Subxiphoid Cross-Sectional Echocardiography in Infants and Children with Congenital Heart Disease

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SUMMARY We developed anatomically related cross-sectional echocardiographic views to image the heart from the subxiphoid area in 100 children and infants with various forms of congenital heart disease studied prospectively before cardiac catheterization. Wide-angle cross-sectional views were achieved using a mechanical sector scanner in a scan plane oriented parallel to a line between the patient’s shoulders (a coronal plane) showing the equivalent anatomy of an anteroposterior angiogram. The subxiphoid technique appeared to be better than chest wall-based imaging in demonstrating obstructive lesions in the proximal portion of the right ventricular outflow tract (19 patients), i.e., the subpulmonic area, which is often at the narrow edge of the sector and behind the transducer artifact in chest wall studies. The subxiphoid technique was also useful for imaging the interatrial and interventricular septa; in subxiphoid views, as opposed to four-chamber apical views, there was significantly less false septal dropout and atrial septal defects (19 patients) as well as ventricular septal aneurysms (seven patients) were easily imaged. Finally, the subxiphoid orientation provided more adequate imaging in patients with discrete diaphragmatic subaortic stenosis (four patients), even when the diaphragm was just beneath the aortic valve. Subxiphoid cross-sectional echocardiography is an easily understood anatomical format for imaging cross-sectional anatomy in congenital heart disease and is a valuable adjunct to cross-sectional echocardiography from the chest wall.

CROSS-SECTIONAL ECHOCARDIOGRAPHY allows noninvasive assessment of cardiac spatial anatomy which is especially useful when evaluating children with congenital heart disease.1-3 Moreover, anatomic details can often be demonstrated more accurately with this method than with single-crystal M-mode imaging. The usual planes of examination require placement of the transducer on the chest wall, which is a limiting factor in patients with chest wall deformities or lung disease. The subxiphoid M-mode technique was first introduced by Chang et al.4 as an alternative method for visualizing the left ventricle and left ventricular outflow tract. In this study, we have verified and evaluated cross-sectional planes for cardiac examinations from a subxiphoid transducer position, as initially described by us and others.5,4,9

The subxiphoid examination is easy to perform and presents easily understood coronal plane anatomy. We studied 100 infants and children with congenital heart disease to determine the usefulness of cross-sectional echocardiography from the subxiphoid position for imaging the right and left atrial cavities, right and left ventricular cavities, the atrial and ventricular septae, and the right and left ventricular outflow tracts.

Methods

Patients (table 1)

We performed a preliminary study of 18 children who did not have cardiovascular disease (ages 2–5.5 years) to identify the structures and cavities which could be imaged from subxiphoid placement of the transducer. These studies were performed after obtaining informed parental consent as part of a Human Subjects Approved Research protocol. Right-sided structures were verified by peripheral venous echo contrast injections10 of 3–5 ml of normal saline solution. Once the identification process was completed, the subxiphoid view was included as routine in

References

cross-sectional echo examinations of 100 consecutive patients (ages 1 day to 18 years) with various forms of congenital heart disease. Eighty-eight of these patients had their diagnoses confirmed by cardiac catheterization, surgery or autopsy. In 79 patients, the echocardiographic examinations were performed and interpreted before cardiac catheterization.

Equipment

A mechanical real-time sector scanner (Smith Kline Ekosector I) with a 30° sectoring transducer head (3.5 and 5 MHz), or a prototype of an 80° mechanical transducer with four rotating 2.25 MHz elements, was used. The wide angle mechanical sector scanner was used only in older children because of the lower frequency and lower line density. We also used a real-time linear array system with improved resolution capabilities (Toshiba SSL-53H) that, although it uses a 2.4 MHz transducer, provides adequate imaging, even in babies. The 8.5 cm transducer of the linear array has 64 elements which are focused at 5 cm. Electronic delays allow small angle sectoring of each group of elements and the line density is increased to 114 lines/frame at 30 frames/sec.

Examination Technique

All patients were examined in the supine position without sedation. A pillow placed under the patient’s lumbar region aided in placement of the transducer under the xiphoid process, especially when using the large multi-element linear array transducer. The examination was started with the transducer scanning a coronal plane parallel to a line between the patient’s shoulders with the scan plane tilted about 45° downward from the plane of the anterior chest wall (fig. 1). This view showed both the atrial cavities and the atrial septum, as well as the ventricular septum, both ventricular cavities and ativoventricular valves (fig. 2). By slightly altering the scan plane, the hepatic veins and the inferior vena cava entering the right atrium, as
well as the pulmonary veins entering the left atrium, could also be imaged. As the scan plane was angled more anteriorly with minor rotational adjustments, first the left ventricular outflow tract (fig. 3) and then the proximal right ventricular outflow tract (fig. 4A) could also be imaged. When attempting to image the right ventricular outflow tract, the examiner was careful not to be misled by the superior vena cava, which parallels the ascending aorta but is posterior and courses to the right (fig. 4B). Minor rotational adjustments of the scan plane often made it possible to image both outflow tracts simultaneously (fig. 4A). In very uncooperative children, it was sometimes difficult to angle far enough anteriorly to image the right ventricular outflow tract with the wide linear array transducer. While a family of sagittal planes could be scanned from the subxiphoid area, they showed anatomy similar to the long axis, short axis or oblique views oriented from the chest wall and will not be discussed in this paper.

**Display and Recordings**

All studies were recorded in real-time on video tape and were evaluated by two independent observers in real-time, slow motion and with frame-by-frame analysis. Images were also stored on Super 8 motion picture film and Polaroid stills.

Each study was performed by one investigator, and interpreted independently by him and another investigator. Both knew the clinical impression and described how and in which views a diagnosis could be made. These impressions were dictated before surgical or angiographic confirmation. The investigators made quantitative echo measurements of the right ventricular outflow tract at the level of the pulmonary valve, and then compared them to angiographic (lateral plane) measurements made by another investigator.

As frequently occurs, problems arose in illustrating real-time cross-sectional observations with selected still frame photographs, and the actual examinations and real-time video tapes and movies were more conclusive than any individual still frame illustrations.

Images were oriented with the transducer artifact at the top (apex of the sector) and the patient's left ventricle and mitral valve on the right side of the image (as if the heart were suspended by its diaphragmatic surface and inverted right-to-left). This image orientation corresponds to the convention for short axis

<table>
<thead>
<tr>
<th>TABLE 1. (Continued)</th>
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<tr>
<td><strong>DX</strong></td>
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<td>Valvar aortic stenosis</td>
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<tr>
<td>Right ventricular outflow tract</td>
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<td>A) Isolated sub-valvar obstruction</td>
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<td>B) Valvar and sub-valvar RVOT obstruction (tetralogy)</td>
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<td>C) Valvar pulmonic stenosis</td>
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<td>D) Pulmonary artery band</td>
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Accuracy of cross-sectional echocardiographic findings are presented. The first column contains the patient diagnosis, the second the number of patients in that category, the next two columns describe the type of definitive confirmation of the anatomy, followed by a notation as to whether the echocardiographic diagnosis was made prospectively. The final two columns before "comments" list whether the diagnosis could be made from cross-sectional echocardiography performed from the chest wall and/or the subxiphoid region.

Abbreviations: DX = diagnosis; ASD = atrial septal defect; 1" = primum ASD; 2" = secundum ASD; PFO = patent foramen ovale; DTGV = d-transposition of the great vessels; AV CANAL = atrioventricular canal; double inlet L. ventricle = double inlet left ventricle (as a form of single ventricle); RV = right ventricle; RVOT = right ventricular outflow tract; MB = muscle bundle as a form of subvalvar obstruction of the right ventricle; INF = isolated infundibular hypertrophy as a form of RVOT obstruction.
Figure 1. Diagrammatic representations of the cardiac anatomy imaged from the subxiphoid position. INF = inferior; SUP = superior; R = right; L = left. The inset shows the positions of the planes of cardiac imaging in panels A, B, and C. Panel A, (the interatrial plane) is most posterior; panel B shows the plane of the left ventricular outflow tract; panel C shows the plane of the right ventricular outflow tract. M = muscle; ANT = anterior; POST = posterior.

(transverse) views as recommended by the Standards Committee of the American Institute of Ultrasound in Medicine and the Cross-Sectional Echo Standards Committee of the American Society of Echocardiography.

Results

Normal Images

Eighteen children without cardiac disease were studied with the informed consent of their parents. Figure 2 is a typical stop-frame picture of the most posterior tomographic plane which corresponds to the anatomic drawing in figure 1A. The apex of the sector images liver tissue. Four chambers of the heart are visualized. The right ventricle occupies most of the diaphragmatic surface of the heart. The left heart is located at the right side of the image, and both atria are imaged.

Both the interatrial septum and the membranous portion of the ventricular septum are somewhat perpendicular to the ultrasound beam and are usually imaged completely, with little echo dropout. The size and shape of both atria and ventricles can be assessed. Mitral and tricuspid valves are imaged and their attachments to the papillary muscles can be imaged in this view.

As the transducer is tilted anteriorly and more toward the horizontal and with a minor rotational adjustment (figs. 1B and 3), the left ventricular outflow tract occupies the center of the image and the aorta and aortic valve can be imaged. The anatomic drawing in figure 1B shows that the interrogating ultrasound beam becomes nearly parallel to the left ventricular outflow tract and perpendicular to the aortic valve cusps.

Figures 1C and 4A show the image which results from still greater angulation of the transducer, which then aligns the plane of the examination to image the subvalvular and valvular region of the right ventricular outflow tract and also allows imaging of the proximal pulmonary artery. The scanning plane at this point is nearly parallel to the sternum. Figure 5 shows this view during peripheral venous injection of sterile saline.

We obtained satisfactory subxiphoid images of cardiac anatomy in all patients. Although many cardiac structures can be imaged from the subxiphoid position, we will discuss only malformations in which the subxiphoid technique has been most useful, and in which it was often better than chest wall-based tech-

Figure 2. Wide angle sector scan along plane A shows normal right and left atria (RA and LA) and left ventricular anatomy (LV). The interatrial septum (IAS) is well imaged.
Figure 3. Thirty-degree sector scan shows imaging of the plane of a normal left ventricular outflow tract and aortic (AO) valve. RV = right ventricle; LV = left ventricle.

FIGURE 3. Thirty-degree sector scan shows imaging of the plane of a normal left ventricular outflow tract and aortic (AO) valve. RV = right ventricle; LV = left ventricle.

niques in providing diagnostic information (see table 1). The plane imaging the right ventricular outflow tract (fig. 1C) was the most difficult to obtain and required pressing the transducer down into the subxiphoid area. It was therefore obtained only upon clinical indication.

FIGURE 4. A) Wide angle sector scan (left) shows simultaneous imaging of the right and left ventricular outflow tracts (RV and LV) as shown on the line drawing (right). PV = pulmonary valve; MPA = main pulmonary artery; AO = aorta. Note the crossing courses of the aorta and pulmonary artery passing around it superiorly and to the left. B) The superior and slightly rightward course of the superior vena cava (SVC) is imaged with the transducer directed posteriorly and to the right. TV = tricuspid valve; RV = right ventricle; RA = right atrium; LA = left atrium.

FIGURE 4. A) Wide angle sector scan (left) shows simultaneous imaging of the right and left ventricular outflow tracts (RV and LV) as shown on the line drawing (right). PV = pulmonary valve; MPA = main pulmonary artery; AO = aorta. Note the crossing courses of the aorta and pulmonary artery passing around it superiorly and to the left. B) The superior and slightly rightward course of the superior vena cava (SVC) is imaged with the transducer directed posteriorly and to the right. TV = tricuspid valve; RV = right ventricle; RA = right atrium; LA = left atrium.

Figure 5. Injection of contrast in a peripheral venous location outlines the inflow and outflow regions of the right ventricle during a subxiphoid examination. R = right atrium; TV = tricuspid valve; RVOT = right ventricular outflow tract; other abbreviations as in figure 4.

FIGURE 5. Injection of contrast in a peripheral venous location outlines the inflow and outflow regions of the right ventricle during a subxiphoid examination. R = right atrium; TV = tricuspid valve; RVOT = right ventricular outflow tract; other abbreviations as in figure 4.
Visualization of the Atrial Septum

Atrial Septal Defects

In contrast to apical and short axis views, the subxiphoid view usually provides complete imaging of the atrial septum, since it is perpendicular to incident sound energy. Echo dropout of the foramen ovale or the secundum septum regions was minimal. In 11 patients with proven secundum atrial septal defects, the diagnoses could be made prospectively by directly imaging the defect. Three false-positive atrial septal defects occurred from the chest wall (apex) views in the secundum position. Only one (a patent foramen ovale discovered at surgery) was a false-positive diagnosis from the subxiphoid. Two other normal patients appeared to have false positive secundum atrial septal defects on apex views but not on subxiphoid views. Atrial septal defects in the secundum location were easily differentiated from primum atrial septal defects by their location. In primum atrial septal defects, atrial dropout started from the atrioventricular valve ring (fig. 6), and the secundum septum was intact. The physiology of shunting in atrial septal defects could be verified by visualization of left-to-right negative contrast shunting imaged with venous contrast echocardiography during cross-sectional scanning in six patients.11

We could also differentiate a primum atrial septal defect from forms of atrioventricular canal (n = 15), since the crest of the membranous ventricular septum could be imaged and the presence or absence of a ventricular septal defect assessed. In patients with atrioventricular canal, the associated abnormalities of the atrioventricular leaflets could be evaluated, as discussed below.
Cardiac and/or respiratory movements of the foramen ovale flap could be demonstrated in newborns (fig. 7). In this infant with persistent fetal circulation, the tissue over the foramen ovale flapped open during expiration or crying, allowing a shunt.

Atrial Septum in d-Transposition of the Great Vessels

In three cases of d-transposition of the great vessels, subxiphoid imaging allowed assessment of the effectiveness of balloon atrial septostomy. Figure 8 shows the atrial septum before and after balloon atrial septostomy in one infant. After the septostomy, a wide atrial flap opened to the left side with every heart beat, showing the position and degree of the atrial septal tear. These observations immediately post-balloon atrial septostomy allowed serial noninvasive evaluations of the results of balloon atrial septostomy in these patients, all of whom, 5–7 months after the procedure, still have adequate atrial communications.

In four children who underwent correction of d-transposition of the great vessels by a Mustard procedure, the new atrial chambers formed by the baffle could be assessed by subxiphoid cross-sectional echocardiography (fig. 9). In one patient, the intraatrial baffle was redundant, resulting in mild obstruction of the systemic venous inflow with dilation of the hepatic portion of the inferior vena cava.

Visualization of the Ventricular Septum and Ventricles

Since the membranous portion of the ventricular septum and the junction of the atrial and ventricular septae (the central fibrous body) are imaged well from the subxiphoid scanning position, the technique was very helpful in the diagnosis of lesions of this part of the septum. In two of seven patients who had ventricular septal aneurysms missed by standard precordial cross-sectional echocardiography, diagnosis could be made from the subxiphoid position, though the aneurysmal sac was imaged close to the diaphragmatic surface of the heart (fig. 10). No false positive diagnoses occurred.
Atrioventricular Canal

We investigated 15 children with atroventricular canal and obtained images of the atrial and ventricular septal defects in all of them. We could also evaluate the abnormalities of the atroventricular valves which were part of the spectrum of this disease. Chordal attachments to the septum and displacement of the papillary muscle apparatus could be imaged. Common atroventricular valves were imaged as if they were composed of one leaflet from the right and one from the left ventricle closing and often inserting in close proximity to the crest of the ventricular septum. In the case shown in figure 11, the images showing the size of the atroventricular canal defect and the distribution of valvular tissue were verified by direct visualization at operation. Fourteen of 15 diagnoses of complete atroventricular canal were made on apex visualization. In the apex study, chordal attachments to the septum were missed in one patient, but these were imaged on subxiphoid views. No false-positive diagnoses occurred.

Hypoplastic Ventricle

In infants with hypoplastic right (tricuspid atresia; n = 5) or left (n = 10) hearts, the subxiphoid technique was of value as an aid for imaging the hypoplastic ventricle, its inflow and outflow tracts. These images provided an accurate assessment, compared with autopsy observations (n = 9), of the size and position of the left ventricular and aortic structures in hypoplastic left heart (fig. 12), and were useful for estimating the size and position of the outflow chamber in tricuspid atresia (n = 5) or double inlet left ventricle (single ventricle) (n = 5) (fig. 13). One outflow chamber was missed on apex views and was imaged on subxiphoid views (table 1). No false positives occurred for any of these diagnoses.

Left Ventricular Outflow Tract

While diffuse fibromuscular subaortic stenosis could be imaged from the chest wall as well as from the subxiphoid position, thin discrete subaortic membranes, especially if they were positioned close to the aortic valve, were difficult to image completely from the chest wall. In three of four patients with discrete subaortic diaphragm, chest wall long axis views suggested the malformation, but the membrane was of-

FIGURE 10. Ventricular septal aneurysm pouting toward the diaphragmatic surface of the right ventricle is shown in a 30° sector scan as well as in a line drawing. Abbreviations as in figure 6.

FIGURE 11. Subxiphoid imaging of a Rastelli (type A) atroventricular canal with the linear array. The image and line drawings show mitral (MV) and tricuspid (TV) portions of the common valve leaflet are attached by chordae to the crest of the ventricular septum (IVS) (white arrows) in the area of the ventricular septal defect. The secondum portion of the atrial septum is not well imaged and was deficient at the time of surgery. Other abbreviations as in figure 6.
ten imaged incompletely. The membrane was much more completely imaged from the subxiphoid scanning position since it was perpendicular to the incident sound energy (fig. 14). In addition, the subxiphoid technique allowed us to image the aortic valve orifice in six patients with severe valvular aortic stenosis. Figure 15 shows a child with critical aortic stenosis who had only a pinhole opening of the valve demonstrated at echocardiography and confirmed at surgery. Both chest wall and subxiphoid views provided complementary information. No false positives occurred for any of these diagnoses.

**Right Ventricular Outflow Tract**

The right ventricular outflow tract, especially in the subvalvular region, is an area of the heart which is often located too close to the transducer to be imaged well from the chest wall, and so far has not been accurately assessed by two-dimensional echocardiography. The subxiphoid technique offers a better window for imaging obstructions within the right ventricular outflow tract (fig. 1C). Nineteen children with various forms of right ventricular outflow tract obstruction were studied, 16 before catheterization. The technique provided imaging of the proximal right ventricular outflow tract in all patients. In three of four patients, we could prospectively diagnose an isolated right ventricular bundle or subvalvular obstruction. In seven of eight patients, we prospectively diagnosed combined valvular and subvalvular pulmonic stenosis. An example is given in figure 16 in a patient with tetralogy of Fallot. In these patients, the subxiphoid position was especially useful for estimating the degree of right ventricular outflow tract hypoplasia.

In one patient, subxiphoid imaging of the pulmonary valve was marginal compared with chest wall views, and we missed one diagnosis of valvular disease. One false-positive diagnosis of valvular pulmonic stenosis was made on chest wall and subxiphoid views. In three patients with a pulmonary band, the position of the band was easily imaged (fig. 17). The subvalvular region was not imaged adequately on any of the chest wall views (table 1).

Comparison of angiographic-to-echocardiographic measurements of the pulmonary outflow tract at the level of the valve in 19 children suggested a correlation coefficient of \( r = 0.93 \) for quantitative determination of the inner diameter of the pulmonary valve ring (fig. 18).

While the diagnosis of septal-great artery relationships in tetralogy of Fallot was best accomplished
FIGURE 15. The narrowed orifice of the aortic valve within the aorta is visualized in an infant with critical subaortic stenosis on this subxiphoid scan. RVOT = right ventricular outflow tract; MPA = main pulmonary artery; other abbreviations as in figure 6.

FIGURE 16. Subxiphoid echocardiogram (right) and line drawing (left) show shifting of the aorta toward the right with prominence of the crista supraventricularis and narrowing of the right ventricular outflow tract (RVOT) in a patient with tetralogy of Fallot. PV = pulmonary valve; RVIT = right ventricular inflow tract. Other abbreviations as in figure 6.

FIGURE 14. The components of the subaortic membrane are visualized in a patient with discrete membranous subaortic stenosis and a ventricular septal defect (VSD). Two aortic valve leaflets are imaged just superior to the obstructing membrane. Other abbreviations as in figure 6.

from the chest wall (long axis), only the subxiphoid view provided adequate imaging of the proximal subvalvular right ventricular outflow tract.

Discussion

The subxiphoid technique is a new window from which the examiner can image the whole heart, its inflow and outflow tracts, and provides a new and easily obtainable four-chamber view. In our experience, the anatomy is easily understood as visualized in these coronal planes.

The examination from the subxiphoid region was tolerated well by most of our patients, without discomfort. Sector scan instruments as well as linear array systems could be used. Severe chest deformities or surgical dressings presented little problem when we used this approach.

At the atrial level of the heart, this view is unique and cannot be replaced by other views. Since the atrial septum is more perpendicular to the incident
sound energy in this plane, fewer spurious areas of echo dropout occur. The size and shape of the atria, movement of the atrial septum, defects and surgical repairs in the atrial region were easily studied. This approach to imaging the interatrial septum has been valuable in evaluating the atrial septum in patients with d-transposition of the great vessels before and after palliation or Mustard’s procedure.

The subxiphoid technique is excellent for imaging the membranous ventricular septum and for demonstrating ventricular aneurysms, some of which are easily missed in other views, and it is also a useful adjunct to the apex view for understanding and evaluating endocardial cushion defects.

The visualization of the left ventricular outflow tract and the right ventricular outflow tract from the subxiphoid position images these areas more completely than other views. Discrete obstructions are

![Figure 17](image1.png)

**Figure 17.** Echocardiographic subxiphoid scan and line drawing (left) show the position of a pulmonary artery band positioned just superior to the pulmonary valve. RPA = right pulmonary artery; LPA = left pulmonary artery. Other abbreviations as in figure 6.

![Figure 18](image2.png)

**Figure 18.** Plot of angiographic (angio) (ordinate) vs echocardiographic (abscissa) estimates of the size of the pulmonary artery (PA) at the level of the valve ($r = 0.93$). The regression equation is shown.
easily imaged because they are more perpendicular to
the incident sound energy. The quantitative accuracy
of the method for imaging the right ventricular out-
flow tract at the level of the pulmonary valve could be
proven angiographically in our study. For the evalua-
tion of the subvalvular pulmonary outflow tract
obstruction, the subxiphoid technique appears to pro-
vide the most accurate approach.

In our experience, the subxiphoid technique has
become an important part of a complete cross-section-
al echocardiographic examination in patients with
complex congenital or acquired disease. The tech-
nique is easy to perform in children and presents easily
understood coronal plane images of the heart.

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