Subxiphoid Two-Dimensional Imaging of the Interaltrial Septum in Infants and Neonates with Congenital Heart Disease

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**SUMMARY** The intertrial septum (IAS) was studied by subxiphoid two-dimensional echocardiography (S2DE) in 88 infants under 12 months of age who weighed 1.2–9.1 kg. The IAS was adequately displayed in 87 of 88 patients. The morphology, presence and localization of defects in the IAS were evaluated by S2DE and retrospectively related to the findings at cardiac catheterization. In seven patients with no intertrial communication at cardiac catheterization, the IAS was straight, with an area of central thinning corresponding to the ventricle-like cover of the septum primum over the foramen ovale. The morphology of the IAS with a stretched, patent foramen ovale (56 patients) indicated the coexistence of a right or left ventricular volume or pressure overload, and was readily distinguishable from the IAS with a secundum type communication (13 patients). In patients with a stretched, patent foramen ovale and left ventricular overload lesions, the IAS was a nearly homogenous, curvilinear structure bowing into the right atrium, with a small area of septal dropout at the superior rim of the septum primum. In the presence of right ventricular overload lesions, the central defect of the foramen ovale was associated with a redundant flap valve of the septum primum billowing into the left atrium. In secundum type communications, the centrally located defect represented a deficiency rather than a redundancy of the septum primum. Balloon atrial septostomy (BAS) in 17 patients produced a secundum-type defect bordered by the flail remnants of the torn septum primum. Blalock-Hanlon septectomy (two patients) resulted in a large, posterior, sinus venosus-type communication which incorporated the preexisting BAS. Ostium primum defects (seven patients) were distinguished from the secundum lesions by their eccentric position in the IAS adjacent to the atrioventricular ring.

ASSESSMENT OF ATRIAL ANATOMY in newborns and infants requires determining viscerocentral situs, identifying intertrial communication and recognizing the intertrial septal response to right-sided obstructive and left-sided volume-overload lesions. Current echocardiographic assessment of the atrial structures and the intertrial septum (IAS) is based on indirect inferences of right ventricular volume overload by M-mode and two-dimensional display of the IAS from the precordial and apical transducer positions. These views are compromised because the echo beam is not perpendicular to the posterior portion of the IAS, causing artifactual dropout of echoes from this portion of the septum which cannot be distinguished from actual defects. Imaging the atrial structures from the precordium or
 apex in infants is further compromised by the proximity of the heart to the transducer and by the small size of the cardiac structures. The purpose of this study was to demonstrate the capabilities of subxiphoid two-dimensional echocardiography (S2DE) in imaging atrial structures in the infant with suspected congenital heart disease.

Materials and Methods

Eighty-eight infants under 1 year of age who had both cardiac catheterization and S2DE between July 1977 and May 1978 were entered in the study. The patients weighed from 1.3–9.1 kg (median 3.7 kg) and ranged in age from 36 weeks gestation to 11 months (median 30 days). The primary diagnostic categories are listed in table 1. We performed S2DE within 48 hours of cardiac catheterization. All echocardiograms were performed with the patient supine using a Picker 80 cardiac imager with mechanical scanner and interchangeable, focused 3.5 and 5 MHz crystals. The IAS was displayed with a 45° sector angle, an image rate of 45 images/sec, and a variable line density. All studies were recorded on ½-inch video cassette tapes. Stop-frame imaging permitted still photographs on 1700 or 084 Polaroid film using a Tektronix C-50/C-70 series land pack camera.

The transducer was placed in the subxiphoid area, perpendicular to the frontal plane. The echo beam was oriented parallel to the horizontal axis of the trunk to identify the normally rightward inferior vena cava (IVC) and leftward abdominal aorta anterior to the spine (fig. 1). These vessels differed in their cross-sectional geometry. The aorta was typically circular. The IVC was generally elliptical; however, despite variation in shape, it could be routinely identified as it received the hepatic veins in the porta hepatitis. Cranial angulation of the transducer permitted tracking of the IVC to its junction with the right atrium (RA). After locating the RA, the transducer was rotated clockwise around its longitudinal axis until both atria, the IAS, right pulmonary vein (RPV), mitral valve leaflets, and tricuspid valve annulus were identified (fig. 2). Further cranial angulation displayed the more superior limits of the IAS, the junction of the superior vena cava (SVC) and the RA, the ascending aorta and the distal right pulmonary artery. The floor of the RA was divided by a prominent eustachian valve (EV) in several cases. The venous valve remnant simulated the IAS by partitioning the intra-atrial RA-IVC junction into anterior and posterior compartments. The EV and IAS were differentiated by their anteroposterior orientations and the anatomy of the IAS. The posterior segment of the EV, its junction with the IAS, was to the left with the anterior segment to the right (fig. 3A). In contrast, the posterior segment of the IAS was rightward, with the anterior segment, its junction with the EV, to the left. Additional cranial angulation above the RA-IVC junction displayed the IAS containing the central thinning of the foramen ovale covered by the septum primum (figs. 3B and C). The anatomy of the IAS communication was categorized according to the echocardiographic appearance. Identification of interatrial structures was confirmed by catheter placement during S2DE in 15 patients. Cardiac catheterization and cineangiography were used to identify interatrial shunts and pressure gradients. Mean interatrial pressure gradients (LA-RA) were obtained on pullback tracings using an end hole catheter with a #1280 Hewlett Packard transducer and #4588 Hewlett Packard recorder. Interaltrial mixing was determined by comparison of SVC, RA and LA saturations (American Optical Oximeter) or biplane cineangiography or both.

Results

The IAS was adequately displayed in 87 of 88 patients; the exception was a patient with dextroposition of the heart secondary to a hypoplastic right lung. The basic morphology of the IAS in these 87 patients is summarized in figure 4 and related to findings at catheterization (table 2).

Intact Atrial Septum

In seven patients with left ventricular overload lesions, no interatrial communication could be established by catheter course, saturation data or cineangiography at cardiac catheterization. In five of these seven patients, the midportion of the IAS representing septum primum, was seen as a thin line either straight or bowed into the RA (fig. 2; fig. 4, type 1a). The IAS on S2DE in two of seven patients (5 and 7 months old) appeared as an abnormally thickened, straight structure without central thinning (fig. 5). Cardiac catheterization revealed torrential pulmonary blood flow in both patients with pulmonary artery saturations of 94% and 96% and systemic or two-thirds systemic pulmonary artery pressure. One of these two patients died with severe congestive heart failure; necropsy revealed an abnormally thickened
Figure 1.  A) The transducer is placed in the subxiphoid position perpendicular to the frontal plane with the echo beam parallel to the horizontal plane (inset). The right-sided inferior vena cava (IVC) and left-sided aorta (Ao) are anterior to the vertebrae (Vert). Magnification of the subxiphoid two-dimensional echocardiogram (S2DE) displaces the main bang, anterior abdominal wall and portions of the liver. The sector format, therefore, does not extend to the abdominal wall. B) Magnified S2DE showing IVC, Ao and vertebrae.
FIGURE 2.  A) After tracking the inferior vena cava (IVC) to the right atrium (RA), additional cranial angulation and clockwise rotation shows the RA, left atrium (LA), interatrial septum (IAS), right pulmonary vein (RPV), mitral valve (MV) apparatus and tricuspid valve (TV) annulus. B) The normal cross-section of the cardiac structures: eustachian valve (Eust Val), RA, LA, IAS, RPV, MV, TV, left atrial appendage (LAA) and foramen ovale covered by septum primum (white arrowheads). C) The corresponding subxiphoid two-dimensional echocardiogram.
septum primum with an anatomically closed foramen ovale. The IAS was patent at catheterization and S2DE in all patients with right ventricular volume or pressure overload lesions.

**Patent Foramen Ovale**

In 56 patients, we classified the interatrial communication by S2DE as a stretched, patent foramen ovale. Twenty of these infants had a right-sided volume overload or obstructive lesion, 22 had left ventricular overload lesions, and 14 were infants with d-transposition of the great arteries (d-TGA) studied before balloon atrial septostomy. In 16 of the 20 infants with right-sided overload lesions, the major outline of the IAS remained flat, but the septum primum bulged into the left atrium (fig. 4, type IIb; fig. 6). All but one of these patients had a right-to-left shunt documented at cardiac catheterization. No echo dropout was seen within the septum primum, or between the septum primum and the inferior or lateral margins of the foramen ovale. A small, central defect was occasionally present at the most superior aspect of the foramen ovale and was attributed to displacement of the superior rim of the septum primum from the septum secundum. The IAS morphology in the four other patients with a patent foramen ovale and right ventricular overload conformed to the type Ia pattern in figure 4. The septum primum did not bulge into the LA, and no defect was seen at its superior rim.

Twenty-two patients who had left ventricular volume and pressure overload lesions showed evidence of variable pressure gradients, with shunting across the IAS at catheterization. In these patients, the IAS was characteristically a nearly homogenous, curvilinear structure bowing into the right atrium. The distinct junction, usually seen between the septum primum and inferior and superior limbic bands, was often lost with thinning of the stretched IAS (fig. 7). Marked bowing and stretching of the IAS in this manner seemed to produce incompetency of the flap valve of the foramen ovale, shown as a small area of septal dropout at the superior rim of the septum primum.

Eighteen of 88 infants studied had d-TGA and 14 of 18 studied before balloon atrial septostomy were the remainder of the group classified as a patent foramen ovale. The intact septum primum appeared to cover the foramen ovale. Interatrial mixing was suggested by the rhythmic displacement of the septum primum from the septum secundum during the cardiac cycle. The morphology of the IAS in each patient alternated between type Iia and type Iib, with bidirectional, interatrial mixing.

**Atrial Septal Defect Secundum**

Thirty-one patients had evidence of a large, unrestrictive IAS defect at cardiac catheterization by saturation data, interatrial mean pressure gradients \( \leq 3 \) mm Hg or cineangiography. In these patients, central dropout in the IAS had no associated redundancy of the septum primum. This pattern suggested a deficiency of the septum primum and was classified as a secundum type IAS defect (fig. 4, type III; fig. 8A).

Twelve patients were studied before and after balloon atrial septostomy; in two of these infants, the septum was also visualized after Blalock-Hanlon septectomy. The septostomy defect was typically located in the central portion of the interatrial septum (fig. 4, type IV; fig. 9).\(^{11,12}\) The single larger defect seen after surgical septostomy was seen as a consequence of the preexisting septostomy with a newly acquired deficiency of the posterior portion of the IAS (fig. 9C).\(^{13}\) The movement of the septum primum reflected the dynamics of interatrial mixing in the 14 patients studied immediately after balloon atrial septostomy. Transseptal blood flow across the acquired defect was suggested by the rhythmic motion of the torn septum primum during a single cardiac cycle (fig. 10). In one patient, the septum primum remained within the RA during the inspiratory phase of
mechanical ventilation but reverted to rhythmic interatrial oscillation with spontaneous respiration.

**Primum Atrial Septal Defect**

Ostium primum defects, either isolated or part of the complete atrioventricular canal complex were found in seven patients and confirmed at cardiac catheterization. In contrast to the secundum type communication, the primum defect was represented by dropout of echoes from the lower portion of the IAS adjacent to the atrioventricular values. (fig. 4, type V; fig. 8B).

**Discussion**

Two-dimensional echocardiography in infants and neonates is limited by near-field imaging, proximity of the lungs, and the size of the cardiac structures. Precordial and subxiphoid two-dimensional views have been successfully used for imaging of the cardiac structures in older patients. Detailed study, however, of the cardiac anatomy in a patient weighing as little as 1.2 kg requires the enhanced resolution of a high-frequency transducer. Interposition of the liver between the heart and transducer eliminates the problem of near field imaging due to beam convergence in a sector format. The subxiphoid position offers a flexible acoustical window in the young infant. The path of the incident echo beam does not cross the pleural space and no constraints are placed on transducer manipulation by ribs or sternal margins. Artifactual septal dropout of the posterior atrial septum from precordial and apical views is eliminated by the more perpendicular relationship of the echo beam to all portions of the septum from the subxiphoid position. The central dropout in the IAS, with bulging of the septum primum, found in right-sided obstructive lesions, represents the opening of the "flap valve" of the septum as the superior aspect of the septum primum separates from the superior aspect of the foramen ovale. This area is visualized when the echo beam is directed superiorly from the subxiphoid posi-
tion. The more complete imaging of the IAS permits differentiation of secundum from primum septal defects as well as recognition of the iatrogenic alterations of septal morphology with balloon atrial septostomy and Blalock-Hanlon septectomy. This facility for imaging is maintained in patients with situs inversus, but is compromised by displacement of the heart secondary to extrinsic factors, i.e., hypoplastic lung.

S2DE permits observation of septal response to right- and left-sided volume and pressure overload lesions. The echo finding of a thickened and intact IAS in two infants with marked LV volume overload lesions was atypical for the group with significant left-to-right shunts. Both infants had pulmonary artery hypertension with a torrential pulmonary blood flow. One 5-month-old infant was markedly cachectic and died after surgical ligation of the ductus. The S2DE finding of a thickened and intact IAS was confirmed by postmortem examination. We speculate that as a result of inability to decompress the LA through a prematurely closed and thickened flap valve of the foramen ovale in the presence of a significant LV volume overload, the effects of the left-sided volume overload are exaggerated.

After balloon atrial septostomy, the area of central thinning of the IAS is replaced by a true defect within the septum primum. The veil of the septum primum covering the foramen ovale is torn, and its fragments flail at the margins of the interatrial communication. The sensitivity of these septal primum remnants to local blood flow is best illustrated in the one patient

### Table 2. Atrial Septal Morphology Related to Catheterization Findings

<table>
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<th>Ib</th>
<th>IIa</th>
<th>IIb</th>
<th>III</th>
<th>IV</th>
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*Step-up in superior vena cava-right atrium saturation ≥ 6% on two or more determinations.
†Left atrial saturation < 95%, without evidence of pulmonary disease.
‡Includes four patients with complete atrioventricular canals and ventricular septal defects.

Abbreviations: IAS = interatrial septum; LVO = left ventricular volume or pressure overload; RVO = right ventricular volume or pressure overload; LA = mean left atrial pressure; RA = mean right atrial pressure; ASD = atrial septal defect; TGA = transposition of the great arteries; BAS = balloon atrial septostomy; PFO = patent foramen ovale.
Figure 5. Thickened, intact interatrial septum (bracket) in a neutral position with marked dilatation of the left atrium (LA). RA = right atrium; TV = tricuspid valve; MV = mitral valve; PVn = right pulmonary vein.

Figure 6. Leftward deviation of the septum primum with opening of the flap valve of the foramen ovale in tricuspid atresia. RA = right atrium; LA = left atrium; MV = mitral valve.
FIGURE 7. Interatrial septum (arrowheads) as a near-homogenous, curvilinear structure bowing into the right atrium (RA). Foramen ovale was not crossed at catheterization, but was probe-patent at surgery. \( PVn \) = right pulmonary vein; \( LA \) = left atrium.

FIGURE 8. A) The centrally located, secundum-type interatrial septal defect (arrowhead). B) In ostium primum-type defects, the atrial septal defect is lower (arrowheads) and bounded inferiorly by the atrioventricular valves. No ventricular septal defect is seen between the mitral valve (MV) and the tricuspid valve (TV) and the crest of the interventricular septum (IVS); \( RA \) = right atrium; \( LA \) = left atrium; \( RV \) = right ventricle; \( LV \) = left ventricle.
who received mechanical ventilation. Persistence of the flail elements of septum primum in the RA during positive inspiratory pressures suggests decreased systemic venous return, resulting in increased pulmonary venous emptying and a net left-to-right shunt. In the absence of positive mechanical ventilation, the bidirectional, interatrial mixing during each cardiac cycle is consistent with Rudolph's description of events after balloon atrial septostomy. Right-to-left blood flow across the IAS, i.e., septum primum remnant in the LA, occurs during ventricular diastole and reverses with the onset of ventricular systole and atrial filling. Blalock-Hanlon septectomy resects a portion of the superior limbic band and results in a single large sinus venosus type defect that is continuous with the preexisting balloon atrial septostomy (fig. 9C).

**Conclusion**

S2DE imaging in infants with suspected congenital heart disease offers detailed information about atrial septal anatomy. Direct visualization of the entire IAS...
permits differentiation of patent foramen ovale from atrial septal defects and localization of secundum and primum defects.

S2DE demonstrates the sensitivity of the septum primum remnants to interatrial blood flow and corroborates the mechanism of interatrial mixing after balloon atrial septostomy proposed by Rudolph. The use of S2DE makes it apparent that flow reverses during each cardiac cycle rather than after successive cycles.

References
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Circulation. 1979;60:80-90
doi: 10.1161/01.CIR.60.1.80

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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