Recognition of Residual Postoperative Shunts by Contrast Echocardiographic Techniques

LILLIAM M. VALDES-CRUZ, M.D., DANIEL R. PIERONI, M.D., JEAN-MICHEL A. ROLAND, M.D., AND JON P. SHEMATEK, M.D.

SUMMARY  A bedside echocardiographic technique was used to detect and localize residual intracardiac shunts in 26 patients who had surgical repair of septal defects. Contrast echocardiography was performed through central venous and left atrial monitoring catheters at the same time as cardiogreen dye curves. Indicator dilution confirmed residual atrial defects in ten patients and ventricular defects in five. Contrast echocardiography indicated the presence and level of shunting in all 15 patients. Temporary flow through newly implanted septal patches was detected and differentiated from shunting across a true residual defect. The contrast echocardiographic technique using injections through the central venous and left atrial catheters as described detects and localizes right-to-left and left-to-right shunting. It is a safe and reliable method to evaluate residual intracardiac defects postoperatively.

The immediate postoperative period for children undergoing surgical repair of congenital heart defects may be complicated by desaturation, persistent congestive heart failure, and/or significant murmurs. It is at this time that the possibility of a residual intracardiac defect must be considered. The purpose of this paper is to report a bedside contrast echocardiographic technique to diagnose intracardiac shunting in the postoperative period.

Materials and Methods

The study included 26 patients, ages three days to 16 years (median age five years), who were selected because their postoperative clinical course suggested a residual defect. The preoperative diagnoses ranged from simpler deformities such as isolated ventricular septal defects to more complicated anomalies such as transposition of the great arteries and atroventricular canal (table 1). The common denominator of the patient population was that all had septal defects preoperatively, the level and size having been established at cardiac catheterization and at surgery. Indicator dilution curves were performed in the first postoperative day using indocyanine green dye injected into the right atrium and sampled from the radial artery. These were carried out at the bedside in the Intensive Care Unit following the flush technique described by Bloomfield. The magnitude and direction of the shunts were determined according to established methods.

Dye curves were immediately followed by contrast echocardiographic studies performed by two of the authors and interpreted, on a double blind basis, by the other two. These were repeated for 3–5 consecutive days in 13/19 patients who had evidence of a residual defect on initial evaluation. Injections were performed through the central venous and/or left atrial monitoring catheters placed at the time of surgery; 1–2 cc of the patient’s own blood was withdrawn and rapidly reinfused by hand through each catheter. A strip chart echocardiogram was recorded simultaneously with each injection using an Ektoline 20A with a Honeywell 1856 recorder. An electrocardiogram and an injection marker were used for timing purposes. The ultrasoundoscope was set at the lowest reject and the highest near and coarse gain settings that permitted adequate outline of cardiac structures and recording of the contrast echoes.

A 2.25 MHz, 5 cm focused transducer was used for all examinations which were conducted with the patients in the supine position. Four areas were used for analysis: 1) the aorta, traversing the right ventricular outflow tract, aortic root and left atrium; 2) the mitral, including the right ventricle, interventricular septum and mitral valve at the atroventricular level; 3) the ventricular, viewing the right ventricular, interventricular septum and left ventricle; and 4) the tricuspid, recording the tricuspid valve within the right ventricular inflow tract. Three to five injections were performed through each of the central lines in all four positions. An injection was acceptable for examination when the side into which it was made became completely opacified with contrast echoes.

A study was considered negative when ultrasonic reflections produced by central venous injections appeared confined to the right heart structures and those created by the
TABLE 1. Comparison of Dye Curve and Contrast Echocardiographic Techniques for the Detection of Residual Shunts

<table>
<thead>
<tr>
<th>Patient</th>
<th>Preoperative diagnosis</th>
<th>Operative procedure</th>
<th>Dye curve results</th>
<th>CET* results</th>
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*Contrast echocardiographic technique.
†Pulmonary valvulotomy.

Abbreviations: AMB = anomalous muscle bundle in right ventricle; AVC = complete atrioventricular canal defect; CTV = corrected transposition of the great arteries; DOR = double outlet right ventricle; DPV = dysplastic pulmonary valve; ECD = ostium primum defect; MIC = mitral insufficiency, congenital; PFO = patent foramen ovale; PPB = previous pulmonary banding; PSV = valve pulmonic stenosis; SIA = single atrium; TOF = tetralogy of Fallot; VSD = ventricular septal defect; O = no shunt; L = left-to-right shunt; R = right-to-left shunt.

LA injections remained in the left side. Therefore, an intracardiac communication was ruled out when structures on the side opposite to that of injections remained echo-free.

Results

Residual atrial defects were documented by indicator dilution in ten patients: six had isolated right-to-left, one had left-to-right, and three had bidirectional shunting. Ventricular defects were diagnosed in five patients: three with right-to-left, one with left-to-right, and one with bidirectional flow. Eleven patients had normal indocyanine green dye curves (table 1).

In the absence of an intracardiac communication, the contrast echo effect produced by the central venous injections was confined to the right ventricular cavity and right ventricular outflow tract, while that produced after LA injections remained in the left atrium, left ventricle, and aortic root (figs. 1 and 2). These patterns were observed in 7/11 patients who had normal dye curves; 4/11 had contrast echocardiographic studies indicative of a left-to-right ventricular shunt.

In the presence of atrial septal defects with right-to-left shunting, the central venous injections produced microcavitations which appeared in the left atrium and aortic root (fig. 3A). In the mitral area, they were seen to opacify first in the mitral orifice followed by the left ventricular outflow area (fig. 3B). In the one patient with only left-to-right atrial shunting, the LA injections were seen to produce ultrasonic reflections which entered the right ventricular cavity and the right ventricular outflow tract (fig. 4). These flowed through the orifice of the tricuspid valve in diastole and then filled the entire right ventricular inflow area (fig. 5). The three patients with bidirectional shunting had cavitations flowing through both mitral and tricuspid valve orifices on central venous and LA injections, respectively.

In the presence of ventricular septal defects with right-to-left shunting, the central venous injections opacified the aortic root, but not the left atrium (fig. 6). When the mitral valve opened in diastole, it remained free of contrast echoes with only blurring of the mitral valve leaflets resulting when the entire left ventricular outflow tract became flooded with echoes (fig. 6). With left-to-right shunting, the right ventricular cavity and the right ventricular outflow tract opacified following LA injections. However, the cavitations did not appear through the tricuspid valve orifice; only minimal and scattered filling of the right ventricular inflow area occurred (fig. 4). The patient with bidirectional ventricular shunting had positive central venous and LA studies. In these cases, ultrasonic reflections were seen in the left and right ventricles with sparing of the atrioventricular valve orifice contralateral to the side of injection.

Discussion

Contrast echocardiography has been used for the past seven years, first for the identification of cardiac structures, and later for the detection of intracardiac shunts and valvular regurgitation. These studies were all done following intracardiac injections of indocyanine green.
The contrast echocardiographic flow patterns may be summarized as follows: 1) right-to-left atrial shunts are diagnosed when central venous injections cause ultrasonic reflections in the LA and opacification of the mitral orifice; 2) left-to-right atrial flows are confirmed when LA injections fill the right ventricle and tricuspid valve orifice; 3) right-to-left ventricular shunts are present when central venous injections produce microcavitations in the left ventricle and aortic root, but spare the left atrium and mitral valve; 4) left-to-right ventricular shunts are established when, following the LA injections, the right ventricle opacifies, but the tricuspid valve remains echo-free.

Pieroni et al. analyzed 12 cases of children undergoing indicator dilution analysis in the cardiac catheterization laboratory and compared these with contrast echocardiographic studies. In their study, forward green dye curves injecting indocyanine green in the inferior vena cava with sampling from the femoral artery confirmed right-to-left shunts as small as 3-5% of the systemic blood flow. Reverse curves injected into the left heart and sampled from the pulmonary artery demonstrated left-to-right shunting in the order of 5% of the pulmonary blood flow. Strip chart echocardiograms recorded simultaneously with injections established contrast echocardiography to be at least as sensitive as indicator dilution for detecting intracardiac shunting. Recently, we reported contrast echocardiographic studies...
following peripheral vein injections of 5% dextrose/water which proved to be as sensitive as forward indicator dilution curves and angiography for detecting intracardiac right-to-left shunting.\textsuperscript{11} No false positive or false negative studies were encountered in either series. Seward et al. in their review of contrast echocardiographic studies suggest the same degree of sensitivity.\textsuperscript{10} Therefore, contrast echocardiography has been shown to consistently demonstrate 3-5% intracardiac shunting. Since the smallest left-to-right shunt that right atrial to radial artery forward green dye curves detect is on the order of 30% of the pulmonary blood flow,\textsuperscript{4} we conclude that the four patients who had normal dye curves but positive LA injections had shunts smaller than 30% of the pulmonary blood flow. The results of these four patients again suggest the greater sensitivity of contrast echocardiography for the detection of left-to-right intracardiac shunting.

Technical aspects of the study include: 1) placement and choice of lines; 2) injectate; and 3) settings in the ultrasonoscope. Central venous and left atrial lines were placed at open heart surgery for postoperative monitoring purposes. These catheters usually have smooth flow on withdrawal of blood for a week after insertion and, other than the precautions of avoiding air or clots, offer no complications on injection.

Blood tested both \textit{in vitro} and \textit{in vivo} by several investigators has been found to be an adequate injectate for the production of microcavitations.\textsuperscript{11, 12} This has been preferred to other substances like saline, 5% dextrose/water, or indocyanine green because of fluid restrictions found necessary in the immediate postoperative period, especially in infants.

Settings in the ultrasonoscope are critical in the recording of ultrasonic reflections. These low amplitude echoes are only detected when low reject and high near and coarse gain adjustments are made since they are otherwise easily damped out of the tracing. To achieve complete opacification of the most proximal chamber, several trial injections are usually necessary before the appropriate calibrations are obtained. Following this, 3-5 injections through each catheter in all four transducer positions are adequate for evaluation of shunting.

Technical false positives have been encountered in this study identical to those described with peripheral vein injections.\textsuperscript{11} These are due to phantom images of the contrast echoes in anterior structures. They are corrected by reducing the pressure applied to the injecting syringe which causes a reduction in the microcavitations produced.

Temporary leakage around surgically-placed septal patches is a well known phenomenon common in the first postoperative days. Thirteen of 19 patients who had positive studies in the first day following surgery underwent contrast echocardiographic injections for 3-5 consecutive days. Of these 13 patients, five had a progressive diminution in the density of contrast echoes appearing in contralateral structures. These patients had a benign recovery. The remaining eight patients had persistent evidence of shunting by contrast echocardiography which coincided with a more complicated postoperative course and need for additional surgical intervention. It was concluded that positive studies in the first day after surgery may represent either temporary flow through the newly-implanted patch or shunting across a true
residual defect. Therefore, follow-up studies are necessary for differentiation.

The contrast echocardiographic technique using central venous and LA injections performed serially during the first five postoperative days, as described, detects and localizes right-to-left and left-to-right shunting. It provides valuable information on the integrity of septal repairs differentiating between flow through the patch and shunting across a remaining defect. In desaturated patients, it differentiates isolated cardiac from pure pulmonary shunting. With congestive heart failure and/or significant murmurs, a negative contrast echocardiographic study excludes shunting and stresses the need for more vigorous medical management. Contrast echocardiography can be used as a reliable alternative method to evaluate the need for early cardiac catheterization and further surgical intervention in patients with postoperative complications.

References


Figure 4. Examples of left atrial injections in a patient with a left-to-right intracardiac shunt. A) Left-to-right shunting at atrial and/or ventricular levels is diagnosed upon appearance of the cavitations in the right ventricular outflow after left atrial injection. B) This is supported by visualization of echoes in the right ventricular cavity.

Figure 5. The tricuspid area is used to diagnose left-to-right atrial shunts following left atrial injection. Complete filling of the right ventricular inflow area through the orifice of the tricuspid valve (TV) established the presence of a left-to-right shunt at the atrial level.

Figure 6. Central venous injection in a patient with right-to-left shunts at the ventricular level. A) Clouding of the aortic root in the absence of a contrast effect in the left atrium indicated the presence of a right-to-left shunt across a ventricular septal defect. B) Sparing of the mitral orifice in diastole with appearance of microcavitations in the left ventricular outflow tract further supported the diagnosis of an isolated ventricular septal defect with right-to-left shunting.
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L M Valdes-Cruz, D R Pieroni, J M Roland and J P Shematek

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