection may be required. Also, it is assumed that the patient is laying flat on the examining table, but if the head is turned to the right, or a pad is under the buttocks, it will rotate the thorax such that the LAO projection is steeper and the detector caudal. This has to be compensated for during the set up for the angiogram. The clue in the former case is that more of the heart silhouette is over the spine.

The first step in setting up a cranial-LAO projection is to achieve the correct degree of steepness or shallowness. After that, the degree of cranial tilt has to be confirmed, so that the basal–apical septum is elongated. This can be estimated by seeing how much of the hemidiaphragm is superimposed over the cardiac silhouette – the more superimposition, the greater the cranial tilt. Additionally, the degree of cranial tilt can be determined by looking at the course of the ventricular catheter, it appearing to be foreshortened or coming directly at the viewer as the degree of cranial angulation is decreased (Figure 2.8).

**Specific lesions**

**Ventricular septal defect (Figure 2.9)**

The imaging of specific ventricular defects is beyond the scope of this review, but is commented upon in detail by various authors. The injections to outline the septum and the lost margins which circumscribe the defect(s) are best performed in the left ventricle using a power injector. Two orthogonal (right angle) projections will give the best chance of profiling the lesion. However, pre-catheterization, the location of the defect should be well characterized by other imaging modalities, such that the projections chosen would give the optimal profile, with little modification. Table 2.1 lists single and biplane angulations for the various projections.

For the perimembranous defect the mid-cranial LAO projection, at about 50° to 60° LAO, and as much cranial tilt as the equipment and patient position will allow (Figure 2.10) should be attempted. Additional projections can include a shallow-LAO with cranial tilt (so-called four-chamber or hepatoclavicular view) to outline the basal septum or inlet extension of a perimembranous defect. The RAO view will outline the high anterior and infundibular (outlet) defects.

**Coarctation of the aorta (Figure 2.11)**

Biplane angiography should be used to outline the arch lesion. Projections that can be used include LAO/RAO,
PA and LAT, or a shallow- or steep-LAO. Our preference is a 30° LAO and left-LAT, with 10° to 15° caudal tilt to minimize any overlapping structures, such as a ductal bump or diverticulum. Modifications to accommodate a right arch are generally mirror image projections (i.e., 30° RAO and left-LAT). The operator must be cautious to examine the transverse arch for associated hypoplasia, and this may be foreshortened in the straight left-LAT projection. In such an instance, for a left arch, a left posterior oblique projection may elongate the arch. This is particularly important if an endovascular stent is to be implanted near the head and neck vessels.

**Aortic valve angiography (Figure 2.12)**

Assessment of the diameter of the aortic valve in the setting of normally related great arteries with ventricular arterial concordance for balloon dilation is best performed using biplane in the long axis and RAO projections (Table 2.1).
Our preference is to obtain the diameter of the aortic valve from a ventriculogram, which profiles the hinge points of the leaflets. Caution must be observed when using an ascending aortogram, as one of the leaflets of the valve may obscure the margins of attachment.

**The Mustard baffle (Figure 2.13)**

Children who have had a Mustard operation may, over time, develop obstruction to one or both limbs of the venous baffle. As atrial arrhythmias are not uncommon in this population, particularly as adults, pacing systems are frequently required for management. In this regard, enlargement of a stenotic, although at times asymptomatic, superior baffle is frequently required. The optimum projection to outline superior baffle obstruction, for potential stent implantation, is a cranial angulated LAO projection (30° LAO and 30° cranial). This view will elongate the baffle pathway allowing accurate measurement prior to stenting. For inferior baffle lesions, a frontal projection will allow adequate localization of the lesion. Leaks along the baffle are more problematic, and require modification of the projection. The initial approach should be a PA projection, with modifications in angulation made thereafter to best profile the lesion for device implantation, not too dissimilar to that of Fontan fenestration closure.

**The secundum atrial septal defect and the fenestrated Fontan (Figures 2.14 and 2.15)**

Secundum atrial septal defects are best profiled in the 30° LAO with 30° cranial tilt. With the injection made in the right upper pulmonary vein, the sinus venous portion of the septum can be visualized, and anomalous pulmonary venous return ruled out. Additionally, any associated septal aneurysm can be outlined. With the application of transesophageal or intracardiac echocardiography, there is less fluoroscopic reliance on device positioning. When
balloon sizing is performed, this projection will elongate the axis of the balloon, for proper measurements.

The interventional management of the child with a fenestrated Fontan, whether a lateral tunnel or extracardiac connection, generally requires selective studies of the superior and inferior caval vein and pulmonary circulations, to determine the presence or absence of obstructive or hypoplastic pathways, and whether venous collaterals have developed. As such, they must be addressed by angioplasty, stenting, or embolization techniques before consideration of fenestration closure. Venous collaterals after an extracardiac Fontan will generally develop either from the innominate vein or from the right upper hepatic/phrenic vein, toward the neo-left atrium, less frequently from the right hepatic veins to the pulmonary veins. The optimum way to outline these lesions is in the AP and LAT projections, with selective power injections in the appropriate vessel. The location and dimensions of the fenestration may also be defined in these views, but for ideal profiling some degree of right or left anterior obliquity may be required.

The bidirectional cavopulmonary connection (Figure 2.16)

Second stage palliation for a number of congenital defects consists of a bidirectional cavopulmonary connection (aka, the bidirectional Glenn anastomosis). Because the caval to pulmonary artery connection is toward the anterior surface of the right pulmonary artery (rather than on the upper surface), an AP projection will result in overlapping of the anastomotic site with the pulmonary artery. Therefore, to determine whether the anastomosis is obstructed, a 30° caudal with 10° LAO projection will generally open that region for better definition. Furthermore, this projection will outline the full extent of the right and left pulmonary arteries. The left-LAT projection with or without 10° caudal angulation will profile the anastomosis for its anterior–posterior dimension. Contrast injection must be made in the lower portion of the superior caval vein. Examination of venous collaterals can be performed from the AP and LAT projections in the innominate vein.

Pulmonary valve stenosis, Fallot’s tetralogy, and pulmonary valve atresia with intact ventricular septum (Figures 2.17 and 2.18)

Percutaneous intervention on isolated pulmonary valve stenosis was the procedure which assured in the present era of catheter based therapies. While angiographic definition of the right ventricular outflow tract and valve is not
Panel (a), left pane, shows an ascending aortogram taken with a shallow-LAO projection without caudal angulation. The catheter was placed through a transeptal entry to the left heart. While the area of the coarctation can be seen, it is the caudal angulation which identifies the details of the lesion, including a small ductal ampulla, right pane. In panel (b), similar information is obtained, by employing caudal angulation to the frontal detector, right pane, while in the shallow-LAO projection in contrast to that information obtained without caudal angulation, left pane. In panel (c), left pane, hypoplasia of the transverse arch can be identified. However, in contrast, in the right pane, the degree of foreshortening is obvious. Panel (d), right pane, shows the standard LAO projection of an ascending aortogram. In this case there is overlap of the area of obstruction, transverse arch hypoplasia, and stenosis of the left subclavian artery, not defined until cranial angulation is employed, right pane.

Figure 2.12
Intervention on the aortic valve requires accurate definition of the hinge points of the leaflets. In panel (a), long axis oblique views from an ascending aortogram do not define the margins of the leaflets due to overlap of the cusps (bicuspid in these examples). In panel (b), long axis oblique (left) and RAO views, the left ventriculogram allows easier identification of the leaflet hinge points, where measurements can be made.
Baffle obstruction after a Mustard operation is, as the population ages, an increasingly common event. This is particularly so, with the need to manage such patients with transvenous pacing devices. In panel (a), left pane, the presence of a superior baffle obstruction can be identified from the left-LAT projection. However, only with cranial angulation (cranial-LAO view, right pane) will the full extent of the lesion be detailed. This is particularly critical, as shown in panel (b), where the frontal view, left pane, does not show the full extent of the obstruction, and only from the angulated view will the length and diameter of the lesion be outlined (middle pane). A stent is placed, followed by a transvenous pacing system, shown in the right pane from a frontal projection. For an inferior baffle lesion, the frontal (PA) projection is optimal, panel (c), before (left) and after (right) a stent is placed.
complicated, several features must be kept in mind when approaching the angiography for an interventional procedure. In the case of isolated pulmonary valve stenosis, and other right ventricular outflow tract lesions, because the outflow tract can take a horizontal curve, a simple AP projection will foreshorten the structure. Therefore, a 30° cranial with 15° LAO will open up the infundibulum, and allow visualization of the valve and the main and branch pulmonary arteries. The best definition of the hinge points of the valve, to choose the correct balloon size, is from the left-LAT projection. Occasionally, 10° or 15° caudal angulation of the LAT detector can be used to separate the overlap of the branch vessels seen on a straight left-LAT projection. However, this is not recommended, as it will also foreshorten the outflow tract and the valve will appear off plane, giving incorrect valve diameters.

**Branch pulmonary artery stenosis (Figures 2.19–2.21)**

Pulmonary artery interventions are most common, and represent the most difficult angiographic projections to separate out individual vessels for assessment and potential intervention. A cranially tilted frontal projection with a left-LAT or RAO/RAO projections is frequently the first
Figure 2.15
Panel (a) shows the appearance of a fenestrated extracardiac Fontan in the frontal projection, and its appearance after device closure. Generally, a frontal projection profiles the defect adequately, but at times some angulation is required, as seen in panel (b), where the defect is best profiled in a shallow-RAO view. Also note coils in the left superior caval vein which developed after the Fontan procedure and required embolization. Occasionally, collateral vessels develop from the hepatic/phrenic vein (panel c, left) or innominate vein (panel c, right), where coils have been placed. The primary view being frontal (PA) and left-LAT.
Figure 2.16
Because of an offset in the anastomosis between the superior caval vein and right pulmonary artery, the optimal view to see the anastomosis without overlap is a shallow with caudal tilt, as seen in panel (a). Panel (b), left pane, is in the frontal projection, where overlap of the anastomosis obscures a potential lesion, as seen in the angulated view, right pane. The combination of an angulated frontal detector and caudal angulation of the lateral tube will allow definition of the anastomosis (left pane) and the pulmonary artery confluence (right pane), panel (c).

Figure 2.17
Panel (a) depicts a case of typical isolated pulmonary valve stenosis in a neonate. The outflow tract is profiled in the cranially angulated frontal projection, with a slight degree of LAO angulation (left pane). The right ventriculogram outlines the form of the ventricle, the main pulmonary artery (and ductal bump) as well as the pulmonary artery confluence, and branch dimensions. The LAT view (right pane) outlines the valve leaflets (thickened and doming) and allows accurate delineation of the valve structures for balloon diameter determination. In panel (b), two right ventriculograms in the cranially angulated slight LAO view depict the size of the annulus and main and branch pulmonary arteries (typical valve stenosis with left pulmonary hypoplasia, left pane; dysplastic valve stenosis, small non-dilated main pulmonary artery and proximal left branch pulmonary artery stenosis with post-stenotic dilation, right pane).
Angiographic projections for intervention in pulmonary atresia with intact septum are similar to that of isolated pulmonary valve stenosis. In panels (a) and (b), cranial angulation is critical to image the valve plate (left panes), while a left-LAT will suffice for imaging the anterior–posterior aspects of the outflow tract. In valve perforation, it is critical to have visual control in 2 orthogonal planes, to avoid inadvertent infundibular perforation. A series of images during valve perforation is seen in panel (c). The left upper pane shows the catheter position; right upper pane, perforation and wire in the right pulmonary artery; left lower pane, the wire guide across the duct for stability; and in the right lower pane, balloon dilation of the valve. In the accompanying panel, viewed from the left-LAT projection, is a series of images taken during perforation: top pane, position confirmation; middle pane, radiofrequency perforation; lower pane, angiography in the main pulmonary artery.

Figure 2.18
Angiography for selective intervention on the branch pulmonary arteries can be most difficult due to overlapping of structures. No single projection is totally representative and frequently multiple views are required. In panel (a), left pane, a scout film is taken in the main pulmonary artery, and in the right pane, the right ventricle. Both images are taken in the cranial-LAO projection and, in these examples, clearly outline the outflow tracts and branch confluences. In panel (b) the dilated main pulmonary artery would have obscured the branch pulmonary artery confluence, and this cranial-LAO (left upper pane) and caudal left-LAT (right upper pane) nicely details the anatomy for subsequent intervention (lower panes). In panel (c), ventriculography obscures the details of the crossed pulmonary vessels (left pane), while selective injection in the cranial (middle pane) and RAO (right pane) projections details the anatomy.

Figure 2.19
In panel (a), the image is taken from a left-LAT projection with caudal tilt. This will separate the proximal right and left pulmonary artery branches, and detail the main pulmonary artery. The outflow tract is foreshortened, and this view will mislead the operator when examining the diameter of the valve, and infundibulum. If such detail is required, a straight left-LAT should be performed. In the caudal-LAT projection, the left pulmonary branch will sweep superiorly and towards the upper right corner of the image, while the left pulmonary artery will appear more medial and in the center of the image.

In panel (b) the child had severe bilateral branch stenosis (left pane), which persisted after surgical repair and valve insertion. Using the left-LAT view, stents could be placed in each branch (middle pane). In panel (c), severe main pulmonary artery dilation has obscured the confluence and very hypoplastic pulmonary arteries (left pane) in this child shortly after surgery. In this case, steep caudal angulation of the frontal tube with 10° or 15° LAO has detailed the lesion for the intervention (right pane).
series of views that can be performed, as scout studies to map the proximal and hilar regions of the pulmonary circulation. The injection may be performed in either the ventricle or main pulmonary artery. Since there is frequent overlap as seen in viewing the right ventricular outflow tract (see above), these standard views can be modified by increasing or decreasing the degree of RAO or LAO, and adding caudal or cranial tilt. Selective branch artery injections are best for detailed visualization, to plan the intervention. For the right pulmonary artery, a shallow-RAO projection with 10° or 15° cranial tilt will separate the upper and middle lobe branches, while a left-LAT with 15° caudal tilt will open up all the anterior vessels. Similarly, to maximize the elongated and posterior leftward directed left pulmonary artery, a 60° LAO with 20° cranial is very effective, with a caudal tilt on the lateral detector. Occasionally, in small babies after surgical reconstruction of the branch pulmonary arteries, the main pulmonary artery is aneurysmal and obscures the confluence. In this case, a steep 30° caudal projection with the frontal detector with 10° to 20° RAO will open up the bifurcation.

Summary
This short introduction to interventional angiography will allow the reader a point of departure to visualize the most common lesions. However, many cases occur that do not fall into a standard categorization and the operator must be prepared to alter the imaging projection to optimally define the lesion. Successful outcomes require patience, perseverance, and the learned experience of others.

References