Measurement of Mitral Valve Orifice Area in Infants and Children by Two-Dimensional Echocardiography

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Two-dimensional echocardiograms of the mitral valve orifice area were obtained in 50 normal pediatric subjects, 15 patients with congenital mitral stenosis and 7 patients with tricuspid atresia. The mitral area was measured near the tips of the mitral valve leaflets from a diastolic cross-sectional image of the left ventricle. The cardiac images were recorded on videotape and later transferred to video disc for high resolution contour tracing. Contour analysis was performed by a special purpose microcomputer system for calculation of the enclosed calibrated area.

In normal patients, there was an excellent correlation ($r = 0.95$) between mitral valve area (MVA) (in cm^2) and body surface area (BSA) (in m^2) described by MVA = 4.83 × BSA − 0.07. Each patient with mitral stenosis had a mitral valve area that measured less than the third percentile predicted from the normal regression formula. In eight patients in whom the Gorlin formula could be applied, there was excellent correlation ($r = 0.95$) between echocardiographic and hemodynamic measurements of mitral valve area. Each patient with tricuspid atresia had a very large mitral valve area (> 99th percentile of normal). It is concluded that noninvasive measurement of mitral valve orifice area can be accurately achieved by two-dimensional echocardiography in pediatric patients with congenital mitral stenosis, allowing serial measurement of their mitral valve area.

Two-dimensional echocardiography has been widely utilized to accurately determine the mitral valve orifice area in adult patients with mitral stenosis, predominantly rheumatic in origin (1–4). This noninvasive method has correlated well with estimates of mitral valve area obtained by measuring the pressure gradient and diastolic flow across the mitral valve during cardiac catheterization and applying a hydraulic formula with an empiric correction factor (5). The absence of a measurable pressure gradient across a normal mitral valve precludes the use of the Gorlin formula for the calculation of the mitral valve orifice area in normal subjects.

This study was performed to determine the mitral valve orifice area in vivo in normal pediatric subjects as a frame of reference for evaluation of patients with congenital mitral stenosis. These findings were contrasted with the large mitral valve area measured in a group of patients with tricuspid atresia, whose total cardiac output traverses a single, large atrioventricular valve.

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Methods

Study subjects and patients. We studied 50 normal neonates, infants and children, 15 patients with congenital mitral stenosis and 7 patients with tricuspid atresia in whom good quality two-dimensional echocardiograms could be obtained (Table 1). The normal subjects were patients with a functional cardiac murmur or normal volunteers. The diagnosis of congenital mitral stenosis or tricuspid atresia was confirmed by cardiac catheterization and angiography or at autopsy examination.

Echocardiography. Two-dimensional echocardiographic studies were obtained with an Advanced Technology Laboratory ultrasonoscope utilizing either a 3.0 or 5.0 MHz transducer. The images were recorded on VHS 0.5 inch (1.27 cm) videotape and later transferred onto a Sony video disc, providing frame by frame forward and reverse features and stable (jitter-free) stop frame (6). The mitral valve orifice was measured near the tips of the mitral leaflets in a cross-sectional view of the left ventricle at the time corresponding to the E point of mitral motion.

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Table 1. Patient Profile

	Age (yr)	Weight (kg)	BSA (m^2)
Normal subjects (n = 50)			
Mean	2.5	10.9	0.52
SD	2.7	5.3	0.22
Range	0.003 to 9.3	2.6 to 25.5	0.18 to 0.93
Patients with congenital mitral stenosis (n = 15)			
Mean	1.4	7.9	0.36
SD	1.9	5.8	0.19
Range	0.006 to 11.2	2.9 to 38.3	0.18 to 0 88
Patients with tricuspid atresia (n = 7)			
Mean	4.7	15.5	0.67
SD	2.4	5.0	0 11
Range	2.5 to 9.2	10 to 26 2	0.52 to 0.88

SD = standard deviation.

Great care was taken to record the distal orifice of the mitral valve leaflets with an appropriate setting of gain attenuation. If the attenuation is too high, then dropout of portions of the mitral orifice may occur, making measurement of its area imprecise. If the attenuation is too low, then the measured mitral orifice will be less than the actual area (3,4).

An interactive microcomputer system was developed for the purpose of analyzing cardiac video images (6). A computer overlay memory with a resolution of 512 × 480 × 1 bit was synchronized and displayed with the video disc still frame memory. A digitizing pad (Summagraphics Bitpad I) was used for tracing contours and for marking linear distances. The high resolution of the computer video overlay exceeds that of the echocardiographic images and gives the illusion of continuous outlined contours.

The calculations of the video processing microcomputer include calibrated length and area measurements. Two calibrations were performed: a vertical calibration factor from the ultrasonoscope's vertical grid and an aspect ratio calibration (ratio of horizontal to vertical amplifications). Standard video monitors display a 4:3 aspect ratio. Our imaging system was adjusted to utilize a 1:1 aspect ratio which was confirmed by periodic use of a calibrated horizontal and vertical phantom grid system.

Statistics. Body surface area was computed based on the formula of Dubois and Dubois (7). Statistical analyses included calculation of mean and standard deviation, linear and nonlinear regression analysis, computation of *t* statistics and analysis of variance (F ratio). The level of significance was designated at a probability (p) value of less than 0.05.

Results

Normal subjects (Fig. 1 to 3). The mitral valve area in 50 normal pediatric subjects was closely correlated (r = 0.95) with body surface area. The data and a linear regression formula with the 3rd and the 97th percentile prediction limits are displayed in Figure 3. Less significant relations between mitral valve area and age, height and weight were found. Nonlinear (quadratic, power and exponential) regression formulas did not significantly improve the simple, linear relation between mitral valve area and body surface area. Separate analyses of the male and female normal subjects yielded similar regression formulas which were not significantly different in either the slopes or intercepts.

Congenital mitral stenosis (Table 2) (Fig. 4 and 5). The mitral valve orifice area was less than the third percentile of normal in all 15 patients with congenital mitral stenosis

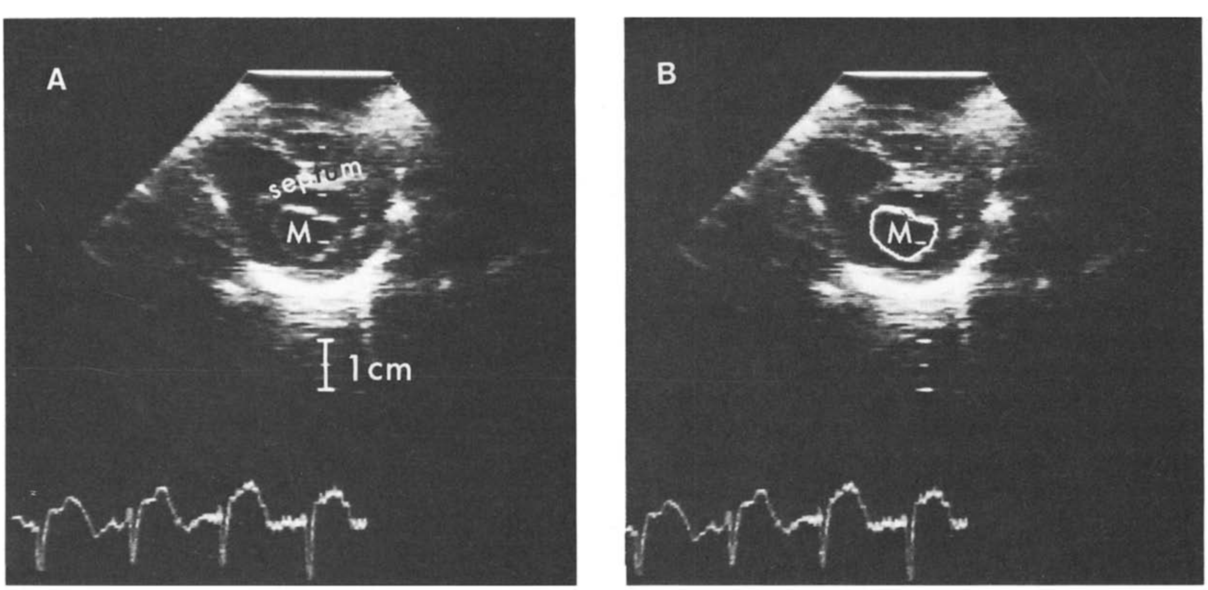


Figure 1. Cross-sectional echocardiogram of the left ventricle near the tips of the mitral valve leaflets, obtained from a normal neonate, demonstrating measurement of the mitral valve orifice (M) area corresponding to the E point during early diastole. **Panel A** is the original echocardiogram and **panel B** shows the high resolution video overlay. Note the 1.0 cm calibration Septum = interventricular septum.

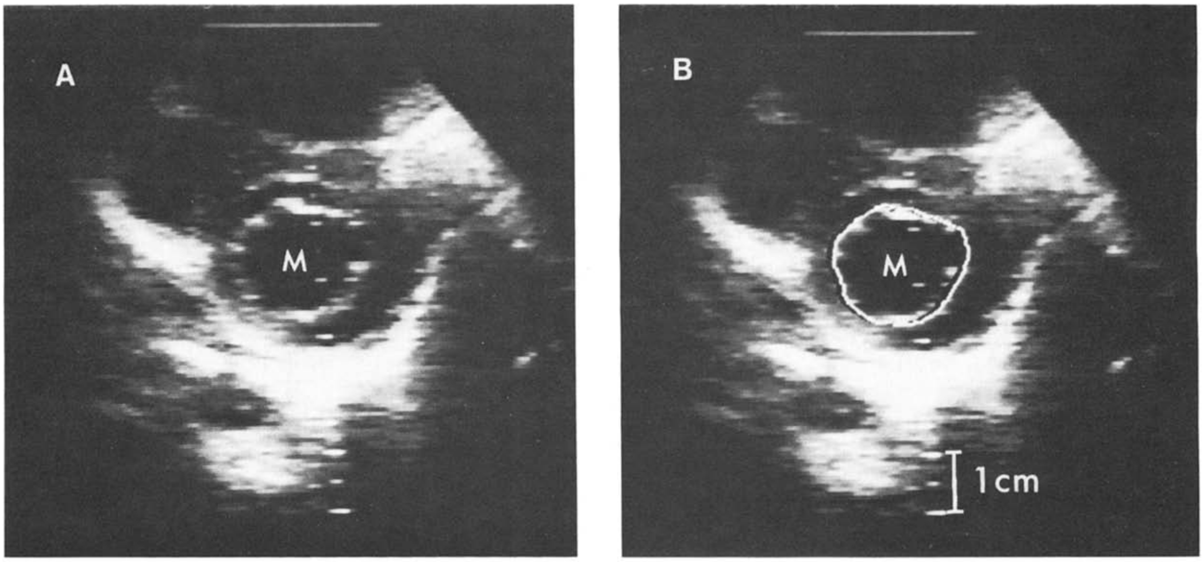
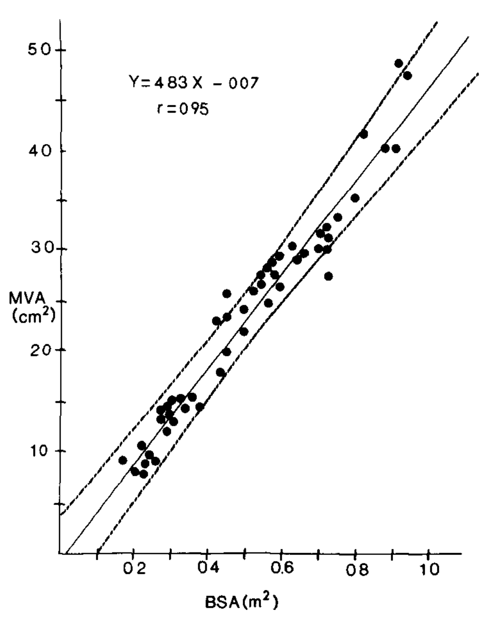


Figure 2. Cross-sectional echocardiogram from a normal child, demonstrating measurement of the mitral value orifice (M) area. **Panel A** is the original echocardiogram and **Panel B** shows the high resolution video overlay.

(Fig. 6). The correlation between echocardiographic and hemodynamic estimates of the mitral valve area was excellent (r = 0.95) in the eight patients in whom the latter estimate could be computed (Fig. 7). Six of our 15 patients had a parachute mitral valve with a solitary papillary muscle

Figure 3. Relation between mitral valve orifice area (MVA) and body surface area (BSA) in 50 normal infants and children. A significant linear correlation (r = 0 95) is noted, described by the regression equation, MVA = 4 83 × BSA − 0.07 The **solid line** demonstrates this regression equation; the **dashed lines** describe the 3rd and 97th percentiles.



(8). This diagnosis was substantiated in all patients at surgery or postmortem examination. Directing the ultrasonic beam in successive cross-sectional planes from the apex of the left ventricle toward the mitral valve allowed evaluation of the papillary muscles and chordal attachments.

Tricuspid atresia. The mitral valve orifice area exceeded the 99th percentile of normal in all seven patients with tricuspid atresia (Fig. 8). The actual mitral valve area averaged 214% of the expected area, based on the body surface area.

Reproducibility of measurements (Table 3). A sample of 20 patients was chosen randomly to assess the inter- and intraobserver variability in measurement of the mitral valve orifice area. This sample included subjects with a normal mitral valve and patients with congenital mitral stenosis. The mean interobserver difference was 15%, and the mean intraobserver difference was 9%. The F ratio computed for analysis of interobserver variation was 0.385 (not significant).

Discussion

Limitations of hydraulic formula for measuring mitral valve area. Although the Gorlin formula is useful in assessing the degree of mitral stenosis, it does not directly measure mitral valve orifice area. Instead, this area is computed with a hydraulic formula in which both the pressure gradient and diastolic blood flow across the valve are known (5). Utility of the formula is often limited in the presence of additional mitral regurgitation because total diastolic mitral flow is not precisely known. Moreover, the pressure gradient across the mitral valve may not be fully expressed in pediatric patients with congenital mitral stenosis, because an atrial septal defect or patent foramen ovale is frequently present. An atrial septal defect may vent the left atrium and

Table 2. Fifteen Patients With Congenital Mitral Stenosis

Case	Age (yr)	BSA (m^2)	Diagnosis	Mitral Valve Area (cm^2) Echo	Cath
1	2.4	0.53	Para MV	1.10	1.0
2	0.58	0.28	Small LV	0.28	0.40
3	0.65	0.31	CoAorta	0.35	0.45
4	2.3	0.44	Truncus	1.25	1.45
5	0.44	0.25	VSD	0.24	0.20
6	0.59	0.28	DORV; Para MV	0.46	0.50
7	0.25	0.30	CoAorta; small LV	0.60	0.70
8	4.12	0.66	Para MV	1.14	0.95
9	1.45	0.36	CAVC; Para MV	0.56	Minsuf
10	0.73	0.27	Para MV	0.80	ASD 2°
11	7.2	0.88	Isolated CMS	1.78	Minsuf
12	0.003	0.18	HLHS	0.26	PFO
13	0.006	0.18	HLHS	0.30	ASD 2°
14	0.009	0.21	HLHS	0.35	ASD 2°
15	0.015	0.22	LVOT tunnel, Para MV	0.48	ASD 2°

ASD 2° = secundum atrial septal defect; BSA = body surface area, Cath = cardiac catheterization (Gorlin formula), CAVC = complete atrioventricular canal defect, CMS = congenital mitral stenosis, CoAorta = coarctation of aorta, DORV = double outlet right ventricle, Echo = two-dimensional echocardiography, HLHS = hypoplastic left heart syndrome, LV = left ventricle; LVOT = left ventricular outflow tract, Minsuf = mitral insufficiency, Para MV = parachute mitral valve PFO = patent foramen ovale, Small LV = small, although not hypoplastic, left ventricle, Truncus = common truncus arteriosus

thus the hemodynamic manifestation of mitral stenosis will be a large left to right shunt at the atrial level rather than left atrial hypertension.

Accuracy of echocardiographic measurement of mitral valve area. Direct measurement of the mitral valve orifice area with two-dimensional echocardiography overcomes these limitations. This pediatric study and previous adult studies indicate that this method is very accurate and can be extended to include patients with mitral regurgitation or an atrial septal defect. One previous study of 14 adult patients (1) demonstrated an excellent correlation ($r = 0.92$) between surgical and echocardiographic measurement of the mitral valve orifice area, corroborating the utility of two-dimensional echocardiography as a means of directly measuring the mitral valve area, rather than indirectly assessing the area from a hydraulic formula.

Mitral valve area in normal infants and children. The normal mitral valve orifice area in adults is stated to range from 4 to 6 cm^2 (5), although in one postmortem study (9) it was reported to range between 4.9 and 10.2 cm^2. A recent

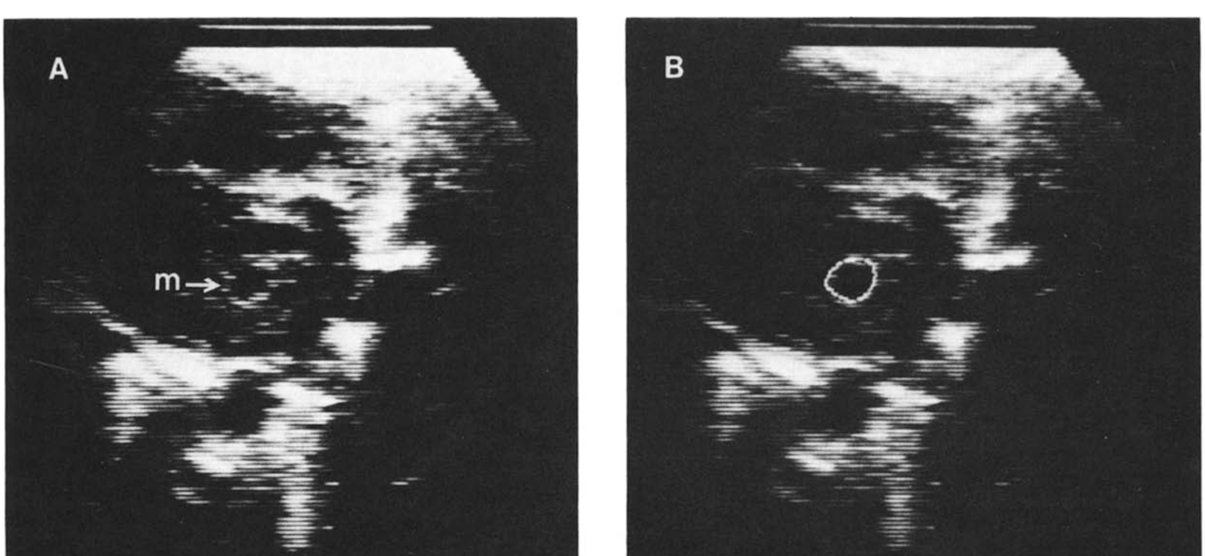


Figure 4. Cross-sectional echocardiogram of the left ventricle from a patient with congenital mitral stenosis. **Panel A** is the original; in **panel B** the mitral valve orifice has been outlined.

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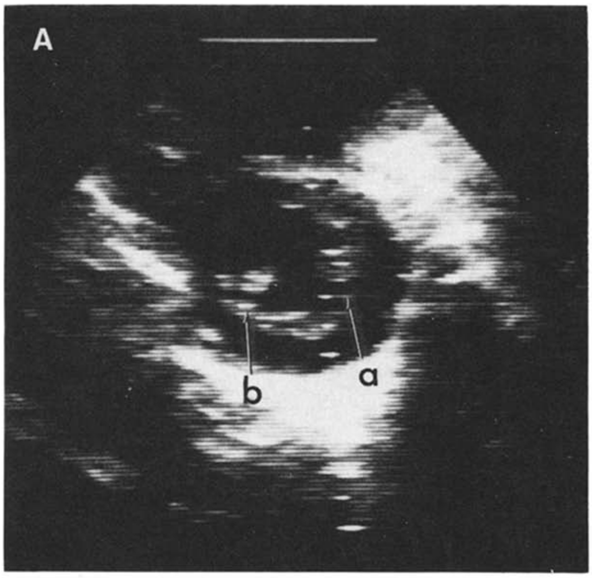
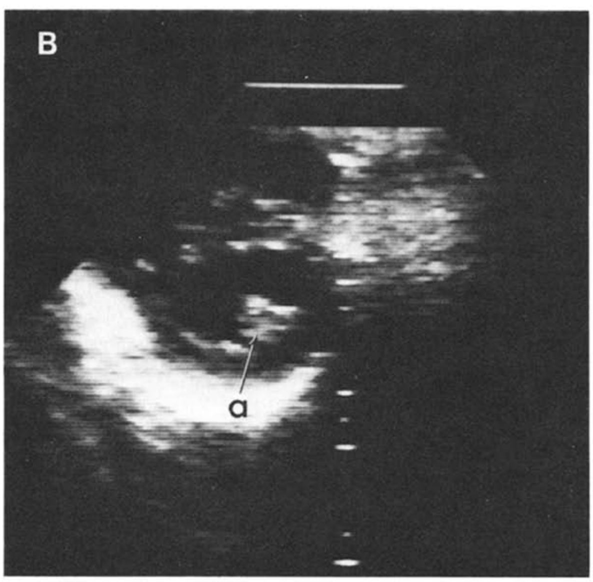




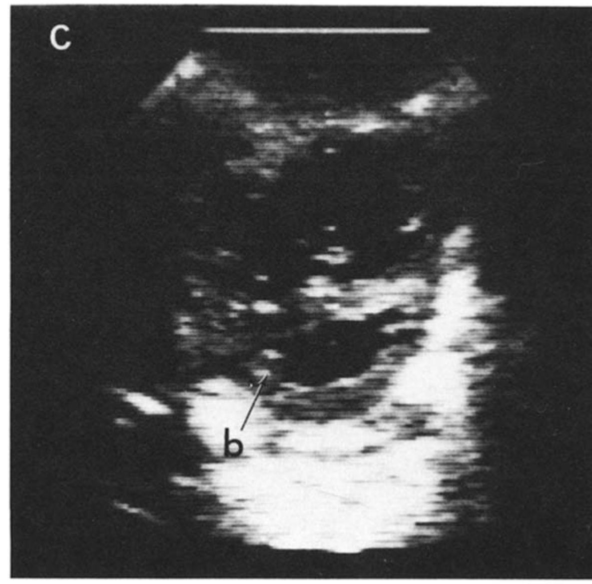
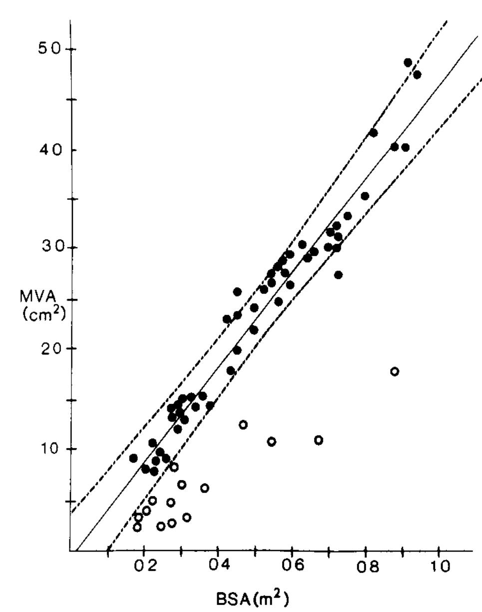


Figure 5. Cross-sectional echocardiograms of the left ventricle of three subjects at the level of the papillary muscles. **Panel A** is from a normal subject with two papillary muscles (a,b), **Panel B** is from a patient with a solitary anterolateral papillary muscle (a) and **Panel C** is from a patient with a solitary posteromedial papillary muscle (b).

echocardiographic study in adults (10) demonstrated a normal mitral valve orifice area of 4.2 cm^2/m^2, which is similar to our value of 4.7 cm^2/m^2. The linear relation between body surface area and mitral valve area in normal infants and children reflects the close relation between body surface area and cardiac output in normal subjects. The normal data are important for evaluation of pediatric patients with mitral stenosis, because the normal infant has a very small mitral orifice by adult standards. The analysis of normal patients and the limits expressed in Figure 3 allow prediction of mitral valve area based on body surface area and evaluation of relative degrees of mitral stenosis.

Technical problems with two-dimensional echocardiography. Previous studies (1,3,4) have emphasized some of the technical problems associated with two-dimensional echocardiographic evaluation of the mitral valve orifice area. The ultrasonic receiver gain setting must be properly attenuated, or the measured mitral valve orifice will not accurately reflect the actual area. Because the stenotic mitral valve may assume a funnel shape, the true minimal orifice must be localized by carefully sweeping the ultrasonic beam

Figure 6. Mitral valve orifice areas of 15 patients with congenital mitral stenosis are contrasted with the normal regression formula. Each patient with mitral stenosis had a mitral valve orifice area less than the third percentile of normal predicted from body surface area. The **closed circles** represented the normal subjects; the **open circles** represent the patients with mitral stenosis.



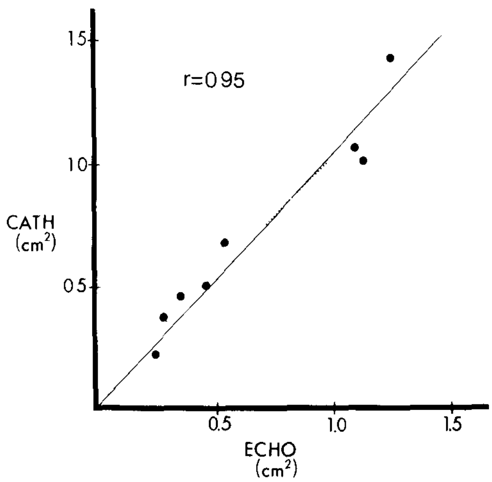


Figure 7. Relation between the mitral valve orifice area calculated from the Gorlin formula on the bases of cardiac catheterization (CATH) findings and that measured by two-dimensional echocardiography (ECHO). The line of identity is the **solid line**, and the regression equation (r = 0.95) is the **dotted line.** The lines do not differ significantly in either slope or intercept.

from the papillary muscles toward the atrioventricular groove. Comparison of the mitral orifice diameter in both cross-sectional and long axial views will help to confirm the proper localization of the minimal orifice of this funnel.

The frequent occurrence of a parachute mitral valve in pediatric patients with congenital mitral stenosis further complicates imaging of the mitral valve orifice. This is because it is eccentrically directed toward the anterolateral or posteromedial papillary muscle (8).

Implications. This study demonstrates that the noninvasive measurement of the mitral valve orifice area can be

Figure 8. Regression equation **(solid line)** describing the normal pediatric population (see Fig 6) and its 3rd and 97th percentiles **(dotted lines)** are contrasted with the large mitral valve orifice areas measured from eight patients with tricuspid atresia (**solid dots**). Each mitral valve orifice exceeds the 99th percentile predicted from the body surface area

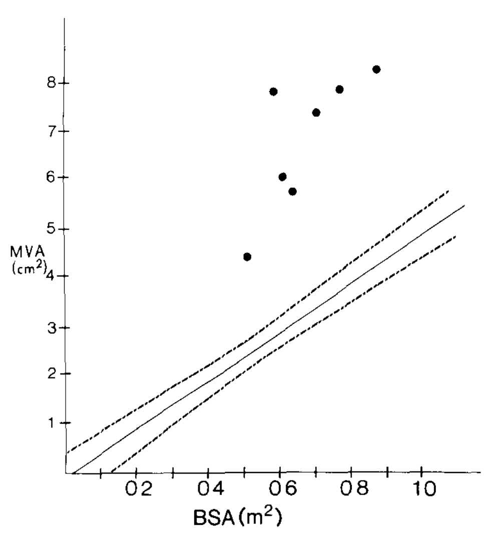


Table 3. Reproducibility of Measurements

	Observer		
	1	2	3
MVA (cm^2)			
Mean	2 22	2.43	1.94
SD	1.30	1.31	1 14
MID = 15%			
F Ratio = 0.385 (p = NS)			

MID = mean interobserver difference, MVA = mitral valve area, NS = not significant, p = probability, SD = standard deviation

accurately and reproducibly achieved by two-dimensional echocardiography. The mitral valve area in patients with congenital mitral stenosis and patients with tricuspid atresia was easily discriminated from that in normal subjects. Reliable, noninvasive serial evaluation of mitral valve orifice area in pediatric patients facilitates optimal timing of invasive studies or surgical procedures.

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