Two-dimensional Echocardiographic Assessment of Left Ventricular Volumes and Ejection Fraction in Children

JEAN C. MERCIER, M.D., THOMAS G. DISELLA, M.D., JAY M. JARMAKANI, M.D., TOSHIO NAKANISHI, M.D., SATOSHI HIRAISHI, M.D., JOSEPHINE ISABEL-JONES, M.D., AND WILLIAM F. FRIEDMAN, M.D.

with the technical assistance of Barbara Stenlight, R.D.M.S.

SUMMARY The ability of two-dimensional echocardiography to measure left ventricular volumes and ejection fraction was evaluated in 25 children with congenital heart disease. Dimensions and planimetered areas were obtained in the short-axis view at the mitral valve and high and low papillary muscle levels and in the apical two- and four-chamber views. Eight algorithms using five geometric models were assessed. Left ventricular end-diastolic volume, end-systolic volume and ejection fraction were compared with data from bpline cineangiograms. The correlation varied with the algorithm used. Algorithms using short-axis views appeared superior to those using only apical long-axis views. Four algorithms estimated left ventricular volumes with equal accuracy (Simpson’s rule, assuming the ventricle to be a truncated cone; Simpson’s rule, assuming the ventricle to be a truncated ellipse; hemisphere cylinder; and ellipsoid bpline). The single algorithm that best estimated left ventricular ejection fraction was the ellipsoid bpline formula using the short-axis view at the papillary muscle level (r = 0.91, slope = 0.94, SEE = 6.7%). Thus, two-dimensional echocardiography can accurately assess left ventricular volumes and ejection fraction in children with congenital heart disease.

NONINVASIVE estimation of left ventricular performance is important in the initial and prospective evaluation of children with congenital and acquired heart disease. M-mode echocardiography has been used to estimate left ventricular volumes and ejection fraction, but its value is compromised by segmental wall motion abnormalities and ventricular overload. Except for abnormalities of septal motion, segmental wall motion abnormalities are unusual in children. In children with left ventricular overload, angiographic and echocardiographic left ventricular end-diastolic diameters correlate poorly. Moreover, various indirect methods for measuring left ventricular performance using mitral valve motion, aortic valve motion, or both have been proved inferior to direct assessment of changes of left ventricular dimensions and volumes. Preliminary reports of electrocardiographically triggered B-mode echocardiographic scanning indicate that two-dimensional echocardiography is better than M-mode echocardiography for calculating left ventricular ejection fraction.

Several investigators have reported the accuracy of two-dimensional echocardiography in assessing left ventricular volumes and ejection fraction in experimental animals and in adult patients with valvular or coronary artery disease. The heart with a congenital defect, however, is subjected to different loading conditions. The use of two-dimensional echocardiography in apical views to estimate left ventricular volumes in children has also been reported. However, all possible models and views for estimating left ventricular volumes were not examined. We further evaluated the optimal two-dimensional views and the geometric assumptions to be made with these views for estimating left ventricular volumes and ejection fraction noninvasively in children with congenital heart disease.

Materials and Methods

Twenty-five patients scheduled for diagnostic or preoperative cardiac catheterization and two-dimensional echocardiography were included in the study. The patients were 6 weeks to 20 years old (mean 6.5 years). The clinical diagnoses are summarized in table 1.

Cineangiograms

After routine catheterization premedication, bpline left ventricular cineangiograms were obtained in the anteroposterior and lateral views at 50 frames/sec. In all patients, angiographic studies were free of extrasystoles and were of adequate technical quality for calculating angiographic volumes. A grid was filmed at the position of the heart and used to correct for linear magnification. Well-opacified, arrhythmia-free beats were used to measure end-diastolic and end-systolic left ventricular volumes. Volumes and ejection fraction were calculated by the area-length method. The computed volumes were then corrected according to previously derived regression equations.
TABLE 1. Details of the Patient Population (25 Patients)

<table>
<thead>
<tr>
<th>Sex</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>10</td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
</tr>
<tr>
<td>Age range</td>
<td></td>
</tr>
<tr>
<td>&lt;6 weeks</td>
<td>3</td>
</tr>
<tr>
<td>6-20 years</td>
<td>12</td>
</tr>
<tr>
<td>10-15 years</td>
<td>6</td>
</tr>
<tr>
<td>15-20 years</td>
<td>4</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
</tr>
<tr>
<td>Aortic stenosis (subaortic stenosis)</td>
<td>6 (2*)</td>
</tr>
<tr>
<td>Aortic insufficiency</td>
<td>2 (1†)</td>
</tr>
<tr>
<td>MV prolapse and insufficiency</td>
<td>1</td>
</tr>
<tr>
<td>ASD</td>
<td>1</td>
</tr>
<tr>
<td>VSD and pulmonary hypertension</td>
<td>2</td>
</tr>
<tr>
<td>VSD</td>
<td>3</td>
</tr>
<tr>
<td>Pulmonary stenosis</td>
<td>4 (1*)</td>
</tr>
<tr>
<td>Congenital cardiomyopathy</td>
<td>1</td>
</tr>
<tr>
<td>PDA</td>
<td>2</td>
</tr>
<tr>
<td>Repaired tetralogy of Fallot</td>
<td>2</td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
</tr>
</tbody>
</table>

*Postsurgical evaluation.
†Associated with aortic stenosis.

Abbreviations: MV = mitral valve; ASD = atrial septal defect; VSD = ventricular septal defect; PDA = patent ductus arteriosus.

Echocardiograms

Echocardiographic studies were performed immediately after angiography. Real-time two-dimensional echocardiographic studies were obtained with a phased-array sector scanner (Toshiba, model SSH-10A). The transducer consisted of 32 2.4-MHz piezoelectric crystals; the ultrasonic beam was focused dynamically and steered electronically through a 78° sector arc. The focal point was adjusted to 4, 5 or 7.5 cm, depending on the size of the patient. Lateral and axial resolution were determined with a 100-mm test object phantom box. Axial resolution was 1 mm at any depth, and lateral resolution was 1.5-2 mm at and before the focal point. Lateral resolution was 2.5 mm at 2 cm from the focal point, and 3 mm at 5 cm from the focal point. The images were displayed in real-time and recorded on 3/4-inch videotape cassette at 30 frames/sec (Nipon Electric Company). The videotape could be played back in real time; at one-ninth, one-eighteenth, one-thirty-sixth and one-seventy-second of real-time, and in stop-frame, frame-by-frame, forward and reverse modes, which allowed isolation of beats for area and dimensional measurements.

Left parasternal short-axis and apical long-axis views were used routinely. The parasternal short-axis views were obtained in the usual fashion. The patient was examined in the left lateral decubitus position. The transducer was placed in the third or fourth left intercostal space with the plane of the sector perpendicular to the left ventricular long axis. The views were obtained at the level of the mitral valve, at the tips of

SHORT AXIS VIEWS

ED

ES

PM₂

PM₁

MV

Figure 1. Two dimensional short-axis views used for echocardiographic estimation of left ventricular volumes. ED = end-diastole; ES = end-systole; MV = mitral valve level; PM₁ = tips of the papillary muscles; PM₂ = base of the papillary muscles.
the papillary muscles, and at the base of the papillary muscles (fig. 1). The apical four-chamber view was obtained as previously described. The transducer was rotated 90° counterclockwise to record the apical two-chamber view. To avoid foreshortening in this view, the aortic valve, aortic root, and the apex were imaged (fig. 2).

Images and a calibration factor were traced with a grease pen on transparent plastic sheets affixed to a 12-inch playback monitor (Setchell-Carlson, Inc.). Calibration was validated with a fluid-filled phantom box. End-diastole was defined as the frame at which the reference ECG reached the peak of the R wave. End-systole was defined as the frame at which the reference ECG reached the end of the T wave or the smallest left ventricular silhouette. Mitral valve motion did not define end-systole and end-diastole accurately. The papillary muscles were excluded from the outline tracings. The images were then retraced with a graphic image analyzer (Neumonics, Inc.) connected to a mini-computer (Wang, Inc.), which allowed analysis of the end-systolic and end-diastolic areas. The short-axis dimension of the left ventricle was measured at the level of the mitral valve and the tips of the papillary muscles by constructing a line from the midpoint of the septum to the posterolateral wall. An axis perpendicular to this short-axis dimension was also constructed in these same views to measure orthogonal short-axis diameters. The long axis was measured in the apical four-chamber view from the mid-mitral valve to the apex of the heart. The apical four-chamber view was selected because the length was greatest in this view. Dimensions and areas were measured at end-systole and end-diastole.

End-diastolic and end-systolic left ventricular volumes were assessed prospectively using eight algorithms based on five geometric models (fig. 3).

Simpson's Rule

Simpson's rule, which uses multiple short-axis views, was applied to two geometric models. In one model, the volume of the left ventricle was considered as the sum of a volume of a cylinder (from the base to the mitral valve), of a truncated cone (from mitral valve to mid-papillary muscle), and of a cone (from mid-papillary muscle to apex). The left ventricle was, therefore, transected by three short-axis sections that divided the ventricle into four parts:

$$\text{Volume} = (A_m + \frac{A_{m1} + A_{m2}}{2}) + (A_{m1} + A_{m2})$$

$$+ \frac{A_{m2}}{3} \left(\frac{L}{4}\right)^2$$

In the second model, left ventricular volume was also calculated assuming the volume of the ventricle to be the sum of small cylinders and a truncated ellipse:

$$\frac{L}{3} \left( A_{m1} + (A_{m2}) \right) + \left( \frac{A_{m2}}{2} \right)$$

$$\frac{L}{3} + \frac{\pi}{6} \left( \frac{L}{3} \right)^3$$

where \(L\) = the longest length measured from the apical four-chamber view, \(A_m\) = the area of the short axis at the mitral valve level, \(A_{m1}\) = the area of the short axis at the tips of the papillary muscles, and \(A_{m2}\) = the area of the short axis at the base of the papillary muscles.

Hemicylinder-Hemiellipsoid Model

The left ventricle was divided equally. The volume of a cylinder was added to the volume of a half ellipse.
**Algorithm**

**Formula**

**Geometric Model**

### Simpson's Rule I

\[ V = \frac{1}{6} \left( \frac{A_m + A_p + A_p_1}{2} \cdot A_t \cdot A_p \right) \]

### Simpson's Rule II

\[ V = \frac{1}{6} \left( A_m + A_p + A_p_1 \right) \cdot \frac{A_t + A_p}{3} \cdot \frac{A_p_1}{3} \]

### Hemisphere Cylinder (MV)

\[ V = \frac{1}{3} \pi b^2 h \]

### Hemisphere Cylinder (IPM)

\[ V = \frac{1}{3} \pi b^2 h \]

### Ellipsoid Single Plane Four Chamber View

\[ V = \frac{4}{3} \pi \text{A}^2 \text{b} \]

### Ellipsoid Single Plane Two Chamber View

\[ V = \frac{4}{3} \pi \text{A}^2 \text{b} \]

### Ellipsoid Biplane (MV)

\[ V = \frac{4}{3} \pi \text{a} \text{b} \text{c} \]

### Ellipsoid Biplane (IPM)

\[ V = \frac{4}{3} \pi \text{a} \text{b} \text{c} \]

(volume = \( \frac{5}{6} \pi \text{A}^2 \)). Short-axis areas (A) at the level of the mitral valve and high papillary muscles were separately applied to this formula. The length (L) of the ventricle was measured from the apical four-chamber view.

### Ellipsoid Single-plane Model

The left ventricle was assumed to be ellipsoidal. Volumes were calculated by planimetering the area (A) of the left ventricle from either the apical four-chamber or two-chamber views and measuring the longest length (L). Volume = \( \frac{0.85 \pi \text{A}^2}{L} \).

### Ellipsoid Biplane Model

Volumes were calculated by measuring the longest length (L) from the apical four-chamber view and the orthogonal minor-axis diameters (D_1, D_2) from the short-axis view at the mitral valve or papillary muscle level. Volume = \( \frac{\pi}{6} \cdot L \cdot D_1 \cdot D_2 \).

### Teichholz Formula

Volume = \( (7.0/2.4 + D) (D^3) \), where D = the internal dimension measured from M-mode tracings.

### Statistics

Left ventricular end-diastolic and end-systolic volume and ejection fraction obtained by each method were compared with volumes and ejection fraction obtained from biplane cineangiography. Linear regression analysis was performed using the least-squares method, and the standard error of the estimate was calculated as:

\[ SD \times \sqrt{(1 - r^2)} \]

\[ \sqrt{\frac{(n - 1)}{(n - 2)}} \]

where r = correlation coefficient and n = number of cases.

### Results

**Left Ventricular Volumes**

There was no significant difference in heart rates at catheterization and echocardiographic study (106 ± 24 vs 96 ± 24 beats/min, respectively). The echocardiographically estimated volumes and injection fraction are shown with the angiographically determined values in table 2. End-diastolic volume calculated from cineangiograms ranged from 25-242 ml. End-systolic volume ranged from 4.8-144 ml. The correlation of volumes estimated with two-dimensional echocardiography and those determined with angiography varied with the algorithm used. All echocardiographically determined volumes underestimated angiographically determined volumes. Algorithms using multiple short-axis views (Simpson's rule) produced a good correlation regardless of
Table 2. Comparison of Echocardiographically Estimated Left Ventricular Volumes and Ejection Fraction with Angiographically Determined Values

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>End-diastolic volume</th>
<th>End-systolic volume</th>
<th>Ejection fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>Slope</td>
<td>SEE (ml)</td>
</tr>
<tr>
<td>Simpson's Rule</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1*</td>
<td>0.98</td>
<td>0.63</td>
<td>7.2</td>
</tr>
<tr>
<td>11*</td>
<td>0.98</td>
<td>0.78</td>
<td>9.1</td>
</tr>
<tr>
<td>Hemisphere-cylinder (MV)</td>
<td>0.98</td>
<td>0.85</td>
<td>10.9</td>
</tr>
<tr>
<td>(PM)*</td>
<td>0.96</td>
<td>0.69</td>
<td>11.7</td>
</tr>
<tr>
<td>Ellipsoid single-plane 4C</td>
<td>0.93</td>
<td>0.56</td>
<td>12.2</td>
</tr>
<tr>
<td>2C</td>
<td>0.73</td>
<td>0.38</td>
<td>20.0</td>
</tr>
<tr>
<td>Ellipsoid biplane  (MV)</td>
<td>0.97</td>
<td>0.69</td>
<td>9.6</td>
</tr>
<tr>
<td>(PM)*</td>
<td>0.97</td>
<td>0.64</td>
<td>8.4</td>
</tr>
<tr>
<td>Teichholz formula</td>
<td>0.79</td>
<td>0.89</td>
<td>30.1</td>
</tr>
</tbody>
</table>

*Algorithms considered most optimal.
Abbreviations: 4C = four-chamber view; 2C = two-chamber view; MV = mitral valve; PM = papillary muscle.

The geometric model (figs. 4 and 5). The biplane ellipsoid algorithm using the longest length from the apical four-chamber view and two minor-axis diameters from the short axis was equally accurate estimating left ventricular volumes (figs. 4 and 5). The hemisphere-cylinder method using the planimetered area from the short axis (mitral valve or papillary muscle level) was only slightly less optimal. The single-plane apical methods and the Teichholz formula (M-mode) were least optimal.

Left Ventricular Ejection Fraction

Two-dimensional echocardiographic estimation of ejection fraction by the Simpson's rule algorithm correlated well with angiocardiographically determined values regardless of the geometric model used, as did the hemisphere-cylinder and ellipsoid biplane methods using the short-axis view at the papillary muscle level (fig. 6). The M-mode Teichholz formula and other two-dimensional methods were inferior and correlated poorly with angiocardiographically determined ejection fraction (table 2).

Discussion

The noninvasive evaluation of left ventricular volumes by two-dimensional echocardiography may provide new insights into left ventricular performance in children with congenital heart disease. Two-dimensional M-mode images [two-dim M-segm of segm overl ated] and ventriculograms of plane left ven

Figure 4. (left) Correlation of left ventricular end-diastolic volume (LVEDV) estimated by echocardiography (echo) with LVEDV calculated by angiography (angio). Echocardiographic estimates by Simpson's rule using multiple short-axis views assumed the ventricle to be a truncated cone. (right) Ellipsoid biplane method using the short axis at the papillary muscle level (PM) as one of the sector planes. The correlation of left ventricular end-diastolic volume estimated by echocardiography with LVEDV calculated by angiography is shown.
Figure 5. (Left) Correlation of left ventricular end-systolic volume (LVESV) estimated by echocardiography (echo) with LVESV calculated by angiography (angio). Echocardiographic estimates by Simpson's rule using multiple short-axis views assumed the ventricle to be a truncated cone. (Right) Ellipsoid biplane method using the short axis at the papillary muscle level (PM) as one of the sector planes. The correlation of LVESV estimated by echocardiography with LVESV calculated by angiography is shown.

Figure 6. (Left) Correlation of left ventricular ejection fraction (LVEF) estimated by echocardiography (echo) with LVEF calculated by angiography (angio). The algorithm used for echocardiographic estimates is Simpson's rule, which assumes the ventricle to be a truncated cone. (Right) Ellipsoid biplane method using the short axis at the papillary muscle (PM) level as one of the sector planes. The correlation of LVEF estimated by echocardiography with LVEF calculated by angiography is shown.
using multiple short-axis views combined with the
longest length from the apical four-chamber view are
superior to algorithms using either single-plane or
biplane apical views, regardless of geometric assum-
ptions. This concept was further supported by studies in
which echocardiography was used to measure left ven-
tricular mass and volumes in dogs. This approach is
particularly useful when left ventricular dyssynergy is
present. The hemispheric-cylinder algorithm can also
accurately estimate left ventricular mass. Our data
support these findings.

In an initial study in children with congenital heart
defects, Silverman et al. used single-plane and biplane
apical views to determine left ventricular volumes. They
used a single-plane and biplane area-length method and a
Simpson's rule method. The biplane area-length method
using both apical views best estimated left ventricular
volumes and ejection fraction. Our data do not confirm
this finding. These investigators, however, used a light-
pen microprocessor system that avoided parallax distortion, which
occurs when the ventsicles are outlined on clear
plastic. This may explain the discrepancy, because
parallax distortion could not be avoided with our
equipment. Because parallax distortion is minimal in
the center of the video monitor screen, algorithms
using short-axis views, which occupy primarily the
center of the monitor screen, are superior to
algorithms using only apical views, which occupy a
greater portion of the video screen. We found optimal
visualization of the anterolateral wall difficult to
achieve in the apical two-chamber view.

All methods used in the present study underestimated
diastolic volume, end-systolic volume and
ejection fraction. The degree of understimation
depended on the algorithm; paired apical and
short-axis views provided the best determinations of
diastolic and end-systolic volume. Because echo-
cardiography underestimated end-diastolic and end-
systolic volumes to the same degree, ejection fraction
correlated well with angiocardiacographic data. The best
ejection fraction data were provided by the ellipsoid
biplane model using the short-axis plane at the
papillary muscle level and the apical four-chamber view.

Ease of data acquisition must be considered in the
clinical practice of medicine. Because four of five
methods produced similar results, the simplest would
be the best. Our Simpson’s rule and hemispheric-
cylinder algorithms require planimemzung one or more
short-axis views. Other echocardiographic methods
applied to left ventricular volume determination in
children with congenital heart disease use a planimem-
ted area. These methods are time-consuming and
tedious. The ellipsoid biplane model, however,
requires only the measurement of two perpendicular
minor-axis diameters from a short-axis view and the
longest length from the apical four-chamber view.
This is the least difficult approach and is therefore the
most practical for clinical use.

We and others agree that two-dimensional echo-
cardiography is superior to M-mode echocardiog-

rhythm in calculating left ventricular volumes and eje-
tion fraction. Of the two-dimensional approaches
evaluated in children with congenital heart disease,
paired biplane methods are superior to single-plane
methods. In addition, at least one plane should be
a short-axis view along the left parasternal border and
four-chamber windows. Algorithms using sections through this plane are the
most accurate, regardless of geometric assumption.

Acknowledgment

The authors thank Cathy Hefienaf for editing and typing the
manuscript.

References

1. Pmbbo JF, Troy BR, Rossel RO: Left ventricular volumes and
2. Murray JA, Johnston W, Reid JM: Echocardiographic deter-
mination of left ventricular dimensions, volumes and perform-
am. Am J Cardiol 30: 252, 1972
3. Fortuin RJ, Hood WP, Sherman ME, Craige E: Determina-
tion of left ventricular volumes by ultrasound. Circulation 44:
575, 1971
4. Keve HH, Tymn M, Hunter S: Validity of echocardiographic
estimates of left ventricular size and performance in infants and
5. Teichholz LE, Kreulen T, Hermann MV, Goriin R: Problems in
echocardiographic volume determinations: echocardiographic-
angiographic correlations in the presence of absence of
asvnergy. Am J Cardiol 37: 7, 1976
6. Linhart JW, Mintz GS, Segal BL, Kawai N, Kohler MM, Left
ventricular volume measurement by echocardiography: fact or
fiction. Am J Cardiol 36: 114, 1975
7. Wilson JR, Reichek N: Echocardiographic indices of left ven-
8. Bhair DR, Jasbel-Jones BJ, Villoria G, Nakazawa M, Yabek
SM, Marks RA, Jarmakani JM: Accuracy of echocardiog-
raphy in assessing left ventricular dimensions and volume. Cir-
culation 57: 699, 1978
9. Kinsele B: Stroke volume and cardiac output by echocardiog-
10. Rauschuss S, Corjia BC, Feigenbaum H, Black MJ, Love-
place E, Phillips JF, Noble RJ, Knebel SB: Stroke volume
calculated from the mitral valve echogram in patients with
and without ventricular dysvnergy. Circulation 58: 125, 1978
11. Jacobs WR, Croke RP, Loeb HS, Gunnar RM: Echocardiog-
graphic aortic ejection area as a reflection of left ventricular
12. Lalani AV, Lee SXK: Echocardiographic measurement of car-
diac output using mitral valve and aortic root echo. Circulation
54: 736, 1976
M-mode echocardiographic formulas for determining left ven-
tricular stroke volume. A correlative study with thremodula-
tion and left ventricular single-plane cineangiography. Circu-
lalion 60: 1308, 1979
14. Teichholz LE, Cohen MB, Sonnenblick EH: Study of left ven-
tricular geometry and function by B-scan ultrasonography in
1974
ventricular volume determination by two-dimensional echo-
volume determination in the isolated ejecting canine left ventri-
cle by two-dimensional echocardiography. Circulation 60: 320,
1979
17. Eaton LW, Maughan WL, Weiss J: Accurate volume determi-
nation in the isolated ejecting canine heart from a limited
number of two-dimensional echocardiographic cross-sections.
(abstr) Am J Cardiol 48: 470, 1980

JA: Our cross-te
19. Bonnle DeMari
20. Nixon Measur
21. Carr K Measur
22. Schiller
23. Fulland
24. Wyatt

THE UI useful in blood flow measured

From the
ology and
Health and
Address
Cardiovasc
Japan
Received
Circulati

S

Circulation
Vol 65, No 5, May 1982
968

Downloaded from http://circ.ahajournals.org/ by guest on November 17, 2017
Pulmonary Regurgitation Studied with the Ultrasonic Pulsed Doppler Technique

KUNIO MIYATAKE, M.D., MITSONORI OKAMOTO, M.D., NAOKAZU KINOSHITA, M.D., MOKUO MATSUSHI, M.D., SEIKI NAGATA, M.D., SHINTARO BEPPU, M.D., YOUNG-DAE PARK, M.D., HIROSHI SAKAKIBARA, M.D., AND YASUHARU NIMURA, M.D.

SUMMARY Sixty patients with pulmonary regurgitation were studied by the pulsed Doppler technique combined with two-dimensional and M-mode echocardiography. Patients with pulmonary regurgitation had abnormal Doppler signals just below the pulmonic valve in the right ventricular outflow tract in diastole on the two-dimensional image. These signals were considered to indicate the regurgitant flow.

There are two patterns of pulmonary regurgitant Doppler signals. In pulmonary hypertension, the maximal component of instantaneous flow velocity is sustained at about the same signal strength throughout diastole, but when the pulmonary arterial pressure is normal, the velocity slows down gradually from early diastole to end-diastole.

Pulmonary regurgitation was detected by phonocardiography in about half the patients. In the remaining half, pulmonary regurgitant murmur could not be differentiated from aortic regurgitant murmur or was masked by coexistent aortic regurgitation or patent ductus arteriosus, whereas the Doppler technique indicated pulmonary regurgitation.

THE ULTRASONIC pulsed Doppler technique is useful in the noninvasive assessment of intracardiac blood flow. Blood flow from the right heart can be measured from the precordial approach because the right heart is located near the anterior chest wall and the flow direction is nearly parallel to the direction of the ultrasound beam for the Doppler technique. We investigated pulmonary regurgitation using a range-gated, pulsed Doppler technique combined with two-dimensional echocardiography and compared its sensitivity for diagnosis of pulmonary regurgitation with phonocardiography.

Methods We examined 1200 patients by the pulsed Doppler method from January 1979 to August 1980. In 60 of these patients, abnormal diastolic Doppler signals were detected in the subpulmonic area and the right ventricular outflow tract. These 60 patients were the...
Two-dimensional echocardiographic assessment of left ventricular volumes and ejection fraction in children.
J C Mercier, T G DiSessa, J M Jarmakani, T Nakanishi, S Hiraishi, J Isabel-Jones and W F Friedman

Circulation. 1982;65:962-969
doi: 10.1161/01.CIR.65.5.962

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1982 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/65/5/962

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org/subscriptions/