Right Ventricular Outflow Tract Assessment by Cross-Sectional Echocardiography in Tetralogy of Fallot

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SUMMARY Cross-sectional echocardiographic (CSE) studies were obtained in 29 children with tetralogy of Fallot. In this study we evaluated the capability of CSE to record the right ventricular outflow tract (RVOT) and compared the severity of infundibular obstruction determined by CSE with cineangiographic (cine) determinations. In addition, we examined capabilities of CSE and M-mode echocardiography (M-mode) to record the diagnostic features of tetralogy of Fallot, including RVOT obstruction, aortic overriding, ventricular septal defect, and presence of the pulmonary valve.

An excellent correlation \( r = 0.925 \) was found for the combined pre- and post-repair patients studied by CSE vs cine, while the correlation \( r = 0.805 \) for M-mode was not as good. The difference was even more striking for the unrepaired patients, in which the correlation \( r = 0.746 \) for CSE was much better than for M-mode \( (r = 0.374) \).

In the unrepaired patients, CSE allowed easier detection of the ventricular septal defect than M-mode \( (95\% \) for CSE vs 76\% for M-mode). The pulmonary valve was recorded in 90\% by CSE, but in only 26\% by M-mode. Aortic overriding was recorded in all unrepaired patients both by CSE and M-mode.

These data indicate that CSE is better than M-mode for recording the RVOT dimensions, ventricular septal defect, and the pulmonary valve in unrepaird patients with tetralogy of Fallot.

TETRALOGY OF FALLOT is the most common cyanotic congenital cardiac lesion presenting beyond the neonatal period.\(^1\) Characteristic pathological features of this disorder are a large subaortic ventricular septal defect, overriding of the interventricular septum by a dextroposed aorta, right ventricular outflow obstruction and right ventricular hypertrophy. The degree of right ventricular obstruction in tetralogy of Fallot is a primary determinant of right-to-left shunting, and therefore is a major factor in determining the severity of the disorder. Right ventricular outflow obstruction in tetralogy of Fallot always occurs at the infundibular area; valvular and supravalvular pulmonary obstruction may coexist. This paper will deal only with the evaluation of infundibular obstruction.

Previous studies\(^2-7\) have documented the usefulness of both M-mode and cross-sectional echocardiography in diagnosing tetralogy of Fallot. The quantitation of the degree of infundibular obstruction, however, has not been reported. In this study, we examined the capability of cross-sectional echocardiography to record the right ventricular outflow tract (RVOT) in patients with tetralogy of Fallot and to assess the severity of infundibular obstruction. The capabilities of M-mode and cross-sectional echocardiography to record the diagnostic features of tetralogy of Fallot were also examined.

Materials and Methods

Patients

This study included 29 children (table 1) with tetralogy of Fallot who consecutively underwent cross-sectional echocardiography and had a cardiac catheterization between February 1974, and December 1977. There were nine females and 20 males. The average age was 4.6 years (range 4 months–11 years). Twenty-two were studied before complete surgical repair and seven were studied post-repair. Of the 22 studied before repair, 10 had undergone a surgical shunt procedure for severe cyanosis. Of the seven patients studied post-repair, five required a RVOT patch and had associated pulmonary insufficiency, while two required only infundibulectomy, but continued to have mild RVOT obstruction (gradients 11 mm Hg and 12 mm Hg). Of the 29 patients, 19 have had surgical repair, with 14 (85\%) requiring an outflow patch.

Cardiac Catheterization

Right- and left-heart cardiac catheterization was performed using a standard technique. We established a catheterization diagnosis of tetralogy of Fallot by angiographically recording the interventricular septal defect, overriding of the ventricular septum by the dilated dextroposed aorta, infundibular pulmonary stenosis, and documenting systemic right ventricular pressures with normal pulmonary artery pressure. The

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RVOT was measured angiographically at end-systole and end-diastole in all patients. The minimum diameter of the RVOT, in the right anterior oblique projection, was used as the end-systolic dimension and the maximum diameter was used as the end-diastolic dimension. Diameters of the venous and arterial catheters, as well as the RVOT dimensions, were measured from projected cineangiograms. By knowing the actual external diameter of the catheters, we could calculate dimensions of the RVOT.

Cross-Sectional Echocardiograms

Cross-sectional echocardiograms were obtained within 24 hours of cardiac catheterization in 24 patients. The remaining five patients were examined early in the study period and had a cross-sectional echocardiogram within 6 months of cardiac catheterization. These five patients were 4 years of age or older and were felt to have had no further increase in the degree of RVOT obstruction during the 3–6 months between angiography and echocardiography.8–10

Cross-sectional studies were performed with either a mechanical sector-scanner (Smith-Kline Instruments, Echo Sector I). The axial resolution was 0.1 cm. A 2.25 MHz transducer (focused at 3.5 cm) mechanically driven through a 30° arc was used in 22 patients. The other seven patients were studied with a rotary transducer system. This wide-angle probe consisted of four acoustically matched 2.25 MHz transducers (focused at 5 cm) which were mounted perpendicularly within a plastic housing and rotated through a full 360° arc. This system produced an 82° sector. Cross-sectional studies were recorded on 1/2-inch videotape with a Sanyo VTC 700 videotape recorder. These records were available for analysis in real-time, slow-motion or single frame format. Still frames were converted to hard copy with a standard Polaroid photographic system.

Patients were examined in the supine or 30° left lateral position. The transducer was initially positioned along the left sternal border, with the plane of the sector aligned parallel to the long axis of the left ventricle (fig. 1). The midportion of the sector was positioned to encompass the free edge of the mitral valve (fig. 2). The transducer was then rotated clockwise approximately 60° to align the plane of the sector parallel to the long axis of the right ventricular outflow tract (fig. 3). The near-field gain and depth compensation were adjusted for optimal visualization.
FIGURE 1. Cross-sectional echocardiographic planes of the long axis of the left ventricle (LV) and the long axis of the right ventricular outflow tract (RVOT) in this study.

FIGURE 2. Typical cross-sectional view of the long axis of the left ventricle in a patient with tetralogy of Fallot. Note particularly the aortic overriding, septal-aortic discontinuity, and mitral-aortic continuity. CW = chest wall; RV = right ventricle; IVS = interventricular septum; LV = left ventricle; AML = anterior mitral leaflet; A-Ao = anterior aortic wall; Ao valve = aortic valve; P-Ao = posterior aortic wall; LA = left atrium.

FIGURE 3. Typical cross-sectional view of the long axis of the right ventricular outflow tract (RVOT) in a patient with tetralogy of Fallot. Note particularly the narrowed RVOT. CW = chest wall; Ao = aorta; LA = left atrium; TV = tricuspid valve; RA = right atrium; PV = pulmonary valve; PA = pulmonary artery.

of the RVOT. Once the RVOT was located, the transducer was swept from the lateral to medial margins, with the scan plane maintained parallel to its long axis to determine its maximum dimension. The dimension of the RVOT was determined by measuring the perpendicular distance between the anterior aortic wall and the right ventricular anterior wall directly anterior to the aortic root. This corresponds to the smallest dimension of the RVOT. The dimension of the RVOT was measured at end-systole (RVOT$_{es}$) and end-diastole (RVOT$_{ed}$) (figs. 4 and 5). The end-systolic frame was taken at the point of maximum anterior motion of the aortic root, when the outflow tract dimension was at its minimum, while end-diastolic was taken as the frame preceding the rapid onset of anterior systolic motion of the aortic root, when the RVOT was at its maximum dimension.

In addition to evaluating the RVOT, we evaluated the presence or absence of other characteristic features of tetralogy. With the sector aligned parallel to the long axis of the left ventricle (fig. 6), we determined the ability to visualize aortic overriding, as
defined by Gramiak, and presence of the ventricular septal defect. An interventricular septal defect was echocardiographically defined as septal-aortic discontinuity with rather abrupt drop-out of septal echoes, rather than normal blending of septal echoes with anterior aortic wall echoes. Finally, with the transducer parallel to the long axis of the RVOT, the transducer was angled superiorly and laterally to evaluate the presence of the pulmonary valve. During diastole a thin linear echo lying within the pulmonary artery was recorded and demonstrated the coapted leaflets. At the beginning of systole this linear echo separated into two discrete linear echoes which moved rapidly toward the lateral margins of the pulmonary artery. Only the posterior leaflet could routinely be recorded along the posterior margin of the pulmonary artery in systole.

There is greater scatter about the regression line at values below 1.2 cm. This may partially be explained by the axial resolution (0.1 cm) of the cross-sectional echo and the lateral resolution of the cineangiogram (0.1 cm, about 10%) being large in relation to the measurements.

In unrepaird patients the echocardiogram yielded a slightly larger RVOT dimension compared with the angiographic dimensions determined by contrast injection into the right ventricular chamber, which may cause infundibular spasm. The cross-sectional echocardiogram was typically done the day after angiography and should not cause infundibular spasm. This was most markedly demonstrated in one patient who developed a severe cyanotic spell during angiography. In this patient the RVOT dimensions were significantly larger as determined by cross-sectional echocardiography, when the patient was only mildly cyanotic, compared with the angiographic study, when the patient had a cyanotic spell (angiographic dimensions RVOTs = 0.3 cm, RVOTD = 0.3 cm; cross-sectional echocardiographic dimensions RVOTs = 0.9 cm, RVOTD = 1.2 cm). This error may also be partially explained by the difficulty in using a known catheter dimension to determine the dimension of a narrow intracardiac structure which may approximate the dimension of the catheter itself.

M-Mode Echocardiogram

Since M-mode echocardiography is the standard in clinical practice, M-mode studies were obtained to compare the capabilities of M-mode vs cross-sectional echocardiography in visualizing the diagnostic features of tetralogy of Fallot, i.e., narrowing of the RVOT, aortic overriding, presence of the ventricular septal defect, and presence of the pulmonary valve. Twenty-three patients (79%) had an M-mode echocardiogram concurrent with cross-sectional echocardiog-
As the study progressed, we found that M-mode echocardiography offered no advantage over cross-sectional echocardiography, which better delineated the characteristic features of tetralogy of Fallot. Therefore, in the later patients, M-mode echocardiograms were not performed with cross-sectional echocardiographic studies.

M-mode studies were performed with an Echoline 20 echograph coupled with a Honeywell 1856 fiberoptic strip chart recorder. We used either a 5 MHz non-focused or a 3.5 MHz non-focused transducer. Studies were done with the patient supine or in a 30° left lateral position. To record the RVOT, we obtained echoes from the position in which the aortic root, aortic leaflets and left atrium were recorded. The dimensions of the anteriorly positioned RVOT were measured as previously described. Determination of RVOT dimensions at end-systole and end-diastole required visualization of the leading edge of the anterior aortic wall and right ventricular anterior wall (fig. 7).

In addition, the transducer was scanned inferiorly and laterally to evaluate the presence of aortic overriding and a ventricular septal defect (fig. 8). We also tried to record the pulmonary valve.

Results

Right Ventricular Outflow Tract Dimensions
By Cross-Sectional Echocardiography

RVOT dimensions were obtained in all patients by cross-sectional echocardiography at either end-systole or end-diastole. Both were obtained in 27 of 29 patients. We found an excellent correlation ($r = 0.925$) between these and the angiographic dimensions (fig. 9). The correlation was $r = 0.746$ for the un repaired group and $r = 0.918$ for the repaired group.

In two patients only an end-systolic or an end-diastolic determination was possible. The first was studied early in the study period, and only the end-diastolic determination was possible. It was first studied early in the study period, and only the end-diastolic determination was possible. It was found that the M-mode echocardiograms offered no advantage over cross-sectional echocardiography, which better delineated the characteristic features of tetralogy of Fallot.
systolic dimension was technically adequate for measurement. The second patient's RVOT was determined only at end-diastole. This patient was noted on cineangiography to have a long tubular segment of infundibular pulmonary stenosis, with complete occlusion during systole.

Right Ventricular Outflow Tract Dimensions By M-Mode Echocardiography

To evaluate the capabilities of M-mode vs cross-sectional echocardiography to determine the RVOT dimensions, M-mode echocardiograms were done in the first 23 patients studied. M-mode echocardiography was successful in recording the RVOT in 70% (16 of 23) at either end-systole or end-diastole. Both end-systolic and end-diastolic dimensions were recorded in only 61% (14 of 23) of the patients. In the unrepaired group, the M-mode echocardiogram recorded RVOT in only 47% (eight of 17) at end-systole and 59% (10 of 17) at end-diastole. In all six patients in the repaired group both the end-systolic and end-diastolic dimensions were recorded.

The correlation between the M-mode echocardiographic and angiographic determinations was \( r = 0.805 \) for the combined pre- and post-repaired groups. A very poor correlation \( r = 0.374 \) was found in the unrepaired group. However, this \( r \) value does not include the seven patients in the unrepaired group whose ventricular outflow tracts were not recorded on the M-mode echocardiogram. In the post-repaired group, a good correlation \( r = 0.918 \) was found.

Aortic Overriding, Ventricular Septal Defect and Pulmonary Valve

Aortic overriding of the interventricular septum was recorded in all unrepaired patients with tetralogy of Fallot both by cross-sectional (22 of 22) and M-mode echocardiography (17 of 17). In patients with unrepaired tetralogy of Fallot, we noted a definite ventricular septal defect in 95% (21 of 22) by cross-sectional echocardiography, but in only 76% (13 of 17) by M-mode echocardiography. The pulmonary valve (figs. 4 and 5) was recorded in 90% (26 of 29) by cross-sectional echocardiography, but in only 26% (six of 23) by M-mode echocardiography. The pulmonary valve was recorded by cross-sectional echocardiography in all seven in the post-repair group and 86% (19 of 22) of the unrepaired group.

Discussion

Right Ventricular Outflow Tract

Narrowing of the RVOT is always found in patients with unrepaired tetralogy of Fallot. The degree of

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<td>Combined</td>
<td>0.925</td>
<td>0.805</td>
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<td>Unrepaired</td>
<td>0.746</td>
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<td>Repaired</td>
<td>0.918</td>
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Abbreviations: CSE = cross-sectional echocardiography; M-mode = M-mode echocardiography.
right ventricular outflow obstruction is one determinant of the degree of right-to-left shunting. A noninvasive evaluation of the severity of infundibular obstruction would therefore be helpful in both unrepaired and repaired patients with tetralogy of Fallot. We therefore performed both cross-sectional and M-mode echocardiographic studies to compare the capabilities of these methods in determining the severity of right ventricular outflow obstruction determined by cineangiography. We also evaluated the ability to record aortic overriding, a ventricular septal defect and the pulmonary valve.

For the combined pre- and post-repair group, the correlation \( r = 0.925 \) of the cross-sectional vs the angiographic determination compared favorably with M-mode determination \( r = 0.805 \). The difference was even more striking for the unrepaired group, in which the cross-sectional correlation was \( r = 0.746 \) and the M-mode was \( r = 0.374 \). Of the unrepaired patients, M-mode echocardiography could not adequately record the RVOT at either end-systole or end-diastole in 41% (seven of 17). The RVOT was recorded in all patients by cross-sectional echocardiography at either end-systole or end-diastole, and in 93% at both end-systole and end-diastole. In the repaired group the correlation between the angiographic and echocardiographic determinations were equal \( r = 0.918 \) for cross-sectional and M-mode studies. The cross-sectional echocardiogram therefore offers a significant advantage over the M-mode echocardiogram in recording the narrow RVOT in unrepaired patients with tetralogy of Fallot. This is explained by cross-sectional echocardiography allowing enhanced spatial determination of the anatomy of the RVOT, thereby ascertaining that the echocardiographic beam traversed the center of the outflow tract.

**Aortic Overriding, Ventricular Septal Defect and Pulmonary Valve**

Aortic overriding of the interventricular septum is echocardiographic evidence suggestive of dextroposition of the aorta. This is an echocardiographic finding in tetralogy of Fallot, double outlet right ventricle, persistent truncus arteriosus and pseudotruncus arteriosus (pulmonary atresia with ventricular septal defect).\(^3\)\(^-\)\(^4\)\(^-\)\(^7\)\(^-\)\(^8\) We observed overriding of the aorta in all patients studied both by M-mode and cross-sectional echocardiography.

We determined the presence of an interventricular septal defect in 95% of the unrepaired patients studied by cross-sectional echocardiography, but in only 76% by M-mode echocardiography. Whether dropout of echoes from the interventricular septum was artifactual or real was more easily ascertained by the wider field of vision offered by cross-sectional echocardiography. Tetralogy of Fallot is associated with a moderate-to-large ventricular septal defect in the subaortic area. Echocardiographic visualization of the ventricular septal defect is easier in tetralogy of Fallot than in an isolated small-to-moderate membranous ventricular septal defect without aortic overriding.

Mitral-aortic continuity is maintained in tetralogy of Fallot, but is lost in double outlet right ventricle. All patients were shown by cardiac catheterization to have tetralogy of Fallot, and on both cross-sectional and M-mode echocardiography had preservation of mitral-aortic continuity. The echocardiographic features of aortic overriding, presence of a ventricular septal defect, and preservation of mitral-aortic continuity are compatible with the diagnosis of tetralogy of Fallot. These are, however, not diagnostic and may be found in persistent truncus arteriosus, and pseudotruncus arteriosus.

**Figure 9. Comparison of right ventricular outflow tract dimensions as measured from cross-sectional echocardiograms and cineangiograms.** The dotted line represents a plot of the linear regression; \( r = 0.925 \), slope = 0.713, \( y \)-intercept = 0.327, SE = 0.25. Dimensions are measured in centimeters. \( \text{RVOT}_S = \) right ventricular outflow tract dimension at end-systole, \( \text{RVOT}_D = \) right ventricular outflow tract dimension at end-diastole.
To rule out these possibilities by echocardiography the pulmonary valve must be recorded, as emphasized by Chung et al.\textsuperscript{17} In our series the pulmonary valve was recorded by cross-sectional echocardiography in 90%.

It was recorded in only 26% by M-mode echocardiography. Cross-sectional echocardiography thus allows for easier detection of the pulmonary valve in patients with tetralogy of Fallot. Weyman et al.\textsuperscript{18} reported similar findings for recording the pulmonary valve in patients with valvular pulmonary stenosis. Cross-sectional and M-mode echocardiograms were not done by the same technician. We would expect a higher yield for recording the pulmonary valve by M-mode echocardiography had the pulmonary valve first been located by cross-sectional study.

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Right ventricular outflow tract assessment by cross-sectional echocardiography in tetralogy of Fallot.
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