Suprasternal Notch Echocardiography

Assessment of Its Clinical Utility
in Pediatric Cardiology

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SUMMARY Echocardiographic suprasternal relationships of the transverse aortic arch (TAA), right pulmonary artery (RPA) and left atrium (Y' LAD) were validated and angiographic-echocardiographic measurement correlations were made for each structure. Normal values were determined with respect to body surface area. In normals, regardless of age or body size, mean dimensional TAA/RPA ratio was 1.2:1 and Y' LAD equaled the anterior-posterior, or Z axis, left atrial dimension (Z LAD). TAA/RPA ratio was increased in aortic stenosis and tetralogy of Fallot and was decreased in ventricular septal defect, atrial septal defect and pulmonary stenosis. Ratio did not correlate with lesion severity as assessed by cardiac catheterization except in pulmonary stenosis. Decreased Y' LAD values (usually increased Y' LAD and decreased Z LAD) occurred in children with various forms of heart disease. Some had sternal compression but others had normal chests. Children with pectus excavatum showed similar compression.

These findings underscore the need for incorporation of a suprasternal examination into the standard echocardiographic examination of children.

ECHOCARDIOGRAPHY HAS BECOME IMPORTANT in the initial diagnosis and serial follow-up of patients with congenital heart disease. To date, most echocardiographic examinations have been performed with a transducer positioned on the anterior chest wall. Although some angulation of the transducer can be accomplished, standard echo examination is mainly confined to the anterior-posterior, or Z axis. Ultrasonic examination from the suprasternal notch after the method of Goldberg provides the capability of imaging the transverse aortic arch, right pulmonary artery and left atrium in a superior-inferior axis. This approach is not unique to echocardiography for Radner previously described passing a long needle inferiorly via the suprasternal notch to measure pressures in these vessels and in the left atrium. The purpose of the present study in infants and children was 1) to validate the echocardiographic location of the transverse aortic arch, right pulmonary artery and left atrium imaged echocardiographically from the suprasternal notch; 2) to establish criteria for measurement and normal values; and 3) to evaluate deviations from normal in patients with various forms of congenital heart disease or chest deformities.

Methods

Echocardiographic Technique

Z-Axis Echocardiography

Single plane echocardiography was performed in the anterior-posterior (Z) axis according to previously described techniques with a Smith Kline Ekoline 20A Echocardiograph and a Honeywell 1856 ultraviolet recorder. A simultaneous limb lead electrocardiogram was recorded for timing purposes. Most echocardiographic examinations were performed with a ¼ inch nonfocused 5 MHz transducer coupled to the chest wall (usually at the left third or fourth parasternal intercostal space) with an airless contact gel. Some older children were studied with a 3.5 MHz or a 2.25 MHz nonfocused transducer. A 7.5 MHz transducer was used in some premature infants. In all instances the transducer was held as perpendicular to the chest wall as possible when imaging the heart. Quantitative measurements were made according to the criteria of Epstein et al.

Suprasternal Echocardiography

Normal Study. Suprasternal notch echocardiograms were obtained after the method of Goldberg. The transducer was coupled to the suprasternal notch by an airless contact gel, and the beam was directed inferiorly and slightly leftward to visualize the transverse aortic arch, right pulmonary artery and left atrium (fig. 1). Discomfort and difficult manipulation with standard-sized transducers in short necked infants led us to modify the transducer to a hammer shape. The hammer-shaped transducer houses a piezo-electric crystal at its tip; electrical connections are in the handle. Usually a 5 MHz transducer was adequate for penetration, but occasionally a 2.25 MHz transducer was required to image the floor of the left atrium in larger patients.

In order to assure repeatable examinations (figs. 2, 3), we required simultaneous imaging of the inner wall of the transverse aortic arch, the right pulmonary artery, and the floor of the left atrium. This was accomplished by transducer manipulation and adjustment of the echocardiographic controls.

Validation and Structure Identification

Imaging of great vessels and left atrium was validated during cardiac catheterization by echocardiography performed via the suprasternal notch following hand injection of 2–3 cc of saline into the vessel or chamber under study. Such injection causes a shower of microbubbles which is detectable by echo. Verification occurred if an opacity appeared in the chamber or vessel immediately after injection.

Measurement

All measurements were made independently by at least two observers with calipers and a variable scale ruler. The

Received April 26, 1976; revision accepted November 15, 1976.
transverse aortic arch, right pulmonary artery and left atrium were measured from inner wall to inner wall at maximal chamber or vessel excursion. Echocardiographic Z axis aortic dimension was measured from outer anterior aortic wall to outer posterior aortic wall in the plane of the aortic valve leaflets at the onset of the electrocardiographic QRS complex. Comparative Z axis left atrial dimension was measured at its widest dimension in the plane of the aortic leaflets from the outer posterior aortic wall to the inner posterior left atrial wall.

Angiographic Comparisons

Angiographic measurements were made by a cardiac radiologist who had no knowledge of echocardiographic values and who used the same measurement and plane constraints as for the echo measurements. Echocardiographic and angiographic suprasternal transverse aortic arch, right pulmonary artery, suprasternal left atrial dimension and Z axis aortic arch and left atrial dimension measurements

![Figure 1](http://circ.ahajournals.org/)

**Figure 1.** The anatomic relationships of the transverse aortic arch (Ao), right pulmonary artery (RPA) and left atrium (LA) are shown in the anterior-posterior and lateral planes. The hammer-shaped transducer is coupled to the suprasternal notch with an airless contact gel. Usually, discomfort is minimal.

![Figure 2](http://circ.ahajournals.org/)

**Figure 2.** Left) This illustration shows validation of the right pulmonary artery in a patient with an atrial septal defect. Right pulmonary artery validation was accomplished by injection of 1 to 2 cc of saline through a catheter placed into the right pulmonary artery during cardiac catheterization. This injection is indicated by the arrow. The resulting opacification of the right pulmonary artery confirms its echocardiographic representation. Calibration dots are best seen in the left atrium coincident with atrial systole on the third beat. Right) is from a newborn with a patent foramen ovale and pulmonary hypertension. This infant had a catheter placed in the umbilical vein and 1 to 2 cc of saline was hand injected. During suprasternal echocardiography, right-to-left shunting into the left atrium is noted and the limits of the left atrium are shown by the echo contrast in that chamber. The transverse aortic arch (TAA) then opacifies in systole. Some contrast material is noted in the right pulmonary artery during systole as well. This represents antegrade pulmonary blood flow from the right ventricle. Such physiologic validations have now been performed in ten infants.
were compared. Angiographic comparisons were made between the suprasternal (Y') left atrial dimension and the true Y (superior-inferior) left atrial dimension. During routine cardiac catheterization, clinically indicated angiograms were performed by injecting Renografin 76 into the vessel or chamber under study via an appropriately placed catheter. Biplane cineangiograms were recorded at 120 frames/sec on 35 mm film. Catheter diameter served as calibration for angiographic chamber or vessel measurement. A maximum of three weeks elapsed between recordings of these two types of examination, and most were performed within 24 hours of one another. Angiographic definition of the superior border of the left atrium was established as that area of the left atrium in contact with the right pulmonary artery. The inferior limit of the left atrial suprasternal axis was defined as the area just anterior to the mitral anulus in line with the suprasternal notch, transverse aorta and right pulmonary artery. Thus, the angiographic and echocardiographic

superior-inferior left atrial dimension is a Y' axis and not a true vertical Y axis, but is the left atrial dimension of the heart with respect to the suprasternal notch plane. Additionally, the true vertical angiographic Y left atrial dimension was measured in a superior-inferior axis from the superior left atrium to its floor, inferior and posterior to the mitral anulus.

Patient Groups

As subjects we studied normal healthy children, patients with various forms of congenital heart disease and a group of patients with skeletal deformities of the chest (pectus excavatum).

Analysis

Data from normals were plotted against body surface area for the transverse aortic arch and right pulmonary artery dimensions. Ratio of the transverse aortic arch to the right pulmonary artery was evaluated in normals of varying age groups. Ratio in children with various congenital lesions was compared to the normal ratio and then correlated with cardiac catheterization data. Echocardiographic Z axis aortic dimension was compared with the suprasternal aortic dimension in normal subjects. Left atrial Y' measurements were compared to left atrial Z axis measurements in the same subjects. Further, the angiographic Y' dimension was compared to the angiographic true Y dimension in the same subjects. A Student t ratio was used to test the probability of group similarity for each echocardiographic and angiographic measurement.

Results

Qualitative

After initially gaining familiarity with performance of the examination, the probability of achieving a satisfactory suprasternal examination was 98% (of 98 prospective consecutive echocardiograms).

Validation of echo representations of the transverse aortic arch, right pulmonary artery and left atrium in the suprasternal notch plane was made by saline contrast injection. Figure 2 shows validation of the right pulmonary artery. The aorta and left atrium were similarly proven.

Figure 3 shows a typical suprasternal notch echocardiogram. The aorta and right pulmonary artery dilate during systole. This dilation is best recorded at the superior transverse aortic wall and inferior right pulmonary artery wall, because the other wall of each vessel is tethered. The left atrial wall contracts just after the electrocardiographic P wave. Occasionally, the right pulmonary artery appears to dilate slightly at this time.

Quantitative

Angiographic/echocardiographic comparisons: Patients with various types of congenital heart disease who underwent cardiac catheterization provided the source for these angiographic/echocardiographic comparative data.

1. Transverse Aortic Arch. Echocardiographic and angiographic transverse aortic arch dimensions were compared in eight patients. A strong correlation (r = 0.96, SEE = ± 1.3 mm) existed for these two methods of measure-

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**Figure 3.** Note the relationship of the transverse aortic arch (aorta), right pulmonary artery (RPA) and the left atrium. The dashed line indicates timing of the electrocardiographic QRS complex. The superior wall of the aorta and inferior wall of the right pulmonary artery dilate with systole. The adjacent walls (inferior aorta, superior RPA) show little motion. The left atrial walls (superior and inferior) contract after the ECG P wave.
Table 1. Left Atrial Dimension Comparisons

<table>
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<tr>
<th>Patient</th>
<th>Lesion</th>
<th>Z LAD (mm) (angio)</th>
<th>Z LAD (mm) (echo)</th>
<th>Y' LAD (mm) (angio)</th>
<th>Y' LAD (mm) (echo)</th>
<th>Y LAD (mm) (angio)</th>
<th>Y LAD (mm) (echo)</th>
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<tr>
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Abbreviations: VSD = ventricular septal defect; ASD = atrial septal defect; AV Canal = complete endocardial cushion defect; AI = aortic insufficiency; MI = mitral insufficiency; PS = pulmonary valvular stenosis; PDA = patent ductus arteriosus; T of F = tetralogy of Fallot; Z LAD = anterior-posterior left atrial dimension; Y' LAD = suprasternal axis left atrial dimension; Y LAD = vertical axis left atrial dimension; echo = echocardiographic; angio = angiographic.

The resulting regression equation is $TAA_{angio} = 1.2 + 4.69$.

2. Right Pulmonary Artery. Eight patients had echocardiographic/angiographic comparisons and the correlation was $r = 0.95 \pm 0.81$ (SEE). The regression equation for this relationship was $RPA_{angio} = 0.61 + 4.39$.

3. Angiographic Y' - Left Atrial Dimension vs Angiographic Y Left Atrial Dimension (table 1). This comparison was made in 13 patients and correlation was $r = 0.77 \pm 0.45$. The regression equation for the line was $Y'_{angio} = Y_{echo} + 3$.

4. Y' - Left Atrial Dimension (table 1). Suprasternal echocardiographic Y' left atrial dimension correlated well with the similarly measured angiographic dimension in 13 subjects ($r = 0.89$, SEE $= 2.2$ mm). The regression equation for this relationship is $Y'_{angio} = 0.72 (Y'_{echo}) + 5$.

5. Z - Left Atrial Dimension (table 1). Anterior-posterior (Z axis) left atrial angiographic and Z axis echocardiographic measurements were compared in 13 subjects. Correlation was $0.95$ (SEE $= 1.5$ mm). The regression equation for these measurements was $Z_{angio} = 0.85 (Z_{echo}) + 2.34$.

Normal Subjects

Transverse aortic arch — right pulmonary artery. Maximal inner dimensions of the transverse aortic arch and right pulmonary artery were measured in 29 normal premature and full term newborns ranging in weight from 1630-4470 grams (age 12 hours to 9 days) and in 71 older children (age 4 months to 19 years, mean 10.1 years) ranging in body surface area from 0.3 to 2.0 m$^2$.

The dimensional data for transverse aortic arch and right pulmonary artery correlated strongly with body surface area ($r = 0.9$ and $r = 0.87$, respectively). These normal curves appear in figures 5 and 7.

Ratio of transverse aortic arch and right pulmonary dimensions (TAA/RPA) was evaluated. Since ratio for prematures and newborns was not significantly different from that of older children, ratio data were combined. Mean TAA/RPA ratio in 100 normal subjects was $1.24 \pm 0.02$.

Aortic root — transverse aortic arch comparison. The TAA was 85% of the size of the aortic root with a 90% probability of not deviating from this value by more than .25 mm.

Left Atrium

Y' axis and Z axis comparison. Anterior-posterior (Z axis) left atrial dimension was compared with suprasternal left atrial (Y' axis) dimensions in 58 normal subjects ranging in age from the newborn period through 18 years. Figure 4 shows that these dimensions were usually equal in normals ($r = 0.99$, SEE $= 1.1$ mm).

Children with Congenital Malformations

A sampling of children with representative lesions was evaluated to assess the usefulness of the suprasternal echocardiogram in congenital heart disease. Table 2 shows the combined data for this population, grouped by lesions.

Aortic stenosis. Eight patients with aortic stenosis had a mean TAA/RPA ratio of $1.51 \pm 0.04$. The mean was significantly higher than that of the control group ($P < 0.0001$). The reason for this ratio difference is shown in figure 5. Although many of the values for each vessel are within normal limits, the ratio is altered because the TAA was dilated with respect to the RPA (fig. 6). No correlation ($r = 0.30$) existed between the left ventricular — aortic pressure gradient and the ratio for these patients.

Tetralogy of Fallot. Twelve patients with tetralogy of Fallot.
Fallot had a mean ratio of 1.89 ± 0.05. This mean was significantly higher than that of the control group ($P < 0.00001$). In this group, the aorta was absolutely or relatively enlarged with respect to the normal-to-small RPA (fig. 5). This disparity accounts for the elevated ratio (fig. 6). Although increased with respect to normal, TAA/RPA ratio in tetralogy of Fallot patients did not have any correlation with respect to whether the patient was unoperated, palliated or repaired ($r = -0.30$).

**Ventricular septal defect** (fig. 7). The mean ratio for 25 patients with ventricular septal defect was 0.92 ± 0.02. The mean was significantly less than that of the control group ($P < 0.00001$). The increased ratio (fig. 6) was due to pulmonary artery dilation and normal transverse aortic arch dimension. When the ratio was compared to the magnitude of left-to-right shunt or pulmonary artery pressure, no correlation existed ($r = -0.20$ and $r = -0.05$, respectively).

**Atrial septal defect** (fig. 7). Seventeen patients with atrial septal defect had a mean ratio of 0.95 ± 0.02. This mean was significantly lower than that of the control group ($P < 0.00001$). Compared to the body surface area related normal data, the decreased ratio was due to a relatively dilated pulmonary artery (fig. 6). No correlation ($r = -0.21$) existed between ratio and the magnitude of left-to-right shunt in atrial septal defect patients.

**Pulmonary stenosis** (fig. 7). Eight patients with pulmonary stenosis had a mean ratio of 0.96 ± 0.05. These values were significantly lower than those of the control group ($P < 0.00001$). Pulmonary arteries were dilated in relation to the transverse aortic arch, accounting for the decreased ratio (fig. 6). A weak correlation existed ($r = -0.74$) between TAA/RPA ratio and right ventricular-pulmonary artery pressure gradient.

### Left Atrial Anterior-Posterior Z Axis Compared to Suprasternal Y’ Dimensions (fig. 8)

Echocardiographic biaxial left atrial dimensions were compared in 89 randomly selected subjects with congenital heart disease (lesions included ventricular septal defect, patent ductus arteriosus, aortic stenosis, pulmonic stenosis, endocardial cushion defect, coarctation of the aorta, tetralogy of Fallot, atrial septal defect, mitral click-murmur syndrome) or acquired disease (systemic hypertension, myocarditis or rheumatic mitral and/or aortic insufficiency). Although most of these biaxial measurements were equal, significant discrepancies occurred in unsuspected patients ($r = 0.81$; SEE = ± 45; regression equation was $Y’_{LAD} = 0.9 \times Z_{LAD} + 1.45$). The single lesion which was significantly different from the group was atrial septal defect, where the $Y’$ axis was slightly greater than the Z axis.

Isolated premature infants with respiratory distress syndrome and patent ductus arteriosus had left atrial “pangcaking,” (i.e., larger Y’ left atrial dimension than Z left atrial dimension). Some members of this group had sternal retraction to account for the discrepancy, others did not. The premature infants as a group, however, were not significantly different from the older group, who demonstrated equal biaxial measurements.

In contrast, marked anterior-posterior elongation of the left atrium (increased Z left atrial dimension compared to Y’ left atrial dimension) occurred in some patients. One boy

### TABLE 2. TAA, RPA Measurements and Catheterization Data in Various Forms of Congenital Heart Disease

<table>
<thead>
<tr>
<th>A. Aortic Stenosis</th>
<th>B. Tetralogy of Fallot</th>
<th>C. Ventricular Septal Defect</th>
<th>D. Atrial Septal Defect</th>
<th>E. Pulmonary Stenosis</th>
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<td><strong>RPA (cm)</strong></td>
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<td>10</td>
<td>1.80</td>
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**Abbreviations:** BSA = body surface area; TAA = transverse aortic arch; RPA = right pulmonary artery; LV-Ao gradient = left ventricular-to-aortic pressure withdrawal gradient measured at cardiac catheterization; unup = unuposed aortic valve; AI = aortic insufficiency; PDA = patent ductus arteriosus; PVOD = postoperative pulmonic valvotomy; PAP = pulmory artery pressure; QP/QS = ratio of pulmonary artery flow to systemic cardiac output; PVOD = bidirectional shunt with pulmonary vascular obstructive disease; RV-PA gradient = right ventricular to pulmonary artery pressure gradient.
with severe pulmonary stenosis had angiographic evidence of marked poststenotic dilation of the pulmonary artery which resulted in compression of the top of his left atrium. Anterior-posterior elongation of the left atrium also occurred in some older children with rheumatic mitral insufficiency and left atrial enlargement and in some patients with VSD who had dilated pulmonary arteries and enlarged left atria.

**Chest Deformity**

Six patients with pectus excavatum were evaluated. Due to sternal compression, this group had "pancaking" of the left atrium with significantly increased Y' left atrial dimension as compared to the Z left atrial dimension (r = 0.83, SEE = ± .56). The regression equation for this patient group was $Y'_{LAD} = 1.06 (Z_{LAD}) + .86$.

**Discussion**

The unique features of this study were the confirmation in children of the echocardiographic suprasternal superior-inferior relationships of the transverse aortic arch, right pulmonary artery and left atrium and determination of the ranges of normal values and characteristics of these measurements in various cardiac defects.

Suprasternal echocardiography may be a technically difficult examination in some patients. To establish the success rate of this technique, three of the authors sequentially studied 98 children, and measurable suprasternal notch echoes were obtained in 98%. In our experience, among the most difficult subjects have been premature infants with respiratory distress with an endotracheal tube in place. The problem in this instance is physical space for placement of the transducer. A special Aerotech transducer was produced with a hammer shape to overcome this difficulty. This transducer configuration has been very helpful in infants. The very tall subject is another difficult subject because penetration and reflection of ultrasound as far as the mitral ring is difficult. Such patients usually require the lowest frequency transducer available.

In order to accomplish identification of the portion of the left atrium which was standardized in this investigation, and to allow proper visualization of the transverse aortic arch and right pulmonary artery, the transducer should be angled slightly leftward and anteriorly. This often requires downward pressure on the transducer into the suprasternal notch and may cause mild discomfort in some subjects. We recommend that the suprasternal evaluation should be the last portion of the echocardiographic examination.

Common examination errors result from visualization of the mitral valve apparatus or the left ventricular posterior wall. Incorporation of electrocardiographic timing assists identification in that the left ventricular posterior wall contracts after the QRS, whereas the left atrial posterior wall contracts prior to the electrocardiographic QRS complex. The characteristic motion pattern of the standardized left
atrial inferior surface is slightly superior just after the electrocardiographic P wave (atrial systole). This is the pattern of atrial motion at the area of the left atrial wall adjacent to the mitral anulus. An equally acceptable standardized area is the anterior edge of the mitral anulus where the motion is flattened. Either pattern is acceptable as measurement results are equal.

The superior-inferior axis recorded in the standardized manner does not represent a true Y axis, but rather one which is deviated slightly anterior to the true Y axis. We refer to this echo axis as a Y' axis. The difference between the two axes (Y' and Y) was determined by angiography and the relationship is relatively constant, with a regression equation for the line of \( Y' = 0.5Y + 3 \) (\( r = 0.77, \text{SEE} = \pm 4.5 \)).

Normal measurement data were developed in order to evaluate deviation from normal. In this study, quantitative curves of normal values for the transverse aortic arch and right pulmonary artery inner dimensions were compared to body surface area for normal children from infancy through age 19 years. In most normal children, the Z axis left atrial dimension equals the Y' axis left atrial dimension. To increase the usefulness of the information, we plot the Y' left atrial dimension against body surface area, after the method of Epstein et al.\(^1\)

The ratio of the transverse aortic arch to the right pulmonary artery in normals (1.2:1) was consistent for all age groups, and this ratio serves as a useful reference for comparing these structures. However, for greatest utility the absolute quantitative dimensions for each structure must also be considered. Patients with congenital heart disease show the expected ratio and absolute vessel size deviations from normal. For example, those with aortic stenosis and tetralogy of Fallot have absolutely dilated aortas or an aorta which is dilated with respect to the RPA. Further, those with tetralogy had smaller than normal pulmonary arteries and the ratio was elevated. In contrast, patients with dilated pulmonary arteries (ventricular septal defect, atrial septal defect and pulmonary stenosis) had smaller than normal ratios. Although a relationship existed (\( r = -0.74 \)) when the right ventricular-pulmonary artery pressure gradient in pulmonary valvular stenosis was compared with TAA/RPA ratio, no other significant correlations were present in any of the lesions studied.

These ratio values have been particularly useful for

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**Figure 7.** Transverse aortic arch/right pulmonary artery findings in ventricular septal defect, atrial septal defect and pulmonary stenosis are illustrated.

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**Figure 8.** Comparison of suprasternal and anterior-posterior left atrial dimension in 89 patients with various forms of congenital heart disease. Unexpected variability occurs, usually with increased Y' measurement, but also occasionally with increased Z axis dimension.
evaluating a child with a midsternal ejection click, a systolic ejection murmur which is heard in the same area, suprasternal notch thrill, and no roentgenographic or echocardiographic abnormality. The patient with aortic stenosis usually has an increased ratio, whereas the one with pulmonary stenosis usually has a decreased ratio. Suprasternal echocardiography has also been quite useful as a confirmatory echo finding in the evaluation of a hypoplastic left heart syndrome, in that the transverse aortic arch is smaller than normal in size, thus providing a cross-check for Z axis single-crystal echo evaluation. Suprasternal notch echo is useful for following absolute and relative dimensions of the right pulmonary artery in patients with tetalogy of Fallot who require aortopulmonary shunts (fig. 9).

Although the normal Z and Y' left atrial dimensions are usually equal, unexpected deviations occur in patients with various types of congenital heart disease. As left atrial dimension reflects the influences of preload and afterload, much emphasis has recently been given to following this measurement in neonates with respiratory distress syndrome and patent ductus arteriosus. Some of these patients have sternal retraction which flattens ("pancakes") the left atrium. This same phenomenon is noted in patients with pectus excavatum, where the Y' left atrial dimension can be encountered in a patient who has increased left atrial size reflected only by vertical elliptical enlargement. Additionally, some patients with larger Y' than Z measurements did not have sternal deformities and thus the normal Z axis measurement alone would have been misleading. In contrast to the patients with superior-inferior elongation, other patients showed left atrial elongation in the anterior-posterior axis, further underscoring the need for bialval evaluation of the left atrium.

This study demonstrates the utility of suprasternal echocardiographic evaluation and increases the capability of single-crystal echocardiography by demonstrating two structures not usually imaged from the precordial examination and providing measurement in another axis for the left atrium. We recommend that suprasternal echocardiography be included in every complete echocardiographic examination of the child with heart disease.

Acknowledgment

Our appreciation to Mrs. Cheryl Czaplicki for secretarial and editorial assistance.

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Circulation. 1977;55:605-612
doi: 10.1161/01.CIR.55.4.605
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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