M-Mode Echocardiographic Assessment of D-Transposition of the Great Arteries and Associated Defects

By

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INTRODUCTION

M-mode echocardiography has proven to be a reliable means for the diagnosis of d-transposition of the great arteries (8, 5). The M-mode echo diagnostic criteria are the demonstration of: (1) an anterior aorta, identified by delayed opening of its semilunar valve compared to the pulmonary valve, and (2) the aorta being situated rightward and anteriorly vis-a-vis the posterior pulmonary artery. Associated lesions such as left ventricular outflow tract stenosis can be qualitatively and quantitatively evaluated (3, 12). Echocardiographic assessments of pulmonary artery (10, 11) and left ventricular pressure (13) have also been reported, but the clinical reliability of these criteria is yet to be tested. The purpose of this study was to evaluate the diagnostic usefulness of various echo parameters and present their hemodynamic correlates, both before and after the Mustard operation and correction of associated lesions.

MATERIAL AND METHODS

Forty-one patients with d-transposition of the great arteries were studied prior to, and 73 following Mustard operation and correction of associated lesions. Seventeen patients had sequential pre- and postoperative echocardiographic and cardiac catheterization studies. The echocardiograms were obtained within 24 hours of cardiac catheterization.

M-mode echocardiograms were obtained in a standard manner using 5.0, 3.5 and 2.25 MHz transducers and an Ekoline echocardiograph connected to an 1856 Honeywell recorder. Echocardiographic examination was done in supine position. Particular attention was given to the transducer angulation while obtaining great vessel images. Repeated scan sweeps from the pulmonary artery to the left ventricle were obtained. Care was exercised in keeping an approximate parallel alignment between the

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pulmonary artery and the interventricular septum, so that quantification of the left ventricular outflow tract could be obtained (3). Ventricular end-diastolic dimension and wall thickness were obtained at the time of the electrocardiographic R wave peak where maximum amplitude of the mitral valve was present (6). In patients with surgically induced complete right bundle branch block, the dimensions were obtained at a point just proximal to the isovolumetric systolic notch on the posterior left ventricular wall tracing. The left ventricular dimensions were measured from the anterior edge of the ventricular free wall endocardium to the posterior edge of the ventricular septal endocardium (3). Since considerable variation of left ventricular dimension was noted (13), an average of five consecutive measurements was obtained. Right and left ventricular dimensions were obtained at the same site. The left ventricular posterior wall was measured from the anterior edge of the pericardium to the anterior edge of the endocardium and the septal thickness was measured between the right and left ventricular endocardial edges (3). We have used our own (3) and previously published normal values obtained for the various echo parameters as described above and not followed the recommendations of the Committee on Echocardiography. Furthermore, the recommended method of measurements does not reflect the anatomic boundaries of structures and there is evidence to suggest that the measurements of left ventricular dimension are larger than angiographically measured values (9). Our own experience suggests that using the recommended methodology the left ventricular end-diastolic dimension is larger, septal thickness smaller than posterior wall thickness, and left atrium/aorta (LA/AO) ratio greater than would be expected in normal controls.

Pulmonary arterial root dimensions were measured at end-systole between the outer edges of the arterial wall echoes. The left atrial dimension was measured between the posterior endocardial-pericardial wall echo to the posterior edge of the pulmonary arterial wall echo at end-systole (3). The left ventricular outflow tract was measured immediately below the pulmonary arterial root as the antero-posterior dimension between the closure point of the mitral valve (anterior edge) and the left ventricular endocardial edge of the ventricular septum (3). The pre-ejection period and ejection time were measured from the pulmonic and aortic valve echoes (11).

Echo measurements were made only when the recordings were considered optimal, and thus the number of measurements do not necessarily match the number of patients in each group.

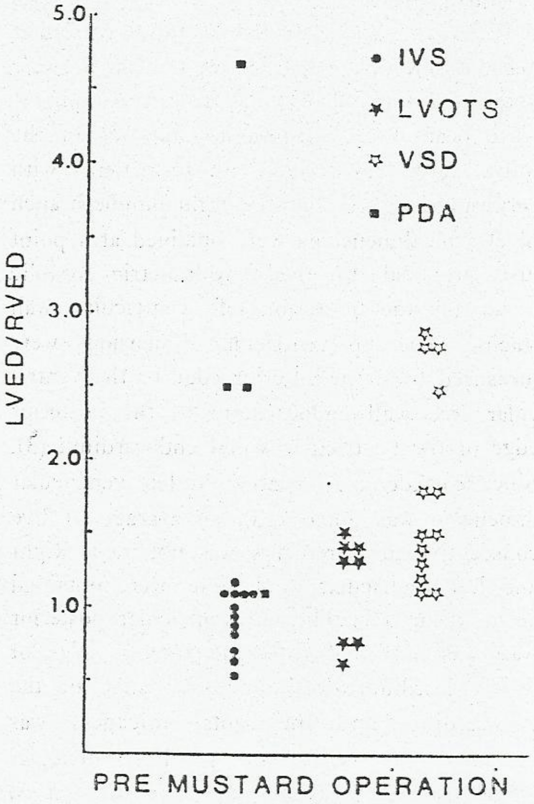
Hemodynamic data were obtained at cardiac catheterization using fluid-filled catheters and Statham gauge pressure transducer prior to the angio-graphic studies. Right ventricular angiographic volumes and ejection fractions were obtained in 18 patients using Simpson's method (7). Superior vena caval, right ventricular and left ventricular selective cineangiograms were also obtained.

RESULTS

Preoperative Studies:

Forty-one patients with d-transposition of the great arteries were studied prior to the

Mustard operation and correction of associated lesions. The echocardiographic and hemodynamic data of these patients are presented in Table 1. The age ranged between 1 day and 13 years (mean 3.2±4.2 years). Nine patients were under 10 days of age. The patients were divided into three groups. Group I included 17 patients with intact ventricular septum with or without an associated patent ductus arteriosus; Group II, 13 patients with large ventricular septal defect; and Group III, 11 patients with left ventricular outflow tract stenosis with or without ventricular septal defect. The results are presented to evaluate the capability of echocardiography for (a) diagnosis of d-transposition and associated lesions such as shunting lesions and left ventricular outflow stenosis, and (b) assessment of right ventricular function.



[*Fig.* 1. Echocardiographically determined left ventricular end-diastolic/right ventricular end-diastolic dimension ratio (LVED/REVD) in patients with d-transposition of the great arteries prior to Mustard operation. None of the patients with intact ventricular septum had LVED/RVED⊳1.2. This parameter effectively separated out the majority of patients with ventricular septal defect and patent ductus arteriosus who had LVED/RVED⊳1.2.

IVS, intact ventricular septum; LVOTS, left ventricular outflow tract stenosis; PDA, patent ductus arterious.]

Preoperative Diagnosis of d-Transposition of the Great Arteries:

The preoperative echocardiographic diagnosis of d-transposition of the great arteries was made in 39 of 41 cases by using one or both of the following criteria: (a) earlier opening of the pulmonic valve compared to aortic valve in all patients (in 3 of 13 patients with large ventricular septal defect this interval difference was only 5 ms which is within the range of interobserver measurement variation), and (b) transducer angulation used to detect an anterior vessel (aorta) to the right and anteriorly (toward the right shoulder) of the posterior vessel (pulmonary artery); in 2 patients although the aorta was imaged to the left of the pulmonary artery the correct diagnosis could be made by combining the clinical criteria.

Table I. Hemodynamic and Echocardiographic Data of 41 D-Transposition Patients before Mustard Operation

		Group I IVS	*No.*	*Group II VSD*	*No.*	*Group III LVOTS*	*No.*
BSA		0.44± 0.37	17	0.56± 0.37	13	0.46± 0.33	11
PEP AO-PEP PA(ms)		25± 11	17	25± 28	13	13± 13	11
LVED DIMENSION(cm)	—WITHOUT PDA	1.45± 0.38**	8	2.75± 0.95**	13	2.35± 1.10	10
	WITH PDA	2.50± 1.10					
PLV (mm Hg)		40.30± 9.60	17	86± 17	9	83± 21	9
PLV/PRV RATIO	—WITHOUT PDA	0.50± 0.15	10	0.98± 0.07	13	0.88± 0.19	10
	WITH PDA	0.82± 0.35	4				
LVED/RVED DIMENSION RATIO	—WITHOUT PDA	0.93± 0.21***	12	1.82± 0.68****	13	1.10± 0.36*	6
	WITH PDA	2.70± 1.40	4				
LVO/PA RATIO		0.76± 0.13***	17	0.79± 0.11	13	0.49± 0.12***	8
AP AT LVO (mm Hg)		15± 8	17	15± 14		56± 28	9
LVPW dt (cm)		0.40± 0.12*	14	0.54± 0.14*	9	0.49± 0.13*	9
LVSW dt (cm)		0.49± 0.10	13	0.60± 0.21	8	0.50± 0.12	9
PEP/RVET RATIO		0.39± 0.07	16	0.40± 0.07	11	0.41± 0.11	8

Test of significance by t test:
* $p < 0.025$
** $p < 0.005$
*** $p < 0.001$

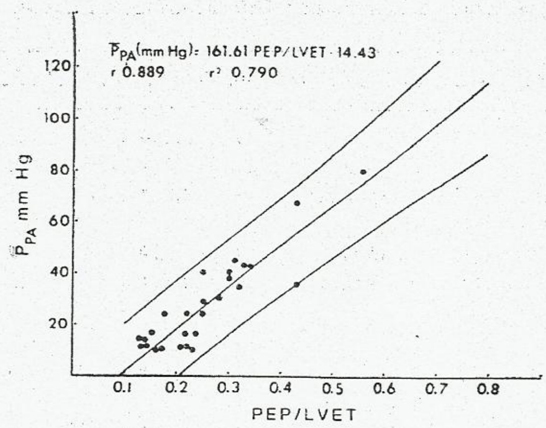
ABBREVIATIONS: AO, aorta; BSA, body surface area; IVS, intact ventricular septum; LVED, left ventricular end-diastolic dimension; LVO, left ventricular outflow tract; LVOTS, left ventricular outflow tract stenosis; PVL, left ventricular pressure; LVPW dt, left ventricular posterior wall diastolic thickness; LVSW dt, left ventricular septal wall diastolic thickness; AP, pressure gradient; PA, pulmonary artery; PDA, patent ductus arteriosus; PEP, pre-ejection period; RVET, right ventricular ejection time; PRV, right ventricular pressure; VSD, ventricular septal defect.

Detection of Associated Lesions: Shunting Lesions i.e., ventricular septal defect and patent ductus arteriosus:

The left ventricular end-diastolic/right ventricular end-diastolic dimensiôn ratio (LVED/RVED) was significantly higher for Group II patients with ventricular septal defect and Group I patients with patent ductus arteriosus compared to Group I patients without ductus arteriosus or Group III patients with left ventricular outflow tract stenosis (Table I). All Group I patients in the pre-Mustard series without patent ductus arteriosus had ratios <1.2 (Fig. 1).

A significant but weak linear correlation between the LVED/RVED and PLV/PRV ratio was noted for the entire preoperative population ($r=0.45$, S.E.E. 0.22), but it was an unreliable index for assessment of left ventricular pressure.

The mean pulmonary arterial pressure was linearly related to the pre-ejection period/left ventricular ejection time ratio (PEP/LVET), $r=0.89$, S.E.E. 8.6 mmHg, but the correlation was weak for predictive purposes. The patients with REP/LVET ratios ≥ 0.30 all showed mean pulmonary arterial pressure of > 25 mmHg though the reverse showed only 2 of 27 exceptions (Fig. 2).



[*Fig.* 2. Relation of mean pulmonary arterial pressure (PPA) to echocardiographically determined left ventricular PEP/LVET (pre-ejection time to ejection time) ratio in patients with d-transposition of the great arteries before Mustard operation. Significant statistical correlation is shown though it was considered inadequate for predictive purposes. Lines representing mean and 95 percent confidence limits are drawn.]

Detection of Left Ventricular Outflow Tract Stenosis:

The left ventricular outflow tract/pulmonary artery dimension ratio (LVO/PA) was similar for Groups I and II and was significantly reduced for patients with anatomically fixed stenosis in Group III (Table I). A dynamic type left ventricular outflow tract stenosis, characterized by early posterior systolic septal bulging and systolic anterior motion of the mitral valve, coarse flutter of the pulmonic valve and relatively normal left ventricular outflow tract dimensions, was noted in 5 patients in Group I. The systolic pressure difference across the left ventricular outflow tract in these patients was between 16-25 mmHg. Four of 11 patients in Group III showed features of dynamic form of left ventricular outflow tract stenosis with pressure gradient across the left ventricular outflow tract $\geqslant$25 mmHg and mean peak systolic left ventricular pressure 66±8 mmHg. In 2 of these 4 patients

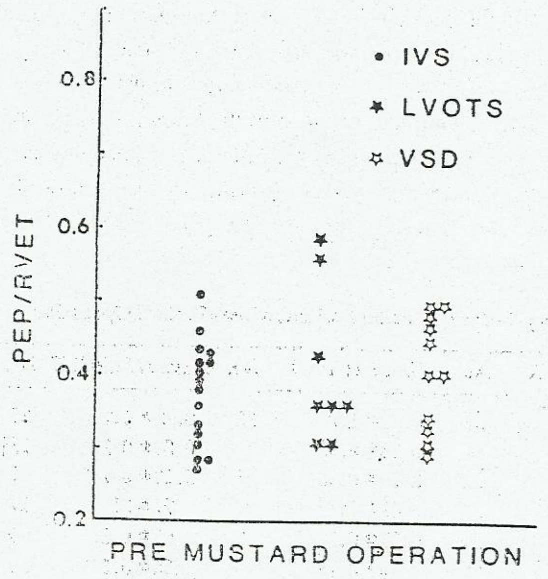
Table II. Anatomic, Hemodynamic and Electrocardiographic Complications in 73 Patients with D-Transpostion after Mustard Operation

	Group I	*Group II*	*Group III*	*Total*
SVC STENOSIS	1	1	0	2
PVA STENOSIS	1	1	0	2
TRICUSPID INSUFFICIENCY	1	1	2	4
RESIDUAL SHUNTS*—				
ATRIAL	3	0	0	3
VENTRICULAR	0	3	0	3
CRBBB	5	3	8	16
CHB	2	1	1	4
DYSRHYTHMIA	2	1	2	5
PVO	1	0	1	2

*Qp/Qs ratio $\leqslant$1.5. ABBREVIATIONS: CHB, complete heart block; CRBBB, complete right bundle branch block; PVA, pulmonary venous atrium; PVO, pulmonary vascular obstructive disease; SVC, superior vena cava.

there were features of both the anatomically fixed and dynamic types of stenosis (LVO/PA ratio <0.53). In 6 of 11 patients in Group III only anatomically fixed stenosis was noted. One remaining patient in Group II had isolated pulmonary valve stenosis and unobstructed left ventricular outflow tract.

Compared to Group I, the left ventricular posterior wall thickness was greater for Groups II and III. Disproportionate septal hypertrophy was not noted in any of the patients (Table I).



[*Fig*. 3. Echocardiographically determined right ventricular pre-ejection period to ejection time ratio (PEP/RVET) in pre-Mustard operation population. Three patients showed ratio>0.5; one with intact ventricular septum (IVS) has clinical evidence of right ventricular failure due to tricuspid insufficiency and 2 had left ventricular outflow tract stenosis (LVOTS).

Abbreviations as in Figure 1, and: PEP/RVET, right ventricular pre-ejection period to ejection time ratio.]

Right Ventricular Function:

The mean pre-ejection period/right ventricular ejection time ratio (PEP/RVET) was 0.39 ± 0.38 for all three groups and no significant difference in the ratio was noted between these three groups (Table I). PEP/RVET ratio of >0.5 was noted in 3 patients (Fig. 3).

Hemodynamic Assessment of Mustard Operation and Correction of Associated Lesions

The significant postoperative anatomic, hemodynamic, and electrocardiographic abnormalities for the entire group are tabulated in Table II.

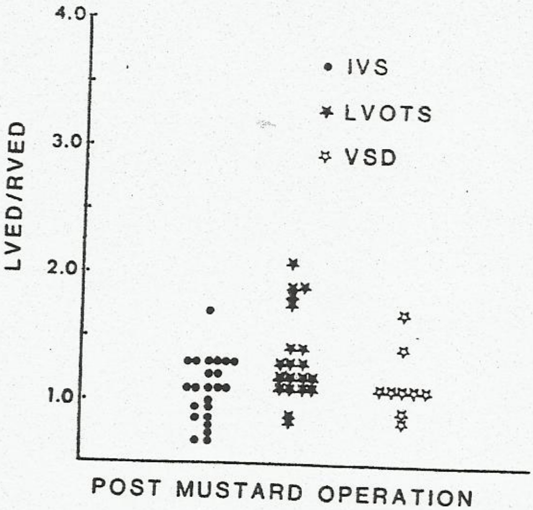
Postoperative Studies:

Seventy-three patients were studied postoperatively (Table III); 33 with intact ventricular septum (Group I), 15 with ventricular septal defect (Group II), and 25 with left ventricular outflow tract stenosis (Group III). The age ranged from 4 days to 18 years. Two patients (included in preoperative studies) in Group III had a Rastelli procedure and are excluded from further analysis. A mean of 3.6 ± 2.6 years elapsed between the Mustard operation and the postoperative echocardiographic analysis.

Echocardiographic Analysis: LVED/RVED:

The LVED/RVED ratio was comparable in Groups I and II (Table III, Fig. 4). A larger LVED/RVED ratio was noted in the left ventricular outflow tract stenosis group (Group III) which continued to show elevated left ventricular peak systolic pressure.

The LVED/RVED ratio for the entire group showed a weak linear relation to the PLV/PRV ratio (r=0.53, S.E.E. 0.13, n—44).



[*Fig.* 4. Echocardiographically determined left ventricular end-diastolic/right ventricular end-diastolic dimension ratio (LVED/RVED) in patients with d-transposition of the great arteries after Mustard operation. The ratio in the shunting lesion group was similar to those with intact ventricular septum. Largest ratio was noted in patients with residual left ventricular outflow stenosis and elevated left ventricular pressure. Abbreviations as in Figure 1.]

Assessment of Pulmonary Arterial Pressure by Systolic Time Intervals:

In this study the presence of complete heart block, arrhythmia, and complete right bundle branch block made this parameter an unreliable indicator of the pulmonary artery pressure. Seven patients with complete heart block, complete right bundle branch block, or atrial arrhythmia were excluded from the analysis. The mean pulmonary atrerial pressure showed a weak linear relation to the PEP/LVET ratio (r=0.55, S.E.E. 8.3, n—43). However, when

Table III. Hemodynamic and Echocardiographic Data of 73 D-Transposition Patients after Mustard Operation

	Group I IVS	*No.*	*Group II VSD*	*No.*	*Group III LVOTS*	*No.*
AGE AT ECHO	4. 9± 3.3	33	6. 3± 4.7	15	8. 2± 4.7	25
BSA	0.74± 0.31		0.95± 0.38		0.89± 0.30	23†
LVED DIMENSION (cm)	2.50± 0.56**	22	2.70± 0.83	11	3.10± 0.78**	23
PLV (mm Hg)	35± 20	23	41± 14		77± 31	17
PLV/PRV Ratio	0.35± 0.18	20	0.37± 0.11	9	0.65± 0.31	16
LVED/RVED RATIO	1.19± 0.24*	23	1.10± 0.29	9	1.36± 0.36*	20
LVO/PA RATIO	0.72± 0.10***	29	0.72± 0.14	15	0.52± 0.10***AS	9
					0.78± 0.13 DS	11
AP AT LVO (mm Hg)	11± 10	29	13± 11	11	54± 27 AS	9
					21± 11 DS	11
LVPW dt	0.44± 0.10***	26	0.51± 0.16	13	0.60± 0.11*** AS	9
					0.50± 0.12 DS	11
LVSW dt	0.40± 0.10***	26	0.55± 0.17		0.62± 0.08*** AS	
					0.56± 0.15 DS	
PEP/RVET RATIO	0.45± 0.13	29	0.46± 0.18	9	0.42± 0.11	23

2 †patients had Rastelli type repair and are excluded.
Test of significance by t test:
* p<0.1 ** p<0.01 *** p<0.001

ABBREVIATIONS: As in Table I, and: AS, anatomically fixed stenosis; DS, dynamic stenosis.

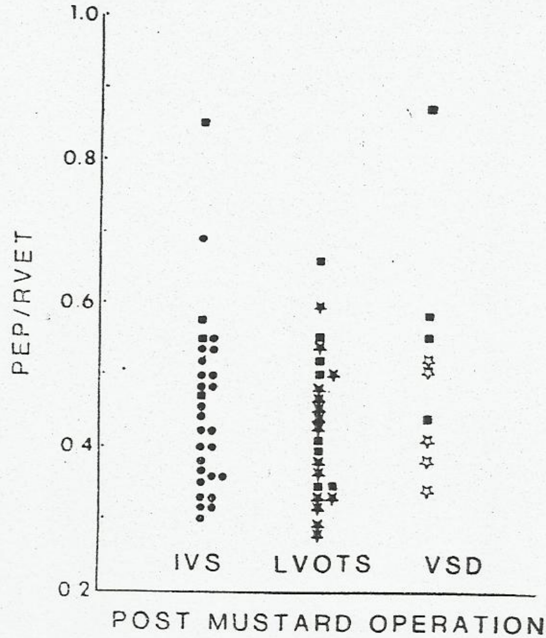
the PEP/LVET ratio was $\geq$0.30 the mean pulmonary artery pressure was $\geq$25 mmHg in all instances. The development of pulmonary artery hypertension following Mustard operation in two patients was indicated by an elevated PEP/LVET ratio (0.43) in one but not in the second patient who preoperatively had anatomically fixed left ventricular outflow tract stenosis with ventricular septal defect.

Left Ventricular Outflow Tract Stenosis:

The LVO/PA ratio was comparable for Groups I and II and those patients in Group III with dynamic left ventricular outflow stenosis (Table III). The patients with anatomically fixed stenosis had pressure gradients of $\geq$25 mmHg across the left ventricular outflow tract. In Group III the posterior wall thickness was increased compared to Groups I and II, reflecting the elevated residual afterload (Table III). Eight patients in Group I showed features of dynamic stenosis and left ventricular outflow pressure gradient $\leq$20 mmHg. Eleven patients in Group III had dynamic stenosis and pressure gradient $\geq$25 mmHg in 7 and between 20-25 mmHg in 4 patients. The posterior wall thickness for patients with pressure gradients $\leq$20 mmHg (0.48$\pm$0.07) was smaller than the wall thickness of patients with left ventricular outflow tract pressure gradient $\geq$25 mmHg (0.59$\pm$0.15) ($p \leq 0.1$).

Right Ventricular Function:

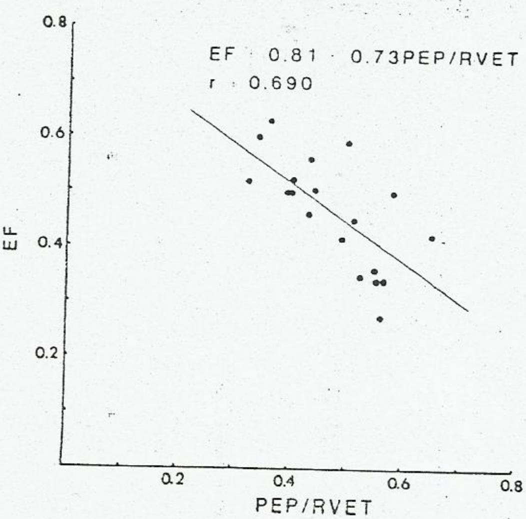
The PEP/RVET ratio was not significantly different between the three groups and the mean ratio for the combined three groups was 0.45$\pm$0.12. Complete right bundle branch block was present in 16 patients; 5 in Group I, 3 in Group II, and 8 in Group III (Fig. 5). Patients with complete right bundle branch block and a higher PEP/RVET ratio (0.54$\pm$0.15, n=16) compared to those without right bundle branch block (0.46$\pm$0.09, n=46) ($p \leq 0.025$).



[*Fig.* 5. Echocardiographically determined right ventricular pre-ejection period to ejection time ratio (PEP/RVET) after Mustard operation. Sxiteen patients showed PEP/RVET values $\geq$0.5, 11 of these had complete right bundle branch block (■).
Abbreviations as in Figure 1; (■) Patients with complete right bundle branch block. Other symbols as on Figure 4.]

The PEP/RVET ratio was evaluated as an indicator of right ventricular ejection fraction. Angiographically determined ejection fraction was available in 18 patients. There was a significant linear relation between ejection fraction and PEP/RVET ratio (EF=0.81-0.73 PEP/

RVET, r=0.69). Eight of 10 patients with right ventricular ejection fraction of <0.5 had a PEP/RVET ratio of ≤0.5 (Fig. 6).



[*Fig.* 6. Angiographically determined right ventricular ejection fraction (EF) and echocardiographically determined right ventricular pre-ejection period/ejection ratio (PEP/RVET) in 18 patients with d-transposition of the great arteries following Mustard operation. A significant linear relationship is shown between these two variables.
Abbreviations as in Figure 1, and: EF, right ventricular ejection fraction; PEP/RVET, right ventricular pre-ejection period to ejection time ratio.]

Sequential Pre- and Postoperative Studies:

The detailed hemodynamic and echocardiographic data are presented in Table IV. Seventeen patients who were studied with M-mode echo before and after Mustard operation included 6 with intact ventricular septum, 4 with ventricular septal defect, and 7 with left ventricular outflow tract stenosis (dynamic stenosis, 2; fixed stenosis, 3; and combined dynamic and fixed stenosis, 2).

Table IV: Hemodynamic and Echocardiographic Data of 17 D-Transposition Patients with Sequential Studies before and following Mustard Operation

Per Mustard Operation	*Group I IVS*	*No.* 6	*Group II VSD*	*No.* 4	*Group III LVOTS (IVS, VSD)*	*No.*
LVP/RVP RATIO	0.49± 0.16	5	0.80± 0.25	4	0.86± 0.21	5
LVP (mm Hg)	67	6	90± 30	4	81± 20	7
LVED/RVED RATIO	0.93± 0.20*	5	2.00± 0.86*	3	1.40± 0.87	6
LVO/PA RATIO	0.73± 0.02***	6	0.73± 0.04	4	0.49± 0.11***	5†
ALVO (mm Hg)					57± 27	7
LVPW dt	0.43± 0.05**	6	0.53± 0.06**	4	0.49± 0.15	7
PER/RVET RATIO	0.37± 0.06	4	0.45.	1	0.46± 0.10	5
Post Mustard Operation						
LVP/RVP RATIO	0.31± 0.10	4	0.48	1	0.68± 0.27	6
LVP (mm Hg)	33.6± 8.8	4	41± 12	3	67± 29	7
LVED/RVED RATIO	1.10± 0.18	4	1.28± 0.30	3	1.20± 0.29	6
LVO/PA RATIO	0.76± 0.06	6	0.74± 0.05**	3	0.60± 0.06**	5††
ALVO (mm Hg)					37± 28	7
LVPW dt	0.48± 0.13	5	0.51± 0.10	3	0.63± 0.27	7
PEP/RVET RATIO	0.39± 0.10	4	0.51	1	0.41± 0.11	5

†Patients with anatomically fixed left ventricular outflow stenosis.
††One patient who developed pulmonary artery hypertension and LVED/RVED ratio of 1.2 is not included.
Test of significance by t test:
* $p < 0.05$ ** $p < 0.025$ *** $p < 0.001$

ABBREVIATIONS: As in Table I.

Preoperatively, 2 patients with shunting lesions (1 in Group I with patent ductus arteriosus and 1 in Group II) had a higher LVED/RVED ratio, which decreasd postoperatively ($p < 0.05$) and became comparable to the non-shunting group. Preoperatively the LVO/PA ratio was < 0.5 in patients with anatomically fixed stenosis. With resection of the left ventricular outflow tract stenosis this ratio increased (paired comparison using t-statistics, $p < 0.05$) with reduction of the left ventricular systolic pressure. The dynamic form of left ventricular outflow tract stenosis present in 2 Group I patients and 4 Group II patients remained unchanged following the Mustard operation.

A PEP/LVET ratio of > 0.30 was associated with mean PAP of > 25 mmHg. Postoperatively in 2 patients with elevated mean PAP (> 25 mmHg) the ratio increased further to > 0.40, and in one remained < 0.30 in spite of elevated pulmonary artery pressures (mean 30 mmHg).

Preoperatively, the PEP/RVET ratio was > 0.50 in only one patient; postoperatively, the ratio was > 0.50 in 4 patients and in 2 of these hemodynamically significant tricuspid regurgitation and angiographically estimated reduced ejection fraction (< 0.50) was noted.

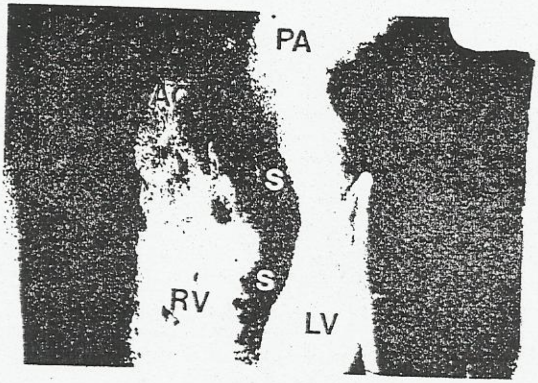
DISCUSSION

This study confirms that M-mode echocardiography is a reliable means for diagnosing d-transposed great arteries. The transducer angulation (from the standard 4th intercostal parasternal space) required to detect the transposed aorta is rightward and anterior (toward the right shoulder) from the posterior vessel, as opposed to an anterior and leftward angulation required to detect the anterior vessel (pulmonary artery) in normally related great vessels. The semilunar valve to the anterior vessel (aorta) opens later than the valve of posterior vessel. In our experience, a high degree of diagnostic accuracy can be achieved by combining these echocardiographic criteria. Even in the presence of a ventricular septal defect and/or patent ductus arteriosus, which delayed the pulmonary valve opening in some patients, the pulmonic valve opened earlier than the aortic valve. Echocardiographically the aorta was located anteriorly and to the left of the pulmonary artery (1-arrangement) in 2 of 41 patients in the preoperative group, a finding consistent with angiographic and postmortem (4, 16) data which has shown a varied incidence of left-sided aorta in complete (simple) transposition. Such cases may be indistinguishable by these echocardiographic criteria from those with normally related great vessels and severely elevated pulmonary vascular resistance and from patients with 1-transposition of the great vessels. A fair degree of technical expertise is necessary for accurate interpretation in the use of transducer angulation as a diagnostic criterion.

In agreement with reported experience (10), the pre- and postoperative as well as sequential echocardiographic studies indicate a significant correlation between the elevated pulmonary artery pressure and pre-ejection period/left ventricular ejection time (PEP/LVET) ratio. A ratio > 0.3 was associated in all cases with mean PAP of > 25 mmHg. Although a PEP/LVET ratio of < 0.3 does not exclude the possibility of pulmonary artery hypertension, ratios > 0.3 are very likely to be associated with an elevated pulmonary artery pressure. Our data confirms that reported in a recent study in which a ratio of < 0.3 was not predictive of pulmonary artery pressure, but a ratio ≥ 0.3 was associated with pulmonary artery hypertension with rare exception (15). Furthermore, in our study postoperative development of pulmonary vascular obstructive disease could be detected by an increase in the PEP/LVET ratio except when complete right bundle branch block, dysrhythmias, or residual left ventricular outflow tract stenosis was present.

This study shows that the dimensions of the left ventricle were influenced both by pressure and volume overload. The preoperative studies show that the left ventricular end-diastolic/ right ventricular end-diastolic dimension (LVED/ RVED) ratio effectively separated patient groups with and without shunting lesions. The presence of both increased pressure and volume together was associated with the largest left ventricular dimensions. Increased left ventricular pressure due either to outflow tract stenosis or increased volume overload resulting from a ventricular septal defect or patent ductus arteriosus, counterbalances encroachment on the left ventricle by the posteriorly bulging interventricular septum causing an increased LVED/RVED dimension ratio. In contrast, a low pressure left ventricle, as in patients with intact ventricular septum, may be markedly encroached upon by the bulging interventricular septum resulting in a pancake deformity of the left ventricle and reduced antero-posterior dimensions and. LVED/ RVED ratio (Fig. 7).

In patients with surgically corrected shunting lesions, the LVED/RVED ratio was comparable to those with intact ventricular septum. Although a highly significant statistical correlation has been reported between the LVED/ RVED ratio and LVP/RVP pressure (13), this relationship was not comparably significant in our study. It is likely that the variance is primarily subject to the difficulties of estimating the right ventricular dimension on M-mode echocardiograms, since this dimension is dependent upon the position of the right ventricle vis-a-vis the transducer position (at left parasternal region). Clockwise rotational abnormalities of right ventricle, particularly in the postoperative patient, bring the right ventricle more leftward and in front of the left ventricle and would tend to increase the right ventricular dimensions, and vice versa. In spite of these reservations, our study shows that an elevated preoperative LVED/ RVED ratio should strongly suggest the association of shunting lesions.



[*Fig*. 7. Biventricular cineangiogram (lateral view) in mid-systole of a patient with d-transposition of the great vessels and intact ventricular septum. Note marked encroachment upon the low pressure left ventricle by the bulging interventricular septum (S).

Abbreviations: AO, aorta; LV, left ventricle; PA, pulmonary artery; RV, right ventricle; S, interventricular septum.]

As previously reported (3), the echocardiographically determined left ventricular outflow/ pulmonary artery ratio (LVO/PA) is helpful in distinguishing between anatomically fixed and dynamic left ventricular outflow tract stenosis. Preoperatively the dynamic type of left ventricular outflow stenosis was not demonstrated in patients with ventricular septal defect. In patients with intact ventricular septum the dynamic stenosis remained unchanged following the Mustard operation. The pressure gradient at the left ventricular outflow tract due to the dynamic form of stenosis varied from mild to moderate. In a few infants this dynamic obstruction was considered responsible for inadequate interatrial mixing in spite of an adequate interatrial septostomy opening and for hypercyanotic spells (2). Our recent observations suggest that pressure gradient across the left ventricular outflow tract can develop or increase with catecholamine stimulation (2). Such gradients are dependent upon the state of the patients' activity, and may appear mild in some patients during the sedated state at cardiac catheterization.

Although our sequential pre- and postoperative study group is small, our findings of echocardiographic features of dynamic stenosis in both pre- and postoperative groups suggest that the Mustard operation does not, per se, cause these echocardiographic changes as has been implied (14).

Right Ventricular Function:

In our study the angiographically determined right ventricular ejection fraction correlated well with an elevated right ventricular PEP/ET ratio, i.e., a ratio of ≥ 0.5 was associated with reduced (< 0.5) ejection fraction; this finding is in keeping with a recent report (1). However, contrary to that study, the PEP/RVET ratio was elevated in most of our patients with complete right bundle branch block or dysrhythmia when compared to those without such abnormalities. Assessment of ejection fraction by the right ventricular systolic time intervals appears to be relatively reliable after Mustard operation when no conduction or rhythm abnormalities are present. Our data show that both complete right bundle branch block (due to conduction delay over the right ventricle) and myocardial dysfunction produced prolongation of the right ventricular pre-ejection period and therefore further studies are needed to evaluate the effect of right bundle branch block on the PEP/RVET ratio as an index of right ventricular function. Patients who developed postoperative tricuspid insufficiency showed diminished right ventricular ejection fraction and elevated PEP/RVET ratio (> 0.5).

Although two-dimensional echocardiography has added a new dimension to the visualization of transposed great vessels, ventricular septal defect, and left ventricular outflow tract stenosis, we believe M-mode echocardiography will continue to provide diagnostic and quantitative information about the hemodynamic effects of the transposed great vessels and associated lesions.

In summary, M-mode echocardiography provides not only a reliable means of diagnosing d-transposition of the great arteries, but is also useful for assessing the presence of associated lesions. Changing hemodynamic parameters in patients with transposition of the great arteries can be followed before and after the Mustard operation by longitudinal echocardiographic assessment.

SUMMARY

M-mode echocardiographic, hemodynamic and angiographic correlations are presented for 97 patients with d-transposition of the great arteries. Forty-one patients were studied before and 73 patients after the Mustard operation; 17 patients were studied sequentially before and after Mustard operation. The echo diagnosis of d-transposition could be made with high accuracy by utilizing two criteria: (1) earlier opening of the posterior semilunar valve (PA) compared to an anterior aortic valve (AO); and 2) location of an anterior vessel (aorta) to the right of the posterior vessel (toward the right shoulder) on transducer angulation. In the pre-Mustard group the presence of associated lesions such as patent ductus arteriosus and ventricular septal defect was suggested by an elevated left ventricular end-diastolic/right ventricular end-diastolic dimension ratio (≥ 1.2). In the post-Mustard group after correction of shunting lesions this ratio was similar to those with intact ventricular septum. In pre-Mustard patients the anatomically fixed type of left ventricular outflow tract stenosis was suggested by a left ventricular outflow tract/pulmonary artery ratio of ≤ 0.5. This ratio was 0.52 ± 0.1 in those in whom resection of the anatomic stenosis and Mustard operation was performed. Right ventricular function could be assessed by the pre-ejection period/right ventricular ejection ratio; a ratio of ≥ 0.5 was associated with angiographically determined ejection fraction of ≤ 0.5.

It is suggested that M-mode echocardiography provides a reliable means for the diagnosis and quantitative and qualitative assessment of the associated lesions.

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