Real-Time Cross-Sectional Echocardiographic Diagnosis of Coarctation of the Aorta

A Prospective Study of Echocardiographic-Angiographic Correlations

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SUMMARY Real-time cross-sectional echocardiographic sector scan examinations were performed from a suprasternal notch location to image aortic arch anatomy in 15 children (ages 1 day to 21 years) who were subsequently shown at cardiac catheterization to have coarctation of the descending thoracic aorta. The resulting echocardiographic images of the ascending, transverse and descending aorta imaged juxta ductal coarctation in all 15 patients. Echocardiography predicted discrete coarctation of the aorta in eight, isthmic hypoplasia in two, hourglass type coarctation deformities in three and longer segment coarctation in four patients. Catheterization and angiography confirmed all of these anatomic observations. The control group, 100 patients with congenital heart disease but without angiographic coarctations, included four patients with right-sided aortic arch and six patients with dextrocardia. The ascending, transverse and descending aorta were adequately imaged in 94 of these and no descending aortic abnormalities were noted. This study shows the potential utility of cross-sectional echocardiography for the noninvasive precatheterization or preoperative assessment of coarctation of the aorta in children and critically ill newborns.

COARCTATION OF THE AORTA in infants and children with or without associated malformations represents a relatively common serious congenital cardiovascular malformation.1-4 The mortality and morbidity of this disease remains high, especially in infancy. Recent interest has been stimulated by mechanistic discussions of fetal physiology which suggest the etiology of various forms of coarctation and also describe the detection of coarctation developing in the perinatal period.5,6 Finally, serial evaluation of postoperative patients remains quite important because of persistent hypertension and the frequent recurrence of significant coarctation in patients who were operated in infancy.7,8

While the clinical diagnosis of coarctation of the aorta is not difficult in infants and children, cardiac catheterization has been necessary to assess the exact anatomy of the coarctation and to detect associated malformations.9 Commonly associated malformations include ventricular septal defect, patent ductus arteriosus, aortic valve stenosis, mitral valve abnormalities, left ventricular myocardial disease and extracardiac aortic arch abnormalities including isthmic hypoplasia and interruption of the aortic arch. Echocardiography has been applied to the evaluation of these associated abnormalities in patients with coarctation, mainly for the detection of bicuspid aortic valve and idiopathic hypertrophic subaortic stenosis.10 It has not been applied to evaluation of the distal aortic arch itself. Because of our recent interest in imaging the distal left ventricular outflow tract and the transverse aorta using single-crystal echocardiography performed from the suprasternal notch,10 we have applied real-time cross-sectional echocardiographic techniques from the suprasternal notch for the evaluation of coarctation of the aorta.11,14

Methods

Patients

Fifteen patients, aged one day to 21 years and weighing 4-78 kg, who had a clinical diagnosis of coarctation of the aorta with or without associated lesions (see table 1) underwent cross-sectional echocardiography as part of their precatheterization examination.

The mean age of the coarctation patients examined before cardiac catheterization was 4.9 ± 0.5 years (SE). Seven of the patients were well under 6 months of age (six patients were less than one month old). Associated lesions in the group included large ventricular septal defects in two patients, bicuspid aortic valve in six patients, subaortic stenosis in three patients (one tunnel subaortic stenosis), and patent ductus arteriosus in three patients. One 9-year-old patient had subaortic stenosis and was postoperative for resection of a coarctation in infancy but had a residual 15 mm Hg pressure gradient across an angiographically proven aortic deformity. Additionally, one patient had mitral prolapse and two had isthmic or aortic arch hypoplasia. Coarctation types classified on the basis of angiographic data were discrete in eight patients, long segment in four patients, and hourglass configuration in three patients, including the patient who had the postoperative aortic deformity (table 1).

While the examiner knew the clinical diagnosis, the study was prospective in that the type of coarctation and associated aortic arch malformations detectable by the suprasternal notch echocardiographic technique were determined prior to angiography.

For control patients, suprasternal notch echocardiograms were performed in 100 infants and children with a variety of congenital heart diseases (table 2). These were evaluated for the adequacy of visualization of the structures imaged from the suprasternal notch and assessment of any causes of potential false positive diagnosis of coarctation. Eighty-two of the 100 control patients had documentation of their diagnoses by cardiac catheterization. None of these patients'
TABLE 1. Coarctation Patients

<table>
<thead>
<tr>
<th>Age</th>
<th>BSA (m²)</th>
<th>Associated malformation</th>
<th>Type of coarct by angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 yr</td>
<td>.84</td>
<td>bicuspid valve, small VSD</td>
<td>discrete membranous coarct distal to left subclavian artery</td>
</tr>
<tr>
<td>9 yr</td>
<td>1.03</td>
<td>subaortic stenosis, postop aortic coarct resection</td>
<td>hourglass deformity distal to left subclavian artery</td>
</tr>
<tr>
<td>2 yr</td>
<td>.45</td>
<td>bicuspid aortic valve</td>
<td>discrete coarctation distal to left subclavian artery</td>
</tr>
<tr>
<td>4 yr</td>
<td>.65</td>
<td>bicuspid aortic valve</td>
<td>juxtaductal hourglass configuration with isthmic hypoplasia</td>
</tr>
<tr>
<td>3 wk</td>
<td>.14</td>
<td>aortic valvar stenosis, large VSD, PDA</td>
<td>discrete membranous coarct significantly distal to left subclavian</td>
</tr>
<tr>
<td>16 yr</td>
<td>1.4</td>
<td>mitral prolapse</td>
<td>discrete coarct distal to left subclavian</td>
</tr>
<tr>
<td>3 wk</td>
<td>.19</td>
<td>left ventricular myopathy</td>
<td>discrete membranous coarct with small transverse aortic arch</td>
</tr>
<tr>
<td>4 mo</td>
<td>.21</td>
<td>tunnel subaortic stenosis, large VSD, PDA</td>
<td>long segment hypoplasia distal to left subclavian</td>
</tr>
<tr>
<td>8 mo</td>
<td>.38</td>
<td>none</td>
<td>long segment coarct involving left subclavian artery</td>
</tr>
<tr>
<td>15 yr</td>
<td>1.4</td>
<td>bicuspid valve</td>
<td>discrete membranous coarct</td>
</tr>
<tr>
<td>4 days</td>
<td>.18</td>
<td>bicuspid valve, aortic stenosis, left ventricular myopathy</td>
<td>long tortuous coarct distal to left subclavian artery</td>
</tr>
<tr>
<td>3 wk</td>
<td>.18</td>
<td>subaortic stenosis</td>
<td>discrete coarct, isthmic hypoplasia (mild)</td>
</tr>
<tr>
<td>21/2 yr</td>
<td>1.68</td>
<td>bicuspid aortic valve</td>
<td>discrete membranous coarct, distal to left subclavian artery</td>
</tr>
<tr>
<td>1 day</td>
<td>.15</td>
<td>small PDA</td>
<td>hourglass shaped coarctation</td>
</tr>
<tr>
<td>3 wk</td>
<td>.2</td>
<td>none</td>
<td>long segment coarct</td>
</tr>
</tbody>
</table>

Abbreviations: BSA = body surface area; coarct = coarctation; PDA = patent ductus arteriosus; postop = status postoperative; VSD = ventricular septal defect.

angiograms showed any suggestion of descending aortic abnormalities. Ten of the patients were included because they either had dextrocardia (N = 6) or right-sided aortic arch (N = 4), in order to specifically evaluate the reliability of aortic arch imaging when the aorta was grossly abnormal but without coarctation.

Echocardiographic Methods

The procedure for examination was as follows: The patients were examined with a mechanical sector scanner (the Echo Sector, Smith Kline) using either a 2.25 or 3.5 MHz transducer oscillating at 30 cycles per second while producing a 30° sector image with 120 lines per frame and with a frame rate of 30 full frames per second. Young children were examined supine with a pillow tucked beneath their shoulder to allow their heads to fall back, providing access to the suprasternal notch. Smaller infants were placed completely on the pillow. A three-lead ECG was recorded simultaneously for timing purposes. After positioning was accomplished and the patient was quieted the transducer was lightly placed in the suprasternal notch and contact achieved with an abundant amount of water-based gel. The transducer was then oriented to image a plane between the right nipple anteriorly and the left scapular tip posteriorly in a line which appeared to approximate the line of the left ventricular outflow tract and aortic arch. The transducer was initially directed along this line so as to point as nearly toward the patient's feet (caudally) as possible and consistent with patient comfort. Fine alignments and gain settings were adjusted for adequate visualization of the transverse aorta with the right pulmonary artery underneath it. The sector scanner was then angled anteriorly and rightward in an arc so as to image the ascending aorta and right pulmonary artery and then swept posteriorly from this position until images were obtained of the junction of the transverse and descending aorta with the transducer angled slightly posteriorly, caudally and to the left of the midline. Having achieved visualization of all three segments of the aortic arch, multiple sweeps from the ascending to the transverse to the descending aorta and back were obtained and recorded in analog form on a portable video tape recorder for subsequent frame-by-frame analysis. Landmarks to be observed during these recordings were the right pulmonary artery and its origin from the main pulmonary artery, visualized beneath the ascending aorta; the innominate artery originating from the top of the transverse aorta, the left carotid and left subclavian arteries originating near the junction of the transverse and descending aorta, the ascending aorta, and the main or left pulmonary artery just anterior to the descending aorta. All patients were examined similarly with an attempt to see as far down the descending aorta as possible using the damping and reject controls to minimize low strength echoes within the aortic lumen.

All the children tolerated this examination quite well, although several experienced discomfort when the transducer was applied too forcefully. Nonetheless, support of the weight of the transducer by the examiner's hand

TABLE 2. Control Patients

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetralogy of Fallot (right aortic arch = 4)</td>
<td>20</td>
</tr>
<tr>
<td>Tetralogy of Fallot, postop</td>
<td>10</td>
</tr>
<tr>
<td>Aortico stenosis</td>
<td>18</td>
</tr>
<tr>
<td>Idiopathic hypertrophic subaortic stenosis</td>
<td>3</td>
</tr>
<tr>
<td>Subaortic stenosis</td>
<td>4</td>
</tr>
<tr>
<td>Pulmonic stenosis</td>
<td>11</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>10</td>
</tr>
<tr>
<td>Ventricular septal defect</td>
<td>18</td>
</tr>
<tr>
<td>Complex dextrocardia with single ventricle, transposition, pulmonic stenosis</td>
<td>4</td>
</tr>
<tr>
<td>&quot;Corrected&quot; transposition with dextrocardia</td>
<td>2</td>
</tr>
</tbody>
</table>
minimized the amount of vibration transmitted to the suprasternal notch and allowed the examination to be completed.

Echocardiographic data were reviewed by replay in real-time as well as slow motion. Records were also stored on standard video tape using a slave monitor and a TV camera as well as on super 8 mm movie film to aid frame-by-frame analysis by the evaluators. Photographs of individual still frames from the real-time echocardiographic record were obtained which included examples of aortic arch and vessel contours as well as a one centimeter standard and the ECG marker. Echoes were evaluated by two independent observers who recorded their observations of aortic arch size and contour.

Images on all patients were graded as to visualization and contour of the ascending, transverse and descending aorta, visualization of the innominate, carotid and subclavian arteries, and description of abnormalities of outer contour or interruptions by bright echoes (apparent obstructions) within the descending aorta. Abnormalities within the descending aorta were described in relationship to the level of the main or left pulmonary artery, whichever segment was in the image, and to the origins of the carotid and left subclavian arteries.

Coarctations diagnosed by echo were further subclassified by aortic contour for surgically pertinent observations in this study, either as discrete, hourglass, or long segment. Transverse aortic arch images were also analyzed as to presence or absence of hypoplasia.

Comparative Studies

The echocardiographic observations were subsequently compared to angiographic observations and the cardiac catheterization data which were graded independently by a third observer. This third observer evaluated the angiograms on the coarctation patients for 1) verification of diagnosis, 2) associated cardiac malformations, and 3) associated aortic arch malformation, i.e., relationship of the carotid and subclavian arteries to the coarctation and the presence or absence of interruption or hypoplasia of the aortic arch. Angiographic and echocardiographic observations were then compared at the end of the study.

Structure Validation Studies

Three of the coarctation patients were studied in the cardiac catheterization laboratory where verification of structure identification of the ascending, transverse and descending aorta, the carotid and subclavian orifices and the position of the coarctation was obtained. These verifications were obtained by visualizing echocardiograms of catheters in known locations and/or by hand injection of saline through the catheters while performing the sector scan echocardiogram. The catheterization laboratory verification studies were performed with informed parental consent in patients with a diagnosis of coarctation undergoing aortography.

Results

Normal Aortic Arch Contour and Configuration

When imaged by this technique, the ascending aorta is seen to ascend toward a transducer angled anteriorly and slightly toward the right. The right pulmonary artery is underneath this ascending segment (fig. 1). If the transducer in this plane is angled slightly toward the left, the junction of the right and main pulmonary artery is visualized and the pulmonary valve cusp may be seen, especially in systole. If the sweep of the sector scanner is continued from the ascending aorta-right pulmonary artery position posteriorly and toward the left, i.e., toward the descending aorta, the transverse aorta and the main pulmonary artery are next visualized. With significant damping in the near field as this transition takes place, the origin of the innominate artery from the superior wall of the aortic arch may be visualized. As the transducer is angled further leftward from the transverse aortic arch, the main pulmonary artery and the origin of the left pulmonary artery may be visualized (fig. 2).

As the sweep is continued posteriorly along the transverse aorta, the origin of the left carotid artery and shortly thereafter the left subclavian artery are imaged. The descending aorta is then visualized for a variable distance almost always without dimensional change distal to the level of the main or left pulmonary artery and usually for several centimeters beyond (fig. 3). Problems in alignment sometimes preclude visualization of the descending aorta much beyond the pulmonary artery, but since the juxtaductal area is just distal to the left subclavian and opposite the

![Figure 1. Superior sweep of the ascending aorta (ASC AO). The main pulmonary artery (MPA) and the origin of the right pulmonary artery (RPA) beneath it are imaged on this still frame from a real-time suprasternal notch cross-sectional echocardiogram. The pulmonary valve cusp (PV) is in its open or systolic position. Image orientation for all echo images in this paper is as shown in the compass. sup = superior, inf = inferior, ant = anterior, post = posterior.](https://clic.ahajournals.org/)

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left pulmonary artery, the lack of further distal visualization is rarely a problem.

Control Group

Of the 100 children studied, ascending, transverse and descending aortas could be visualized in all; in none was there a coarctation-like abnormality of the descending aorta. The left subclavian and left carotid arteries were imaged in 92 of the 100 children and the innominate artery in 60. The aorta was visualized distal to the level of the left pulmonary artery in 94 of the 100 children; in six, visualization was obtained only to the inferior wall of the pulmonary artery. In this regard, it would appear that a smaller handheld right angle probe, similar to that which we have designed for the suprasternal notch M-mode echocardiogram would allow a greater degree of horizontal positioning for distal visualization of the aortic arch. Nevertheless, in these children, the limited visualization obtained might fail to detect coarctations significantly distal (inferior) to the level of the ductus or ligamentum arteriosus.

An additional imaging problem encountered which was not unexpected was that some portions of the posterior wall of the descending aorta drop out because of their parallel alignment to the transducer. While this sometimes precluded total visualization of the back wall of the aorta in normal children, the orientation of the coarcted segments themselves, which are more perpendicular to sound energy transmitted from the suprasternal notch, allowed them to be adequately visualized (see below).

Echo Images of Coarctation

Coarctations which occurred in the descending aorta distal to the left subclavian usually appeared as bright echoes within the lumen of the descending aorta with or without a change in the outer contour of the aorta. The left carotid and left subclavian arteries were usually somewhat enlarged and the aortic arch was grossly pulsatile. Figure 4 shows an ex-
ample of a patient with a discrete type of coarctation of the descending aorta. A single thick echo was visualized across the lumen of the aorta without significant change in contour. The echocardiogram corresponds closely to the anatomy shown in the accompanying angiocardioagram from this same patient. The innominate artery was well imaged in this patient.

Figure 5 shows the echocardiographic image of the aortic contour in a patient with longer segment coarctation. Tortuosity and lengthy narrowing distal to the subclavian artery are seen in both the echocardiogram and the subsequently performed angiocardioagram.

Prospective Accuracy

Of the patients with coarctation, the eight with discrete coarctation were accurately diagnosed prospectively (fig. 6). Hourglass deformities were correctly predicted in three
patients, one of whom was the postoperative patient. Long segment coarctations were correctly predicted in four patients. In two patients, isthmic hypoplasia distal to the left carotid artery and between the left carotid and subclavian arteries was correctly predicted. In one patient, a beam width error projected the echo from the inferior wall of the left carotid artery over the distal aortic arch, producing false positive narrowing of the isthmus which was not substantiated at cardiac catheterization. In two of the patients with isthmic hypoplasia, and an additional patient in whom the subclavian was visualized originating in the long coarcted segment, subclavian involvement was predicted correctly. There were no false negatives for diagnosis of coarctation in these patients, and no subclavian involvement or isthmic hypoplasia was missed. The innominate, carotid and left subclavian arteries were identified in 13 of these 15 patients. The innominate artery was not imaged in two patients. Two patients had isolated origin of the right subclavian and right carotid as opposed to having a single innominate vessel. The isolated origins of these extra vessels was missed in both. As can be seen by comparison of the angiogram to the echocardiographic contours of these coarct (figs. 4,5), and that of the postoperative patient in figure 7, the cross-sectional echocardiogram was an accurate predictor of aortic disease. 

**Discussion**

The results of this study validate the echocardiographic identification of the ascending, transverse and descending aortic arches as well as the origins of the great vessels of the head and neck. The echocardiographic technique has been proven acceptable even in infants and small children who ex-

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**Table:**

<table>
<thead>
<tr>
<th>Actual Pattern</th>
<th>Diagnosed Pattern</th>
<th>Coarctation</th>
<th>Associated Aortic Hypoplasia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Normal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100*</td>
<td>(94 normal, 6 inad)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discrete</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourglass</td>
<td>3 (1 post op)</td>
<td>1 false</td>
<td></td>
</tr>
<tr>
<td>Long Segment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Associated Isthmic Hypoplasia</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* (includes 6 patients with dextrocardia, 4 with right aortic arch)
experienced only minimal discomfort during the performance of these echocardiograms.

Noninvasive detection of the contour of the aorta will be of significant importance, not only in the initial precatheterization assessment of infants with coarctation of the aorta, but in the serial assessment of infants who may develop coarctation after their initial catheterization and in the longitudinal follow-up of infants in the post-coarctectomy period.\(^8\)\(^9\) Since surgically important observations are provided by this technique, cardiac catheterization may be avoided, especially in high risk infants.

Several problems with instrumentation exist which, when rectified, should facilitate this type of evaluation. The first is that the image format, which has a narrowed area in the near field, allows only a limited portion of the aortic arch to be visualized at a given time. Also, problems with near field resolution of the structures closest to the transducer, usually the innominate artery in a small infant, account for lack of recognition of that vessel in approximately 30% of our patients. The narrow field of view with the sector scan image over the aortic arch was not found to be a significant limitation during the actual performance of the examination since the sector scanner could be angled within the suprasternal notch to sweep up the ascending aorta, across the transverse aorta, and down the descending aorta, but it accounts for difficulties encountered in illustrating our findings in this paper.

The problem of echo dropout is inherent in the reflected ultrasound technique and although it caused problems in visualization of the posterior wall of the descending aorta, it did not produce difficulties in the visualization of the coarcted area itself.

This study dealt primarily with the validation of aortic arch contour by angiocardiographic observations. No attempt to quantitate the size of the structures visualized was made in comparison to angiography. The aortic arch, as it sweeps posteriorly, occupies variable areas within the chest cavity. Magnification factors were therefore difficult to standardize for quantitation of angiographic vs echocardiographic size. While catheters appeared in many of these angiograms, often the catheter location was in the anterior ascending aorta while the area of most interest to quantitate size was the transverse or descending aorta. Quantitation of the size of these structures will probably be most accurate when compared to surgical observation at the time of coarctectomy. Such a study is currently underway in our laboratory.

Cardiac catheterization, especially in infancy, carries increased risk compared to the adult.\(^10\) While the application of percutaneous technique and balloon flotation catheters in pediatrics has reduced the morbidity of this procedure to some extent, some infants with coarctation require axillary artery cutdowns for adequate delineation of the anatomy of the aortic arch. This, in addition to poor tolerance of contrast load in infants with significant myopathy, makes the infant with coarctation a particularly high risk candidate for catheterization and angiography. While the diagnosis of coarctation and to some extent the assessment of left subclavian or aortic arch involvement can be obtained clinically, the delineation of associated malformations and the exact anatomy of the aortic arch has required cardiac catheterization and angiography, prior to surgery, especially in infants.\(^10\) Such studies can potentially be avoided if this technique can provide the answers to the surgically pertinent questions about aortic arch anatomy. Therefore, accurate noninvasive visualization of the aortic arch anatomy, as demonstrated in this paper, potentially represents another major contribution of ultrasound to the diagnosis and management of infants and children with congenital heart disease.

References
SUMMARY
Real-time, cross-sectional echocardiograms of the pulmonary valve were recorded in 22 patients with valvular pulmonary stenosis (VPS) (14 mild, eight moderate or severe) and 25 normal subjects. Normally during systole the pulmonary leaflet echoes moved rapidly apart and in the fully opened position lay parallel and in close apposition to the margins of the pulmonary artery. In 20 of 22 patients with VPS in whom the pulmonary valve was recorded the systolic configuration of the leaflets, opening pattern of the leaflet echoes, and presence of presystolic doming served to differentiate the stenotic valve from normal.

In contrast M-mode recordings of the pulmonary valve were possible in only 12 of these 22 cases (seven mild and five moderate or severe) and suggested VPS in only the five cases with moderate or severe stenosis. Cross-sectional echocardiography offers a direct, noninvasive method for visualizing the stenotic pulmonary valve and should be an improvement over the indirect M-mode data.

M-MODE ECHOCARDIOGRAPHY can help detect valvular pulmonary stenosis. The M-mode diagnosis rests on the observed effects of altered right ventricular and pulmonary artery pressure relationships on pulmonary leaflet motion. In patients with pulmonary stenosis decreased right ventricular compliance and forceful right atrial contraction frequently result in right ventricular end-diastolic pressure exceeding simultaneous pulmonary artery pressure which results in pre-systolic opening of the pulmonary valve. This opening or doming of the valve following atrial contraction is reflected on the M-mode record as a marked increase in the posterior deflection of the posterior pulmonary leaflet which normally occurs following atrial contraction (A wave).

There are unfortunately a number of limitations to the M-mode diagnosis of valvular pulmonary stenosis. 1) The pulmonary valve may be difficult to record preventing visualization of the diastolic motion pattern. 2) The technique does not permit direct visualization of the stenotic valve but rather provides indirect diagnostic information based on the effects of abnormal presystolic pressure gradients on pulmonary valve motion. 3) The exaggerated A waves seen with valvular stenosis are not specific for this disorder but may occur in any situation in which there is an elevation of right ventricular end-diastolic pressure which equals or exceeds simultaneous pulmonary artery pressure. 4) This technique is not generally useful in patients with mild valvular pulmonary stenosis since in these cases the hemodynamic derangement is not reflected on the pulmonary valve echogram. For these reasons M-mode echocardiography has found only limited diagnostic applications in patients with valvular pulmonary stenosis.

Cross-sectional echocardiography, by enlarging our field of vision and displaying the echocardiographic data in an appropriate spatially oriented format, should facilitate visualization of the pulmonary valve and permit direct recording of the domed stenotic valve leaflets. The purpose of this study therefore was to evaluate the ability of cross-sectional echocardiography to record pulmonary valve motion and to detect valvular stenosis.

Material and Methods
M-mode and cross-sectional echocardiographic studies of the pulmonary valve were performed in 22 consecutive patients with valvular pulmonary stenosis. There were 12 males and 10 females. The average age was 9.4 years (range 2 to 22 years). The diagnosis of pulmonary stenosis was established at cardiac catheterization by the presence of a
Real-time cross-sectional echocardiographic diagnosis of coarctation of the aorta: a prospective study of echocardiographic-angiographic correlations.
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