PEDIATRIC CARDIAC IMAGING

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Radionuclide Evaluation of Circulatory Shunts

PREFACE

The diagnosis of cardiovascular disease has become extremely precise. A major factor in this precision has been the depiction of cardiovascular anatomy in patients using several imaging techniques developed over the past three decades. Cardiac catheterization with angiography was the initial study that provided definitive diagnosis and subsequently fostered the amazing progress in the operative treatment of cardiovascular disease that has ensued over this time period. In the last decade we have experienced more progress in techniques for and change in concepts regarding cardiovascular imaging than in all preceding years combined. No longer does definitive anatomic diagnosis rely solely upon cardiac catheterization and angiography. Progress in cardiac diagnosis during the 1970's and continuing into the current decade has been characterized in a major way by the emergence of noninvasive and semi-invasive imaging techniques. These new techniques not only provide critical anatomic information but also assess global and regional myocardial function, blood flow and perfusion, and even *in vivo* myocardial metabolism.

The time seems appropriate to review the current status of cardiovascular imaging in pediatric cardiology. In general, there has been greater utilization and experience with the new cardiac imaging techniques in adult patients, and, indeed, some were initially developed for the assessment of ischemic myocardial disease. Most, if not all, of the new imaging techniques do have important applications in pediatric cardiology. Techniques such as angulated angiography have become established as critical for the preoperative evaluation of congenital cardiovascular abnormalities. Other modalities, such as computed tomography and magnetic resonance imaging, have infrequently been used for evaluating heart disease in children but may find considerable utility as greater experience accumulates.

In the past decade we have witnessed the introduction or rapid development of the following imaging modalities: sector scan echocardiography, radionuclide imaging, computed cardiac tomography, position emission tomography, and magnetic resonance imaging. Remarkable technical advances have supported these new and imaginative approaches to imaging the anatomy, physiology, and metabolism of the heart. Nonetheless, the complexity of cardiocirculatory disorders in the fetus, infant, and child still strains the capacities of these techniques in attaining precise diagnostic information.

Major aims of this volume were to review the latest experiences and refinements in the more familiar imaging modalities and to examine the capabilities and potential of the nascent imaging techniques for the diagnosis of heart disease in children. The latter aim should provide insight into future application of these new computer-based imaging techniques in pediatric cardiology.

The first portion of this volume gives an update on established methods of imaging the malformed heart. Thus, the sophisticated use of angulated views for cardiac angiography has received considerable attention. Angulated angiography and its applications are discussed in general and also in defining the frequently complex pathologic anatomy of the critically ill infant. Modern approaches to the evaluation of cardiocirculatory performance are detailed by using the non-invasive technique of radionuclide imaging and echocardiography. The use of echocardiography to help define abnormalities of situs and cardiac malpositions is described and serves as an example of how diagnostic accuracy can be improved beyond that achieved by even the traditional approach of cardiac catheterization.

The second portion of the book is intended to introduce and show the potential of several new cardiac imaging techniques. Not much experience is currently available with infants and children as the subjects for these new cardiovascular imaging techniques. The new techniques described in this volume include digital subtraction angiography and computed tomography for anatomic and physiologic imaging and positron emission tomography and magnetic resonance for the imaging of metabolic junctions. These later approaches, in particular, excite the imagination because they offer powerful tools for examining new dimensions of performance of the cardiovascular system. Positron emission tomography and magnetic resonance imaging will considerably expand our insights into the dynamic metabolic events associated with the transitional circulation, the responses of infants, children, and adolescents to diseases, alterations in the physical and chemical milieu associated with complex cyanotic heart disease, and the responses of the pediatric patient to cardioactive drugs.

The complexity of each imaging technique and the broad variety of imaging techniques currently extant make it unlikely that any single institution or person is any longer a pervasive authority on cardiovascular imaging. Consequently, the most practical approach to a volume that is intended to provide a truly updated view of this discipline is to gather a group of experts to review and discuss each of these many imaging modalities.

We express our appreciation to our splendid group of contributors for state-of-the-art presentations on cardiovascular imaging and for their pointing the way to exciting possibilities. We also thank Mrs. Linda Belfus at the Saunders Company for her advice and encouragement in the preparation of this volume

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ANGLED ANGIOGRAPHY

General Approach and Findings

LARRY P. ELLIOTT, M.D., LIONEL M. BARGERON, JR., M.D.,
and CURTIS E. GREEN, M.D.

Advancements in cardiovascular surgical techniques have made feasible the repair of many complex congenital heart lesions that until recently had been considered inoperable. Because of this, it is untenable simply to make a generalized diagnosis of tetralogy of Fallot or ventricular septal defect from routine angiography. It is necessary to establish a "surgical diagnosis," which by definition, is one that demands more accuracy and refinement than that offered by conventional angiography or forward venous digital angiography (Fig. 1*A*). This accuracy and refinement can only be achieved with biplane cineangiographic systems (Fig. 1*B*).

This approach involves precise and consistent techniques in film exposure and development techniques that place the pathologic lesion at a right angle to the x-ray beam. The term that best describes these projection techniques is "axial" cineangiography.[2-6]

PRINCIPLES OF AXIAL CINEANGIOGRAPHY

Two basic patient (or equipment) maneuvers are involved: (1) the long axis of the heart is aligned perpendicular to the x-ray beam and (2) rotation of the 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) hepatoclavicular or four chamber, (2) long axial oblique, and (3) anteroposterior axial. The "sitting-up" projection, a fourth, will be discussed. The hepatoclavicular position profiles the posterior ventricular septum and atrial septum, separates the AV 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, and 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.

TECHNICAL CONSIDERATIONS OF THE FOUR-CHAMBER VIEW

Left Ventricle and Ventricular Septum. In the infant, raising the body 40 to 45° (or angling the tube 35 to 40° cranially in the adult) places the x-ray beam of the vertical image intensifier perpendicular to the long axis of the heart (Fig. 2). The 40 to 45° upward movement of the left shoulder or the combined left anterior oblique movement of the patient and image intensifier (adult) roughly aligns the atrial septum and the posterior part of the ventricular septum perpendicular to the x-ray beam. Therefore, in the initial phases of the ventriculogram, the posterior or inlet portion of the ventricular septum is first visualized. In addition, contrast medium fills the sinus, and the attachment of the posterior leaflet of the mitral valve is seen en face

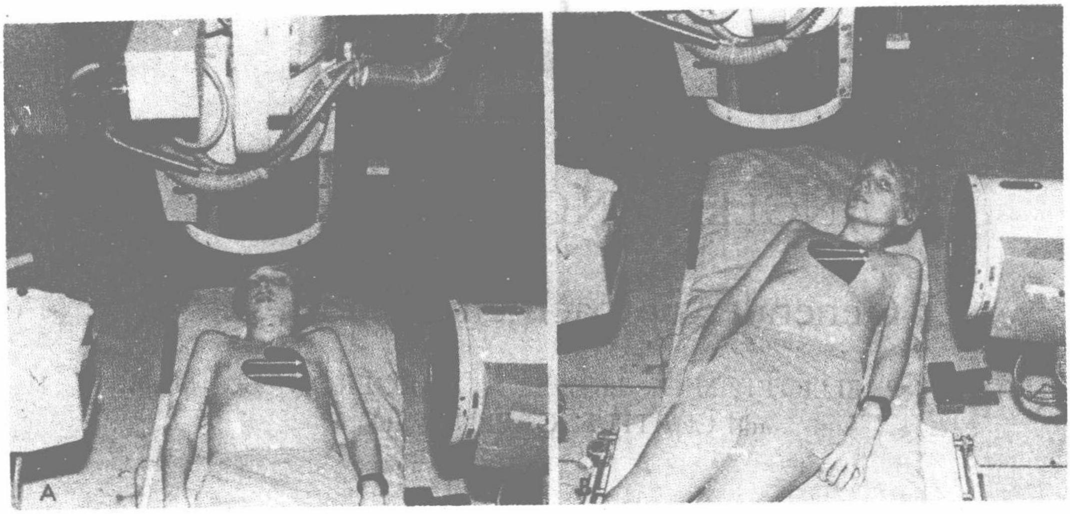

Figure 1. *A*, The relationship of the x-ray beam (white arrows) and the heart to the lateral x-ray tube, as seen with conventional angiography (fixed anteroposterior and lateral tubes). When the beam is not perpendicular to the long axis of the heart, there is always foreshortening of the ventricles, which obscures certain intracardiac structures, especially the left ventricular outflow tract and septum. *B*, The relationship of the lateral x-ray beam and heart to the lateral tube, as seen with axial alignment. One method of obtaining this angle is to slant the patient on the table in order to position the long axis of the heart perpendicular to the x-ray beam.

(Figs. 3 and 4). An anatomic landmark useful in proper positioning 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 (see Figs. 3 and 4). During ventricular systole, the area of the free wall shows a slight localized bulge, characteristic of the projection (Fig. 4*B*). Distinctive ventricular septal defects (defects of the persistent arterioventricular

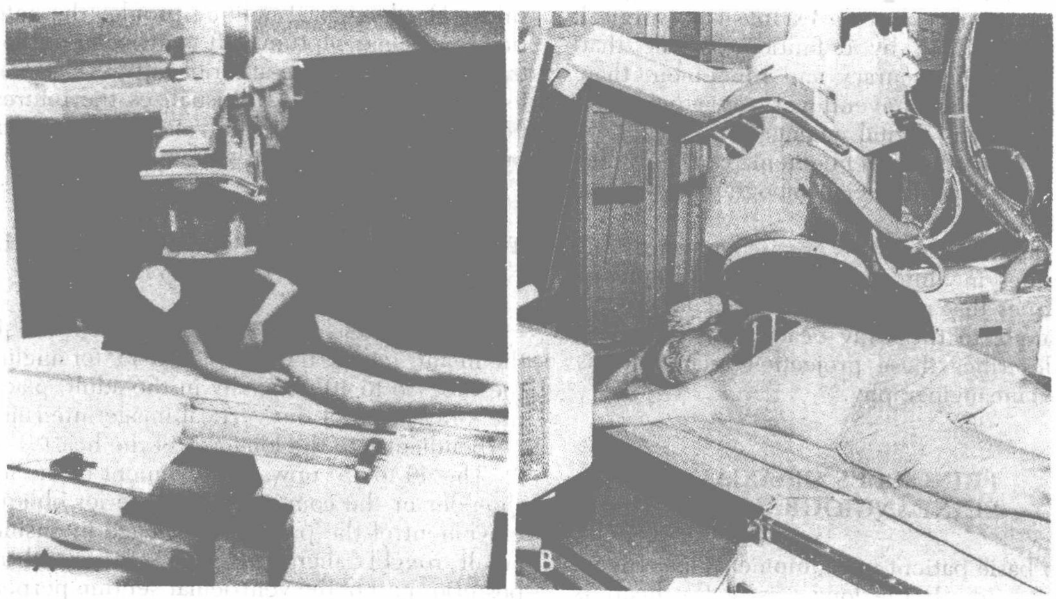

Figure 2. Two methods of obtaining the four-chamber view. *A*, The fixed tube system with the vertical image tube serving as the source of the four-chamber view. The patient sits at a 35 to 45° angle and the left shoulder is elevated 35 to 45°. For axial alignment with the lateral image tube (complementary right anterior oblique view), the patient is slanted 20 to 25° in relation to the table. *B*, The mobile anteroposterior tube (Philips parallelogram). The patient is rotated 20 to 25° in the left anterior oblique position, and the anteroposterior image is moved leftward 20 to 25°, with cranial movement of 30 to 40°.

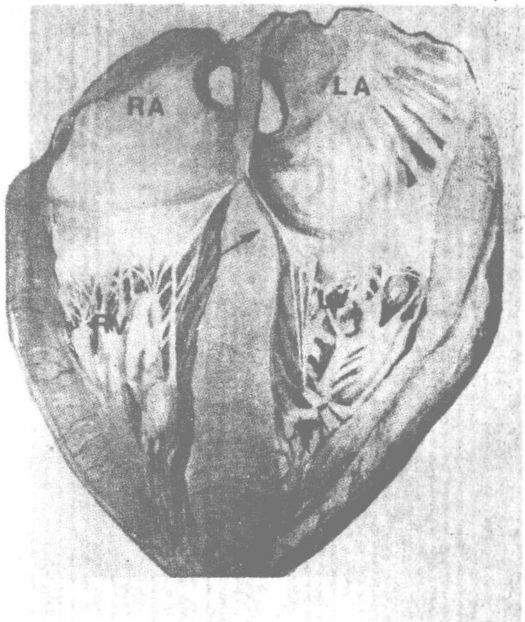

Figure 3. Drawing of an actual heart specimen as it would be seen by the vertical image intensifier in the four-chamber view. This shows the relationship of the two atrioventricular valves, the atrial septum, and the posterior ventricular septum. The arrow points to the junction of the posterior ventricular septum with the free wall of the septum and the junction of the posterior mitral valve commissure. This region is crucial and is seen best in the first few frames of the cine before opacification of the left ventricular outflow tract. RA: right atrium, LA: left atrium, RV: right ventricle, and LV: left ventricle.

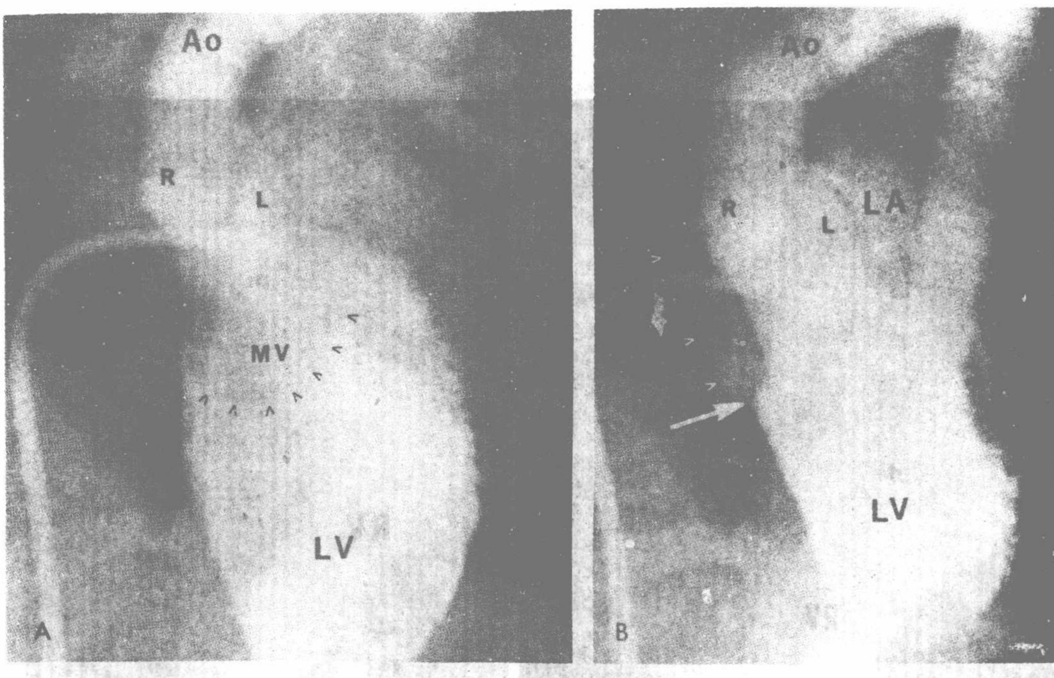

Figure 4. Normal left ventricle (LV) in a four-chamber view. *A,* Diastole. The arrow shows the crucial junction of the posterior mitral valve and the anterior mitral valve commissure with the posterior and free wall of the ventricular septum. The arrowheads depict the posterior mitral valve attachment. The left ventricular outflow tract is opacified and is seen between the mitral valve (MV) and the aortic valve (Ao). The left atrium is opacified because of catheter-induced incompetence of the mitral valve. However, note how the left atrium is completely separated from the right atrium. This is of great help in diagnosing mitral valve incompetence and shunting between the left ventricle and the right atrium. *B,* Systole. The junction of the mitral valve, posterior ventricle, and free wall septum (arrow) is usually characterized by a localized bulge during systole. The entire length of the muscular septum is also well visualized. The arrowheads show the relationship of the atrial septum ot the ventricular septum. LA: left atrium, R: right cusp, and L: left cusp.

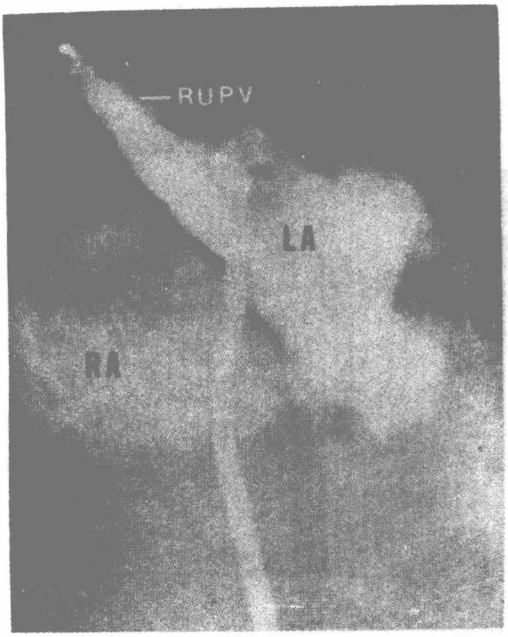

Figure 5. Analysis of the atrial septum. The patient is in the four-chamber view, and the catheter tip is in the right upper pulmonary vein (RUPV). The atrial septum is in profile. The right atrium (RA) opacifies via a defect in the ostium primum in the most inferior aspect of the atrial septum. LA: left atrium.

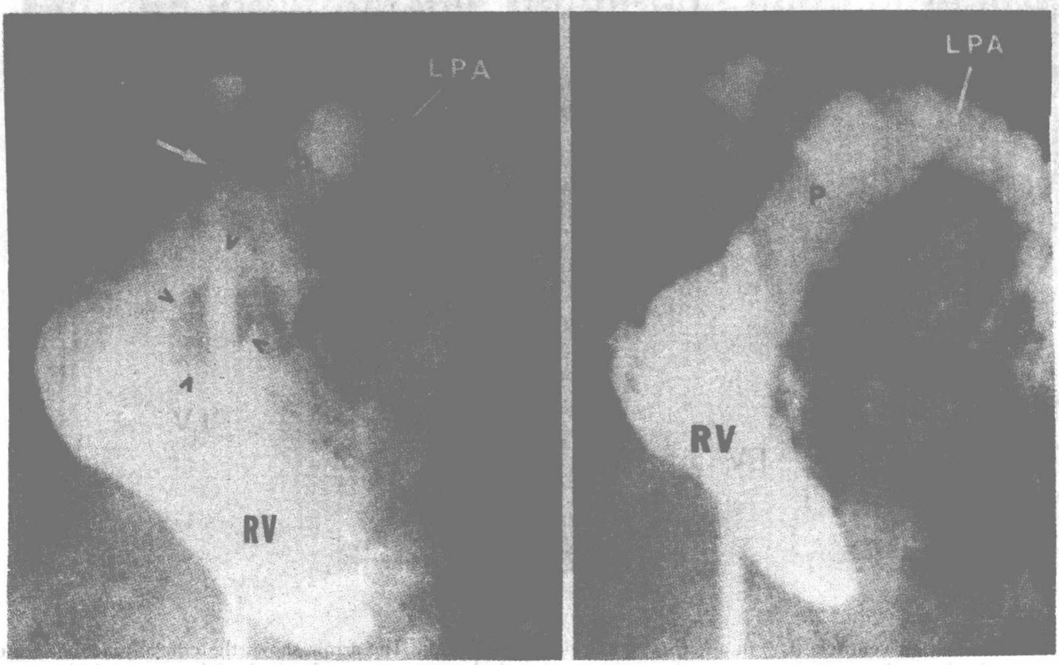

Figure 6. Normal right ventricle (RV) in the four-chamber view. *A*, Ventricular diastole. This view gives a clear visualization of the entire tricuspid valve ring (arrowheads), the pulmonary valve, pulmonary trunk (P), the bifurcation and course of the left pulmonary artery (LPA). *B*, Ventricular systole. This view also depicts accurately the location and size of the ventricular septal defect in conditions involving systemic pressures in the right ventricle, especially in the transposition and double outlet right ventricle complexes.

canal type) occur in this area and can be localized best in this projection.

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. 5). Defects occurring anywhere along the septum are then visualized, since contrast material streams along the septum in order to reach the mitral valve (see Fig. 5).

Additional Left-Sided Structures and Relationships. A number of other structures are usually well visualized in this projection. Mitral valve incompetence and shunting between the left ventricle and the right atrium can usually be distinguished and is especially helpful in the diagnosis of the persistent common atrioventricular canal spectrum of the lesion.

Relationships between the mitral valve and semilunar valve are distinctly visualized in conditions marked by a double-outlet right ventricle or bilateral infundibula.

Abnormal attachments of the mitral valve to the left ventricular outflow tract or subaortic diaphragms can be seen to best advantage in this projection.

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

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

Right Ventricle and Pulmonary Trunk. From the side of the right ventricle, the ventricular septum is seen in profile (Fig. 6). The tricuspid valve ring is well visualized, and this view is extremely valuable in detecting the phenomenon of "straddling" valve. With straddling, the valve ring would be deviated further to the left. The inflow portion of the ventricle is seen to the right of the septum and is not superimposed over the left ventricle (see Fig. 6*A*).

COMPLEMENTARY AXIAL RIGHT ANTERIOR OBLIQUE VIEW WITH FOUR-CHAMBER VIEW

This view is approximately 70 to 80° from that obtained with the vertical tube and the patient in this same position. It is not always needed but often gives much additional information. The slanting of the body 10 to 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° upward rotation of the left shoulder 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 a number of cusps of the aortic valve. This projection is also the best for visualizing the supracristal ventricular septal defect (see Fig. 16*A*).

Right Ventricle and Pulmonary Trunk. The horizontal tube produces an excellent view of the ostium of the right ventricular infundibulum, the musculature comprising the posterior wall of the infundibulum itself (this musculature between the two semilunar valves is usually termed the body of the crista supraventricularis in normal hearts and infundibular septum in abnormal ones), as well as the sinus and inflow portions of the right ventricle (Fig. 7).

LONG AXIAL OBLIQUE VIEW

Method of Positioning. In infants and most children, the technique of positioning involves the following maneuvers (Fig. 8). The entire torso or long axis of the patient's body is slanted 30° away from the horizontal image intensifier, or in some instances the child is positioned with the feet to the right side of the table, and the right shoulder is elevated 15 to 20° (see Fig. 8*A*).

In large children and adults, the patient is rotated into a 30 to 35° left anterior oblique position, and the anteroposterior image intensifier of the parallelogram is rotated 35 to 40° to the left and angled cranially 25 to 30° (see Fig. 8*B*). A third method is shown in Figure 8*C*. So much of the angulation depends on the position of the heart in the thorax. A heart horizontally positioned will require more angulation of the patient or the cranial tube than a heart vertically positioned. This is not a cookbook technique.

Angiocardiographic Aspects of the Long Axial Oblique View. Of the two planes of viewing in the infant and small child, the horizontal tube is usually the most useful. Slanting the body on the table places the long axis of the heart perpendicular to the x-ray beam (see Fig. 8*A*). 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. 9 and 10). The lateral tube is essentially viewing the ventricular sep-