Angled Views in Cineangiocardiography of Congenital Heart Disease

KENNETH E. FELLOWS, M.D., JOHN F. KEANE, M.D., AND MICHAEL D. FREED, M.D.

SUMMARY Simple and compound sagittally angled views of the heart obtained cineangiocardiographically with a parallelographic U-arm device were evaluated clinically in 132 patients with congenital heart disease. The principle advantage of the apparatus was the ease with which axial and oblique projections were obtained without repositioning of the patient, although rotation and angulation of the image intensifier-X-ray tube unit resulted in some increase in scattered radiation. Certain angled views, particularly the 40° cranial and the compound 25° cranial/70° left oblique projections, were better than standard frontal and lateral views for visualization of pulmonary arteries in the mediastinum, in ventricular septal defects and anomalies of the left ventricular outflow tract.

FOR MANY YEARS ANGIOCARDIOGRAPHIC DIAGNOSIS in patients with congenital heart disease has been primarily dependent upon frontal (vertical) and lateral (horizontal) projections. Oblique views have been recognized as helpful, but their use has been limited by the inconvenience and delay caused by repositioning of an infant or child on the catheterization table. The same reluctance to turn or move sedated children, combined with the inflexibility of many biplane angiographic installations, has led to minimal use of cranially and caudally angled views (except for the work of Bargerot). For the past two years we have evaluated a cine angiographic unit with parallelographic motion which allows both sagittally angled and compound angled-oblique projections without moving the patient from the recumbant position. Experimental and clinical use led to the development of angled views which are diagnostically superior to standard frontal and lateral projections in many cases. The views which have been most useful and the types of congenital heart disease which are best studied using these projections are described in this report.

Materials, Terminology, and Methods

All studies are performed using a single plane, floor mounted, X-ray tube and 6-inch image intensifier system suspended on a rotating U-arm (fig.1) which allows 270° circumferential movement as well as sagittal angulation through a potential arc of 80°, 40° cranially and 40° caudally. Specially coupled, parallel supporting arms facilitate compound angulation (simultaneous cranial-caudal and oblique projection) (fig. 2). Because the intensifier tube remains orthogonal to the incident beam in all movements (figs. 1 and 2), distortion of the image is minimal. With the patient's heart isocentrically located between the X-ray source and image intensifier tube, no movement of the patient and little adjustment of the angiographic table is necessary to accomplish these views. In all studies, the patient remains supine; there is no elevation or rotation of the shoulders, trunk and pelvis.

Terminology

Varying degrees of obliquity are obtained by circumferential rotation of the U-arm device about the patient. Beginning with the image intensifier directly above the patient (0°), rotation toward the patient's left (0 to 90°) produces the left oblique projection (fig. 2) while rotation (0 to 90°) to the patient's right gives the right oblique projection.

Tilting or angling the image intensifier from the vertical position (0° above the patient) in the sagittal plane toward the patient's head causes the X-ray beam to be directed cranially toward the intensifier phosphor (fig. 1); this is termed cranial angulation and is mechanically possible to an extreme of 40°. The opposite movement, which results from moving the image intensifier sagittally toward the feet so that the X-ray tube is aimed caudally, is termed caudal angulation and is mechanically possible over the same 40° range. Thus, the combined maximum cranial-caudal angulation is an arc of 80°. Compound views result from simultaneous sagittal (cranial-caudal) angulation and oblique rotation of the apparatus (fig. 2).

Heart Specimens

Experimentally, normal specimens were used to help in the determination of the best angles and projections for viewing parts of the heart. The cardiac structure to be studied was marked with barium paste, tantalum powder or metal pins. The heart was placed on the radiographic table in the normal anatomic position (as determined fluoroscopically) so that filming in varying degrees of angulation and rotation could be carried out. In this way, a range of usable projections was determined for the interatrial septum, interventricular septum, left ventricular outflow tract, both atrioventricular valves and both semilunar valves. These results were used to establish appropriate angulation for clinical cineangiocardiography.
14 years old; only ten infants were studied. Patients were selected for angled angiocardiology because more information was required than was available from previous routine studies, or because routine views were thought unlikely to demonstrate the defect in question. These special views were often supplemental to other studies and, in general, were reserved for those patients in whom there was potential benefit from improved or additional anatomic information.

Findings

A summary of the simple and compound angles which were found most useful angiocardiographically are listed in table 1. These angles, determined from experimental studies with heart specimens and from clinical usage, are average values; variations of 5 to 10° can be expected in any individual patient. Specifically, the following observations were made about the evaluation of congenital heart defects with these angled views.

Tetralogy of Fallot, Peripheral Pulmonary Stenosis and Pulmonary Atresia

Steep (30-40°) cranial angulation improves visualization of the length and bifurcation of the main pulmonary artery as well as the proximal segments of the right and left pulmonary arteries. This projection is particularly helpful in demonstrating bifurcation stenosis and pulmonary artery size in tetralogy of Fallot (fig. 3), and is also the best view for evaluation of reconstituted pulmonary arteries in pulmonary atresia with a ventricular septal defect (pseudotruncus) (fig. 4). When the main pulmonary segment is large, additional obliquity (10-15° to the ipsilateral side) may be necessary to see the origin of either the right or left pulmonary artery. Because opacification is denser, injections in the main pulmonary artery provide better anatomic delineation than right ventricular injections.

Table 1. Useful Angled* Views in Congenital Heart Disease

<table>
<thead>
<tr>
<th>Angle</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>40° cranial</td>
<td>Peripheral pulmonary stenosis (origins of right and left pulmonary arteries)</td>
</tr>
<tr>
<td></td>
<td>Pulmonary arteries in tetralogy of Fallot</td>
</tr>
<tr>
<td></td>
<td>Pulmonary artery band (postoperative)</td>
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<tr>
<td></td>
<td>Reconstituted pulmonary arteries in pulmonary atresia (with ventricular septal defect)</td>
</tr>
<tr>
<td></td>
<td>Supravalvar pulmonic stenosis</td>
</tr>
<tr>
<td>Compound 40° cranial/30° left oblique</td>
<td>Left ventricular-right atrial shunt</td>
</tr>
<tr>
<td>Compound 40° cranial/30° right oblique</td>
<td>Fontan shunt (right atrium to pulmonary artery conduit)</td>
</tr>
<tr>
<td>Compound 25° cranial/70° left oblique</td>
<td>Atrial septal defect</td>
</tr>
<tr>
<td></td>
<td>Overriding tricuspid valve</td>
</tr>
<tr>
<td></td>
<td>Pulmonary and subpulmonary stenosis in d-transposition</td>
</tr>
<tr>
<td></td>
<td>Subvalvar aortic stenosis</td>
</tr>
<tr>
<td></td>
<td>Ventricular septal defects (membranous and muscular)</td>
</tr>
<tr>
<td></td>
<td>Ventricular septal defect and coronary artery distribution in tetralogy of Fallot</td>
</tr>
<tr>
<td>Compound 15° caudal/80° left oblique</td>
<td>Mustard interatrial baffle (postoperative d-transposition)</td>
</tr>
</tbody>
</table>

*Angles listed are the average; individual cases vary ± 10°.
†10-15° additional obliquity to the ipsilateral side is needed in many patients.

Requires right pulmonary vein injection and 25° cranial/80° oblique projection.
VENTRICULAR SEPTAL DEFECTS

A left oblique projection of 65–75° facilitates tangential viewing of the interventricular septum; by compounding this obliquity with 25° of cranial angulation, foreshortening of the septum is reduced, allowing better separation and differentiation of membranous and muscular defects. Straddling of the ventricular septum by the tricuspid valve, which usually is associated with a ventricular septal defect of the endocardial cushion type, is better evaluated with this compound view also (fig. 5).

LEFT VENTRICULAR OUTFLOW OBSTRUCTION

The addition of 25° cranial angulation to the 65–75° left oblique projection markedly improves demonstration of the left ventricular outflow tract. In patients with subaortic obstruction, this projection enhances visualization of any fibrous or fibromuscular tissue which is present (fig. 6), and shows best the attachments of this tissue to the interventricular septum and mitral valve. Improved demonstration of asymmetric septal hypertrophy is also possible with this compound projection.

The outflow area of the left ventricle in d-transposition is also better visualized by a compound 25° caudal and 65–75° left oblique projection (fig. 7). The ventricular septal surface and mitral valve anulus are viewed in profile, allowing most forms of subvalvar pulmonic stenosis in transposition to be seen and pulmonary stenosis to be occasionally excluded where it appeared to be present in other projections.

SECONDUM ASD

The size and level of congenital defects of the interatrial septum and the presence or absence of partial anomalous pulmonary venous return to the right atrium can often be determined by an injection in a right pulmonary vein and filming in compound 20° cranial and 80° left oblique projection. In this view, the intartrial septum is seen tangentially from above, allowing differentiation of sinus venosus, secundum, and primum defects by their position in the septum. A right pulmonary vein injection enhances visualization of these anomalies because of the preferential flow from these veins through the defects.
Left Ventricular-Right Atrial Shunt

The angiocardiographic diagnosis of this shunt is improved by combining 40° cranial angulation and 30° left obliquity, so that the heart is viewed from above, separating the four cardiac chambers and allowing demonstration of the shunt from the left ventricle to the right atrium without superimposition of the left atrium or right ventricle (fig. 8).

Postoperative Angiocardiography

Pacemakers implanted in the soft tissues of the thorax may be projected over the heart in routine views; either cranial or caudal angulation can be used to project the pacemaker apparatus away from the heart. Compound angled views also offer excellent demonstration of the Fontan conduit (fig. 9) and the Mustard baffle (table 1).
Discussion

The approach to the angiocardiographic evaluation of patients with congenital heart disease is likely to be modified in the future as the advantages of angled views and compound projections become known and as pediatric cardiologists and radiologists become familiar with the new equipment (or the techniques of patient positioning) necessary to produce these views. It is already apparent from our experience that combining cranial angulation with the left oblique projection is superior to standard lateral and oblique projections for visualization of the left ventricular outflow tract and the interventricular septum. This compound view need not be merely supplemental but may replace the lateral projection for left ventricular injections in patients with subvalvular aortic stenosis, d-transposition with pulmonary stenosis, and ventricular septal defect. Many of the other angled views are complementary to standard frontal, lateral, and oblique projections because they offer specific information about a small part of the heart or one great vessel only. For instance, improved demonstration of supravalvar and peripheral pulmonary stenosis in tetralogy can be gained by 40° cranial angulation, although other views are necessary for ventricular anatomy. The additional cranial view is important because bifurcation stenosis is often unseen on routine views and may even be overlooked at the time of surgery. Cranial angulation for demonstration of the pulmonary anatomy in pulmonary atresia with a ventricular septal defect not only shows the size and continuity of the pulmonary vessels in the mediastinum (fig. 4), but it does this with considerable decrease in radiation to both the patient and the catheterization laboratory personnel by eliminating the necessity of biplane filming.

There are other forms of congenital heart disease which may be better studied with angled views, although our experience is too small to show superiority over standard projections. These defects include aortic stenosis (with or without angiography of the aortic anulus and stenotic orifice), endocardial cushion defect, coronary artery distribution in complex congenital heart disease, vascular ring and pulmonary sling.

Some of the angled and compound projections described in this report are reproducible without a special U-arm by moving the patient on the catheterization table and leaving the cineangiographic units fixed in standard frontal and lateral positions. For example, cranial angulation can be accomplished with the standard vertical image intensifier by elevating the patient's head and chest on pillows or sponge padding to a 40-45° ("sitting") angle. The compound cranial-left oblique view can be produced by using the horizontal cine apparatus, elevating the patient's right shoulder, and rotating the patient in frontal plane across the X-ray table (in a clockwise direction) so that his left shoulder is moved away from the usual position of the operator. These movements of the patient on the table are easily accomplished under general anesthesia. However, when the catheterization is done with sedation and local anesthesia, movement of the child usually induces agitation and resistance, making it sometimes difficult to obtain and maintain these views long enough for filming.

When the parallelographic U-arm is used with a specially designed catheterization table, the full range of longitudinal angulation (40° in either the cranial or caudal direction) can be obtained, and any degree of obliquity used, without interference from metal table edge or other obstructions. The use of this table also facilitates biplane filming; by using the U-arm for the horizontal projection, simultaneous vertical views are obtained by an X-ray tube mounted in the floor beneath the table and a second image intensifier brought into position over the patient's chest. With this arrangement, simultaneous frontal and lateral, or frontal and compound oblique views, are possible.

Practically, smaller (6-7 inch) image intensifiers are well suited for use with this special U-arm device. Larger, dual mode intensifiers (of 9, 10, or 11 inches) are not only heavier to move, but may limit angulation and oblique motion by their increased size (i.e., in sagittal movements, the intensifier may touch the patient before full angulation can be obtained, and in oblique views the intensifier may be restricted by the table edge). A limitation of the 6 and 7 inch intensifiers is their field size; in older children and adolescents with congenital heart disease, it is possible to see only a part of the heart at one time. Although this may be of some concern for routine angiocardiography, it represents little limitation to angled viewing because, in these special projections, the focus is on a specific part of the heart.

Some views employing sagittal angulation for cineangiography require more radiation than standard frontal views because the X-ray beam must penetrate an additional thickness of tissue. For large patients, the entrance dose for the 40° cranial view may be 2 to 3 times that of a standard frontal projection. However, there is often no significant
TABLE 2. Sample Scattered Radiation Doses* from Standard Projections and U-arm Angled Views

<table>
<thead>
<tr>
<th>Projection</th>
<th>Factors</th>
<th>Operator exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal (vertical) view</td>
<td>73</td>
<td>63</td>
</tr>
<tr>
<td>40° cranial view</td>
<td>102</td>
<td>70</td>
</tr>
<tr>
<td>Lateral (horizontal) view</td>
<td>110</td>
<td>158</td>
</tr>
<tr>
<td>20°/70° left oblique view</td>
<td>125</td>
<td>163</td>
</tr>
</tbody>
</table>

*Phantom and X-ray factors used simulated angiography in an adult patient, so that exposures are the upper limits of those normally encountered.
†Unshielded (air) readings at one meter from central beam, at patient's right side, table top level.

difference between the amount of X-ray required for standard lateral and compound axial-oblique views because the tissue equivalent thickness is similar for both. Because cine filming in any special view is usually limited to 6–10 seconds, total increases in radiation to the patient are small. The changing position of the U-arm image-intensifier and X-ray tube during angulation can result in more scattered irradiation to medical personnel. However, because routine fluoroscopy is not done in these angled projections, and because cineangiography takes a short time, the doses are quite acceptable for clinical work and within safety limits for medical personnel. A sample of some of the comparative measurements obtained with our own equipment is listed in table 2. These doses can be minimized by observing careful collimation of the X-ray beam, keeping personnel as far from the U-arm apparatus as possible, and wearing wrap-around lead aprons.

Specialized mounting of the described angiographic equipment does result in increased expense. However, the floor mounted parallelogram does replace two ceiling support cranes for an image intensifier and X-ray tube. The resulting added cost is approximately 12% of the expense of a biplane installation.

Conclusion

Cranial angulation improves visualization of the main pulmonary artery and its branches in peripheral and supravalvar pulmonic stenosis, (particularly in tetralogy of Fallot) and the reconstituted pulmonary arteries associated with pulmonary atresia. Compound views employing cranial angulation and oblique projections have been found superior to standard views for demonstrating obstruction of the left ventricular outflow tract in patients with normally related great arteries and d-transposition, atrial and ventricular septal defects, and left ventricular-right atrial shunts. The unusual anatomy of the heart after repair of complex congenital defects can often be better delineated with these angled views also.

Although angled projections can be obtained with standard cine angiographic apparatus and repositioning of the patient on the catheterization table, they are easily accomplished by a special U-arm cine unit which facilitates viewing of cardiac structures from almost any useful degree of angulation and obliquity without disturbing the supine and sedated patient.

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References

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