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Recognition of Residual Postoperative Shunts by Contrast Echocardiographic Techniques
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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.1 The magnitude and direction of the shunts were determined according to established methods.2, 4

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defects with bidirectional ventricular shunting and aortic root fusiform dilatation (fig. 2). In both cases, the left atrium appeared patent, with dilated aorta and right ventricular outflow tract (fig. 4). These were also confirmed by contrast echocardiography and cardiac catheterization.

**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.
Figure 1. Central venous injections in a patient with no residual intracardiac communication. A) The contrast echo effect is confined to the right ventricular outflow tract (RVOT). The left atrium (LA) and aortic root (Ao) are echo-free. B) The right ventricular cavity (RV) fills with contrast echoes while the left ventricle (LV) remains clear.

usually in the laboratory during the course of cardiac catheterization. The present study is another practical use of the technique adapted to the postoperative period.

The course of flow of contrast echoes following right-sided or peripheral venous injections is well known.5, 8-11 These microcavitations follow the downstream flow of blood and disappear in the pulmonary system. Similarly, left atrial injections cause cavitations which flow to the systemic circulation where they disperse. Observation of echoes in a contralateral chamber indicates the presence and direction of the shunt. Consequently, central venous injections were used for the determination of right-to-left shunts and LA injections for the demonstration of left-to-right shunts. The level is established by observation of the atrioventricular valve orifices outlined by their respective leaflets. A shunt is diagnosed at the atrial level when the atrioventricular valve orifice opposite to the side of injection opacifies, and at the ventricular level when it remains clear. Therefore, the first injections are made with the transducer aiming at the ventricular area which determines the presence or absence of an intracardiac shunt. If these are positive, then the aortic root and mitral areas clarify the level of the right-to-left shunt and the tricuspid valve position that of a left-to-right shunt.

Figure 2. Left atrial injections in two patients with no residual intracardiac communication. A) The ultrasonic reflections are observed within the left atrium and aortic root. The right ventricular outflow tract is free. B) The left ventricular cavity is completely obliterated, but the right ventricular cavity is clear. IVS = interventricular septum, MV = mitral valve.

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.9 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, 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 in vitro and 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.

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