Echocardiographic Detection of Intracardiac Right-to-Left Shunts following Peripheral Vein Injections

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SUMMARY A contrast echocardiographic technique using peripheral vein injections for the detection and localization of intracardiac right-to-left shunting is described. Fifty children underwent cardiac catheterization and peripheral contrast echocardiographic studies. The site, degree, and direction of shunting were established at catheterization by oximetry, indicator dilution analysis and/or angiography. Peripheral vein injections were performed from the right antecubital vein or the right saphenous vein. Right-to-left shunts were documented at catheterization in 27/50 patients; contrast echocardiographic studies indicated the presence and level of shunting in all 27 patients. The contrast echocardiographic technique using peripheral vein injections detects and localizes right-to-left intracardiac shunting. It is a safe and sensitive method to evaluate systemic desaturation in ambulatory and postoperative patients.

THE PEDIATRIC CARDIOLOGIST is often faced with the dilemma of determining whether or not a child with congenital heart disease is truly cyanotic. Minimal arterial desaturation may cause equivocal cyanosis. In these cases, a simplified technique to detect and localize right-to-left intracardiac shunting would be of great value. The purpose of this report is to propose a contrast echocardiographic technique as the answer to this problem. The technique uses peripheral vein injections to produce echocardiographically detectable ultrasonic reflections which follow right-to-left intracardiac flow patterns. The sensitivity of this technique in detecting and localizing the level of these shunts is assessed.

Materials and Methods

The study population consisted of 50 patients with congenital heart disease, ages 1 day to 16 years (median 7 years), all of whom underwent diagnostic cardiac catheterization and contrast echocardiographic studies.

The site, degree and direction of shunting was established in the cardiac catheterization laboratory by oximetry, indicator dilution analysis and/or angiography. The oxygen content of the blood was measured with an Instrumentation Laboratory 182 photometric co-oximeter and corrected by the Van Slyke technique. Indicator dilution curves were performed using indocyanine green and following the flush technique described by Bloomfield. The magnitude and direction of shunts was established according to the methods described by Swan and Carter et al. Angiograms were analyzed for signs of intracardiac shunting with specific emphasis placed upon the detection of right-to-left shunts.

Contrast echocardiographic studies were recorded within 24 hours of catheterization in all patients. Peripheral vein injections were carried out through a 16 F Intracath catheter positioned in the right antecubital vein in 32 patients and through a #5 F angiographic catheter in the saphenous vein isolated for cardiac catheterization in 18 patients. This large caliber Intracath was chosen because several injections were necessary to evaluate the technique. Theoretically, a smaller line or needle should be appropriate. Two to three cc of 5% dextrose/water or the patient’s own blood were forcefully injected by hand through the venous line. This was consistently found to be a suitable injectate for producing microcavitation even for older children and adolescents. Five percent dextrose/water has been preferred to indocyanine green because it is more physiologic, less expensive and more readily available to all centers. In infants, the patient’s own blood rapidly withdrawn and reinjected has not only been satisfactory but is preferred since it avoids possible fluid imbalances. A strip chart echocardiogram was recorded simultaneously with each injection using a SKI Ecoline 20A with a Honeywell 1856 recorder. An electrocardiogram and an injection marker were used for timing purposes whenever circumstances permitted. A 2.25 MHz, 5 cm focused transducer was used for all examinations regardless of the size of the patient. During all studies the patients were supine and tracings were recorded from two areas: 1) the aortic position, which included the right ventricular outflow tract, aortic root and left atrium; and 2) the mitral position, which traversed the right ventricle, interventricular septum and left ventricular outflow area, including the mitral valve orifice. This was defined as the funnel created by the anterior and posterior leaflets of the mitral valve.

The echocardiographic machine was set at low reject and high near and coarse gain. This was the critical factor in the recording of ultrasonic reflections. Microcavitations are echoes of low amplitude which are easily damped out of the tracings. Therefore, low reject and high near and coarse gain settings, while still preserving the integrity of the chambers, produced the best results. These had to be regulated for each patient with several trial injections until the best records were obtained. Once this was attained, 3–5 injections in each position were appropriate for evaluation of flow to the left side of the heart. A technically acceptable tracing was one in which the contrast effect was seen to completely opacify the right ventricle while remaining bound by the outlining borders of solid intracardiac structures such as the interventricular septum (fig. 1). An injection was discarded as a technical false positive when contrast echoes were seen to obliterate the delineating walls of intracardiac structures (fig. 2).

A study was assessed as positive for intracardiac R-L
shunting when ultrasonic reflections were observed within the demarcated limits of right-sided cardiac structures and also in the left heart chambers. In a negative study, the echoes were confined to the right side.

Results

Right-to-left intracardiac shunts were documented at catheterization in 27 of 50 patients: ten at atrial, eight at ventricular, and nine at both levels. Isolated left-to-right shunts were found in seven patients and no intracardiac communication in 16 patients. Peripheral arterial saturations obtained from the patients with right-to-left shunts ranged from 45-98% with eight having values higher than 90%. In this latter group, the right-to-left shunt was further verified in five patients by indicator dilution analysis and in two patients by right ventricular angiography. The femoral artery saturation in the remaining patient was 6% lower than the simultaneously obtained pulmonary venous sample, which was 98% saturated.

In the absence of intracardiac shunting, the contrast echoes produced by the peripheral vein injections were confined to the right ventricular cavity and right ventricular outflow tract while the left-sided structures remained clear (fig. 1). This pattern was seen in all 16 patients who had no shunt identified at cardiac catheterization as well as in the seven patients who had isolated left-to-right shunting.

All ten patients with right-to-left shunting confirmed at the atrial level had contrast echoes appearing in the left atrial cavity and the aortic root (fig. 3A). With the transducer beam traversing the mitral valve, ultrasonic reflections immediately opacified the mitral orifice followed by the left ventricular outflow area (fig. 3B).

In all eight patients with a right-to-left shunt at the ventricular level, microcavitations filled the left ventricle around rather than through the mitral orifice, sparing the valve with each diastole. In some instances, ultrasonic reflections were seen to blur the borders of the anterior and posterior leaflets of the mitral valve. This occurred 3-4 cardiac cycles after injection of the ultrasound contrast agent (fig. 4A). In the aortic root position, the contrast effect was limited to the aortic root while the left atrium remained echo-free (fig. 4B).

There were nine patients who had right-to-left shunts documented at both the atrial and ventricular levels. In all of these patients, cavitations were seen in the left atrial cavity. Two distinct patterns were recognized in the mitral position: 1) complete opacification of both the mitral orifice and the left ventricular outflow area (fig. 5A); and 2) scattered clouding of the mitral orifice compared to dense opacification of the left ventricular outflow tract (fig. 5B).

There were no false negative or false positive contrast echocardiographic studies compared to the hemodynamic results obtained at cardiac catheterization.

Discussion

Contrast echocardiography was first used clinically for the identification of the aortic root and intracardiac structures by Gramiak et al. Subsequently, a number of reports appeared in the literature outlining the clinical applications of contrast echocardiography. These studies involved in-
tracardiac injection of substances, usually indocyanine green, during routine cardiac catheterization.** Performed in this manner, contrast echocardiography was demonstrated to be at least as sensitive as indicator dilution techniques for detecting intracardiac shunting.11

An echocardiographic contrast effect occurs when the ultrasonic wave encounters microcavitations that result from injection of contrast agents.10 Cavitation is the production of cavities or bubbles in a fluid due to a drop in pressure. This pressure drop allows the gases dissolved in the liquid to escape in the form of bubbles following the Bernoulli principle.11 Blood is ideal for the creation of cavitation because of its high availability of gases which serve as initiating nuclei. For this reason, much lower flow rates are required in clinical studies. Once the bubbles are formed, they leave the low pressure zone and return the gases to liquid by diffusion. This is a slow process called stable or gas cavitation and has been demonstrated to persist for over ten seconds. With higher flow rates, lower pressures result and transient or vapor cavitation occurs, which collapses rapidly upon leaving the low pressure area. These are not pertinent in clinical observations.10

The contrast effect produced by these injections has been observed echocardiographically to persist through several cardiac cycles and follow the downstream flow of blood within the heart.9 Once the cavitations reach the pulmonary circulation they are filtered by the lungs, thereby preventing their appearance in the left side.4,10 Therefore, a right-to-left intracardiac shunt can be ruled out when microcavitations are seen only in right-sided structures (fig. 1).

In patients with right-to-left atrial shunts, blood crosses the septum to enter the left atrium during the rapid filling phase of ventricular diastole as well as at the onset of left ventricular contraction for a period of 80–140 msec.12 Shunted blood then enters the left ventricle through the mitral orifice. The microcavitations follow this sequence of shunt flow, accounting for the contrast echo pattern observed in the ten patients with atrial septal defects. Therefore, a right-to-left shunt at the atrial level can be diagnosed when ultrasonic reflections 1) appear in the left atrium, and 2) completely opacify the mitral orifice and then the left ventricular outflow area (fig. 3).

Right-to-left shunting occurs through a ventricular septal defect when the peak right ventricular systolic pressure reaches or exceeds 70 mm Hg.13 In these patients a right-to-left pressure gradient is established at the onset of isovolumic relaxation when the left ventricular pressure falls more rapidly than that of the right ventricle. In patients with equal systolic ventricular pressures, the right ventricle exceeds the left ventricle during late ventricular ejection as well as diastole.

**FIGURE 3. Examples of right-to-left shunt at the atrial level. A) A right-to-left shunt at the atrial level is confirmed by the sequential appearance of contrast echoes in the left atrium and aortic root following peripheral vein injections. B) Opacification of the mitral orifice during diastole further substantiates the presence of a shunt at the atrial level.

**FIGURE 4. Examples of right-to-left shunt at the ventricular level. A) Sparing of the mitral orifice in diastole with appearance of microcavitations in the left ventricle indicates the presence of a ventricular septal defect. B) Clouding of the aortic root in the absence of a contrast effect in the left atrium further supports the diagnosis of a ventricular shunt.
as during isovolumic relaxation. It is at these points in the cardiac cycle that right-to-left shunting occurs. Shunting into the left ventricular cavity and/or left ventricular outflow tract occurs only during isovolumic relaxation since, during late ventricular ejection, blood flows from the right ventricle directly into the aortic root. In the eight patients with a right-to-left shunt at the ventricular level, the peripheral injections produced ultrasonic reflections in the right ventricle which traversed the septal defect reaching the left ventricle when the mitral valve was closed. The mitral orifice was spared of microcavitations as echo-free blood flowed through it from the left atrium in each diastole. With the transducer in the aortic position, the left atrial cavity remained clear while the right ventricular outflow tract and aorta filled. Therefore, the diagnostic pattern of a right-to-left ventricular shunt is 1) absence of ultrasonic reflections in the left atrium, and 2) left ventricular opacification with sparing of the mitral valve orifice.

In patients with right-to-left shunting at both atrial and ventricular levels the atrial communication allows blood to enter the left ventricle through the mitral valve in early ventricular diastole; in addition, blood crosses into the left ventricle via the ventricular defect during isovolumic relaxation. The degree of shunting occurring at each level is dependent on several hemodynamic factors. Accordingly, the contrast echo patterns observed in these patients varied. All of them had opacification of the left atrial orifice. In the mitral position, both the mitral orifice and the left ventricular outflow area filled, but with different relative densities. Some records exhibited equal clouding of the mitral orifice and left ventricular outflow tract and were indistinguishable from those of patients with isolated atrial septal defects (fig. 5A). Other tracings had dense echoes in the left ventricle with scattered filling of the mitral orifice during the initial diastole after injection of the echocardiographic contrast agent (fig. 5B). This latter finding differentiated a combined level shunt from an isolated ventricular septal defect. As noted previously, shunts at the ventricular level spared the mitral image. Any streaking across this valve occurred 3-4 cardiac cycles after completion of the injection and only to a minimal degree (fig. 4A). Preliminary observations suggest that the pattern of equal mitral and left ventricular density is seen in patients with a larger atrial than ventricular defect, whereas that of scattered mitral clouding is obtained from patients with a major ventricular shunt. Further data are needed on intracardiac flow patterns before definitive conclusions can be reached. Until such data are available, the contrast echocardiograms of these patients are interpreted as supportive but not diagnostic of a combined level shunt.

A false positive can occur when the right ventricle is overloaded with echoes (fig. 2). Normally, the ultrasonic reflections are confined by solid structures such as the interventricular septum. In overload, the contrast echoes are seen within as well as through the walls of the septum and then taper rapidly. This can be falsely interpreted as a positive study since cavitations do appear in left-sided structures. This phenomenon is due to re-reflection or duplication of the right ventricular echoes and is what has been generally termed in the literature as phantom images. When overload is encountered, a reduction in the pressure applied to the syringe corrects it by diminishing the microcavitations produced.

The contrast echocardiographic technique using peripheral vein injections as described detects and localizes right-to-left intracardiac shunting. It has been demonstrated to be a safe, reliable, sensitive, and minimally invasive method. It also obviates the need for arterial entry in evaluating systemic desaturation in the ambulatory and postoperative patient.

References

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FIGURE 5. Examples of combined level shunts. All patients demonstrated opacification of the mitral orifice and the left ventricular outflow area but with different relative densities. A) Equal clouding of the mitral orifice and left ventricular outflow tract indistinguishable from those of patients with isolated atrial septal defects was observed in some records. B) Dense opacification of the left ventricular outflow tract with scattered filling of the mitral image immediately following completion of the injection was seen in other patients. This early streaking of the mitral orifice with clouding of the left atrium differentiated these records from those of isolated ventricular septal defects.
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Echocardiographic Features of Congenital Left Ventricular Inflow Obstruction
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SUMMARY The echocardiographic features of congenital left ventricular inflow obstruction are described in six patients. The echocardiograms in two patients with cor triatriatum were distinguished by normal mitral valve motion and an abnormal echo within the left atrium. In two patients with supravalvar mitral ring, in addition to abnormal mitral valve motion, an abnormal echo, presumably originating from the obstructive membrane, was located between the anterior and posterior mitral leaflets. In two cases of parachute mitral valve, mitral valve motion was abnormal. In one of these cases there were multiple mitral valve echoes similar to those found in supravalvar mitral ring.

The echocardiographic identification of an obstructive membrane within the left atrium is difficult because of the occurrence of artifacts. However, membranes may be identified if careful scanning techniques are employed in patients in whom left ventricular inflow obstruction is suspected. The echocardiogram is useful in detecting mitral valve abnormalities in these patients and is valuable in cases where mitral valve replacement is contemplated.

COR TRIATRIATUM, supravalvar mitral ring, and congenital mitral stenosis (most commonly parachute mitral valve) are congenital lesions which obstruct filling of the left ventricle.1, 2 These malformations can cause pulmonary venous and pulmonary arterial hypertension with very similar clinical manifestations.3 A few reports have dealt with the echocardiographic findings in cases of congenital mitral stenosis,4 cor triatriatum,5 6 and supravalvar mitral ring,7 8 but a comparative study of the echocardiographic findings in these three entities has not appeared previously in the literature.

Materials and Methods
The six patients in this study ranged in age from 22 days to 15 years (table 1). They represent all the patients who presented to the Children's Hospital Medical Center from May 1974 to December 1975 with surgically proven left ventricular inflow obstruction and with technically satisfactory echocardiographic studies. Patients with left atrioventricular (A-V) valve atresia were not included in this study. The diagnosis of left ventricular inflow obstruction was documented at cardiac catheterization by the presence of an end-diastolic pressure gradient across the mitral valve and by angiography. In addition to surgical confirmation of obstruction in all cases, postmortem confirmation was obtained in case 3. Three types of obstruction were found in the six patients (table 1): cor triatriatum (2), supravalvar mitral ring (2), and isolated parachute mitral valve (2). One patient with supravalvar ring had an associated parachute mitral valve, the other an abnormal mitral valve with commissural fusion.

Echocardiographic examination was performed with a Hoffrel model 101B ultrasonoscope, utilizing either a 5.0 or a 3.25 MHz transducer. The echocardiographic signal was recorded by a Cambridge Fiberoptic multichannel recorder. Standard scanning techniques were performed. Total amplitude and diastolic velocity (E-F slope) of the anterior mitral valve leaflet were measured and compared to previously published data.9 12 All patients except case 5 had echocardiograms pre and postoperatively.

Results
Cor Triatriatum (Patients 1 and 2)
The amplitude and diastolic closure rate of the anterior leaflet of the mitral valve were normal (table 2). The motion
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