CROSS-SECTIONAL ECHO OF STENOTIC PV/Weyman et al. 769

Cross-Sectional Echocardiographic Visualization of the Stenotic Pulmonary Valve

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SUMMARY Real-time, cross-sectional echocardiograms of the pulmonary valve were recorded in 22 patients with valvular pulmonary stenosis (VPS) (14 mild, eight moderate or severe) and 25 normal subjects. Normally during systole the pulmonary leaflet echoes moved rapidly apart and in the fully opened position lay parallel and in close apposition to the margins of the pulmonary artery. In 20 of 22 patients with VPS in whom the pulmonary valve was recorded the systolic configuration of the leaflets, opening pattern of the leaflet echoes, and presence of presystolic doming served to differentiate the stenotic valve from normal.

In contrast M-mode recordings of the pulmonary valve were possible in only 12 of these 22 cases (seven mild and five moderate or severe) and suggested VPS in only the five cases with moderate or severe stenosis. Cross-sectional echocardiography offers a direct, noninvasive method for visualizing the stenotic pulmonary valve and should be an improvement over the indirect M-mode data.

M-MODE ECHOCARDIOGRAPHY can help detect valvular pulmonary stenosis.1,4 The M-mode diagnosis rests on the observed effects of altered right ventricular and pulmonary artery pressure relationships on pulmonary leaflet motion.1 In patients with pulmonary stenosis decreased right ventricular compliance and forceful right atrial contraction frequently result in right ventricular end-diastolic pressure exceeding simultaneous pulmonary artery pressure which results in pre-systolic opening of the pulmonary valve.4 5 This opening or doming of the valve following atrial contraction is reflected on the M-mode record as a marked increase in the posterior deflection of the posterior pulmonary leaflet which normally occurs following atrial contraction (A wave).

There are unfortunately a number of limitations to the M-mode diagnosis of valvular pulmonary stenosis. 1) The pulmonary valve may be difficult to record preventing visualization of the diastolic motion pattern. 2) The technique does not permit direct visualization of the stenotic valve but rather provides indirect diagnostic information based on the effects of abnormal presystolic pressure gradients on pulmonary valve motion. 3) The exaggerated A waves seen with valvular stenosis are not specific for this disorder but may occur in any situation in which there is an elevation of right ventricular end-diastolic pressure which equals or exceeds simultaneous pulmonary artery pressure. 4) This technique is not generally useful in patients with mild valvular pulmonary stenosis since in these cases the hemodynamic derangement is not reflected on the pulmonary valve echogram.6 For these reasons M-mode echocardiography has found only limited diagnostic applications in patients with valvular pulmonary stenosis.

Cross-sectional echocardiography, by enlarging our field of vision and displaying the echocardiographic data in an appropriate spatially oriented format, should facilitate visualization of the pulmonary valve and permit direct recording of the domed stenotic valve leaflets. The purpose of this study therefore was to evaluate the ability of cross-sectional echocardiography to record pulmonary valve motion and to detect valvular stenosis.

Material and Methods

M-mode and cross-sectional echocardiographic studies of the pulmonary valve were performed in 22 consecutive patients with valvular pulmonary stenosis. There were 12 males and 10 females. The average age was 9.4 years (range 2 to 22 years). The diagnosis of pulmonary stenosis was established at cardiac catheterization by the presence of a
pressure gradient at the valvular level in the absence of intra or extracardiac shunts, as well as the typical angiographic appearance of a domed valve. There were 14 patients with mild valvular pulmonary stenosis (peak systolic pulmonary valve gradient of < 50 mm Hg) and eight patients with moderate or severe valvular pulmonary stenosis (peak systolic pulmonary valve gradient ≥ 50 mm Hg). M-mode and cross-sectional pulmonary valve echograms were also performed in a control group of 25 normal subjects. Patients were considered normal on the basis of an absence of heart disease by either history or physical examination and normal M-mode and cross-sectional echograms.

Cross-sectional studies were performed using either a mechanical sector scanner developed at Indiana University in conjunction with the Fortune-Fry Research Laboratories or a commercially available mechanical scanner (Smith-Kline Instruments, Echosector 1). A 2.25 MHz transducer focused at 7.5 cm was utilized in each study. Cross-sectional studies were recorded on ½ inch videotape using a Sanyo VTC-700 videotape recorder. These records were then available for analysis in real-time, slow motion or single frame format. Still frames were converted to hard copy using a standard Polaroid photographic system.

Patients were examined in the supine or 30° left lateral position. The transducer was positioned along the left sternal border at a level generally one and frequently two interspaces higher than that used for optimal mitral valve recordings. All studies were performed with the plane of the cross-sectional probe oriented parallel to the long axis of the pulmonary artery (fig. 1).

M-mode studies were performed using an Ekoline 20A echograph combined with a Honeywell 1856 fiberoptic strip chart recorder. Either a 2.25 or 3.5 MHz transducer focused at 7.5 cm was utilized in these studies. Several techniques for pulmonary valve recording have been previously described.

**Results**

Cross-Sectional Studies

In each of the 25 normal subjects the coapted pulmonary leaflets appeared during diastole as a thin linear echo lying within the pulmonary artery midway between the anterior and posterior margins of the vessel (fig. 2A). At the onset of systole this single linear echo separated into two discrete linear echoes which moved rapidly away from each other toward the margins of the vessel. During systole the echo from the posterior pulmonary leaflet could generally be seen lying parallel to the posterior margin of the pulmonary artery (fig. 2B). The echo from the anterior leaflet generally was lost within the mass of echoes from the anterior chest wall.

There were several important differences in the appearance and motion pattern of the pulmonary leaflets in patients with valvular pulmonary stenosis. First, during systole the leaflets did not lie parallel to the margin of the pulmonary artery but rather curved inward toward the mid portion of the pulmonary vessel (figs. 3 and 4). This curved configuration of the leaflet echoes reflected systolic doming of the valve and produced an effective narrowing of the pulmonary valve orifice. Secondly, the systolic motion pattern differed between the two groups. In normals, the leaflet echoes remained parallel during opening; in patients with pulmonary stenosis the proximal portion of the leaflet echoes moved through a wide arc while the distal tips remained relatively close together. This resulted in an increasingly obtuse angle between the leaflet echoes terminating in full doming of the valve (fig. 5). Finally, although during most of diastole the appearance of the pulmonary valve echo in patients with valvular pulmonary stenosis was indistinguishable from that observed in normal subjects (fig. 3), the leaflets frequently moved to a fully open or domed position following atrial systole (fig. 6).

In the majority of cases (14/22) both the anterior and posterior pulmonary leaflets were visualized. Occasionally only the posterior leaflet could be recorded. In these cases it was still possible to make a diagnosis of pulmonary stenosis based on the curved systolic configuration of the posterior leaflet (fig. 7).

Comparison of M-mode and Cross-Sectional Studies

Data concerning the relative abilities of the M-mode and cross-sectional systems to visualize the pulmonary valve and determine the presence of pulmonary stenosis are contained
FIGURE 2. Long axis recording of a normal pulmonary valve. Figure 2A is recorded during diastole. The coapted pulmonary leaflets appear as a linear echo midway between the anterior and posterior margins of the pulmonary artery. Figure 2B is recorded during systole. The fully opened pulmonary leaflets lie parallel, and in close proximity, to the anterior and posterior margins of the pulmonary artery. Figure 2C is a diagram illustrating the position of the fully opened pulmonary leaflets. APA = anterior margin of the pulmonary artery, PPA = posterior pulmonary artery, PV = coapted pulmonary leaflets during diastole, APL = anterior pulmonary leaflet, PPL = posterior pulmonary leaflet.

FIGURE 3. Long axis cross-sectional recording of the pulmonary artery and pulmonic valve from a patient with valvular pulmonary stenosis. Figure 3A is recorded during diastole and again depicts the linear echo in the mid portion of the pulmonary artery produced by the coapted pulmonary cusp. Figure 3B illustrates the domed systolic configuration of the pulmonary leaflets. Figure 3C is a line drawing corresponding to the domed systolic appearance of the leaflets in figure 3B.
in table 1. The pulmonary valve was successfully recorded using the cross-sectional system in 13 of 14 patients with mild pulmonary stenosis and seven of eight patients with moderate or severe valvular pulmonary stenosis. In each of the cases in which the valve was recorded it was possible to diagnose the presence of pulmonary stenosis based on the systolic configuration of the valve leaflets.

In contrast using the M-mode system the pulmonary valve was recorded in only seven of 14 cases with mild pulmonary stenosis (50%). In each of these seven cases the pulmonary valve A waves were within normal limits (mean 4.8 mm, range 2–7 mm), and therefore could not be differentiated from normal. The pulmonary valve was recorded in five of eight patients with moderate or severe pulmonary stenosis using the M-mode system. In four of the five patients in whom the pulmonary valve was recorded, A waves of 8 mm or greater were observed. In a fifth case, a 4½-year-old child, A waves were only 6 mm in depth. However, this represented full opening of the valve and was present throughout the respiratory cycle permitting a diagnosis of pulmonary stenosis on a qualitative basis.

Discussion

This report suggests that cross-sectional echocardiography facilitates pulmonary valve recording and provides a direct method for visualizing the stenotic pulmonary valve. The ability to record any intracardiac structure using pulsed reflected ultrasound is a function of the physical characteristics of the ultrasonic beam and appropriate direction of the interrogating signal, rather than display characteristics. Data relative to the ability of the M-mode and cross-sectional systems to record the pulmonary valve therefore may be somewhat misleading. It might be
Although the reflectors of valvular presence in the pulmonary artery were recorded, the curvature or arcing of the leaflet into the pulmonary artery reflects the systolic doming of the valve and confirms the presence of valvular stenosis.

reasonably argued that any structure which can be recorded with the cross-sectional system can also be recorded using the M-mode technique if the examination is pursued diligently enough. This concept is further supported by our success in recording the pulmonary valve in earlier studies; the ability to generate M-mode recordings of the pulmonary valve from the cross-sectional display; and the increased ease of pulmonary valve recording after the location of the valve has been established with the cross-sectional system.

The important question is not the relative ability of these systems to record the pulmonary valve, but rather the quality of the information available from these recording techniques. This study suggests that there are several important areas in which direct cross-sectional display of the domed stenotic pulmonary valve offers a significant improvement over the M-mode data. In patients with mild valvular pulmonary stenosis where the hemodynamic derangement is ordinarily not of sufficient magnitude to produce presystolic opening of the pulmonary valve, the M-mode record fails to differentiate the stenotic pulmonary valve from normal. In this study the A wave depth was not observed to be abnormal in any of the seven patients with mild pulmonary stenosis in whom the pulmonary valve was recorded using the M-mode technique. In contrast the diagnosis of valvular pulmonary stenosis was possible based on the systolic configuration of the domed leaflets in 13 of 14 total patients in whom the valve was recorded with the cross-sectional system.

In addition to eliminating false negative diagnoses, the cross-sectional system may also be helpful in excluding situations in which large A waves may occur in the absence of valvular pulmonary stenosis. Since the A wave reflects the relative pressures across the pulmonary valve at end diastole, any factor which decreases pulmonary artery diastolic pressure or increases relative right ventricular end-diastolic pressure may augment A wave depth. Thus increased A wave depth is seen during periods of marked inspiration, with significant bradycardia, following atrial and ventricular premature contractions, and in patients with augmented right ventricular diastolic volume or decreased right ventricular compliance. Directly visualizing the domed stenotic valve should permit differentiation of premature pulmonary valve opening occurring as a result of the altered hemodynamics associated with valvular pulmonary stenosis from that arising in other conditions in which the timing of valve motion may vary but the opening sequence and systolic position of the leaflets are normal.

Finally if one is to quantitate severity of pulmonary stenosis echocardiographically, it will be necessary to record both the anterior and posterior pulmonary leaflets and hence the pulmonary valve orifice. With the M-mode system it has been virtually impossible to record the anterior pulmonary leaflet in patients with valvular pulmonary stenosis: over a four-year period while examining over fifty patients with valvular pulmonary stenosis, we have been successful in recording the anterior leaflet on only one occasion, In contrast, with the cross-sectional system it was possible to record both the anterior and posterior leaflets and to estimate the pulmonary valve orifice size in 14 of 22 patients with valvular pulmonary stenosis. Because of the wide variation in patient age and size, the limited group studied here does not permit quantitation of severity of pulmonary stenosis. Preliminary data, however, suggest that there may be a relationship between orifice diameter recorded in the long axis and the severity of pulmonary stenosis.

This report indicates that the cross-sectional echocardiographic technique is a reliable method for recording the pulmonary valve and provides a means for noninvasive visualization of the domed stenotic valve. Further studies are required to determine the feasibility of measuring the pulmonary valve orifice and relationship of this echocardiographic measurement to severity of pulmonary stenosis.

**Table 1. Cross-sectional and M-mode Echoes Compared**

<table>
<thead>
<tr>
<th></th>
<th>Ps with VPS (N = 22)</th>
<th>Mild (N = 14)</th>
<th>Mod.-Sev. (N = 8)</th>
</tr>
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<tbody>
<tr>
<td><strong>Cross-sectional echocardiography</strong></td>
<td></td>
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<td></td>
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<tr>
<td>PV recorded</td>
<td>13/14 (93%)</td>
<td>7/8 (88%)</td>
<td></td>
</tr>
<tr>
<td>Dx of PS</td>
<td>13 (93%)</td>
<td>7 (88%)</td>
<td></td>
</tr>
<tr>
<td>Anterior leaflet</td>
<td>9 (64%)</td>
<td>5 (63%)</td>
<td></td>
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<tr>
<td><strong>M-mode echocardiogram</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV recorded</td>
<td>7 (50%)</td>
<td>5/8 (63%)</td>
<td></td>
</tr>
<tr>
<td>'a' wave 7 mm</td>
<td>0/7 (0%)</td>
<td>4-5/5 (100%)</td>
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</table>

Abbreviations: VPS = valvular pulmonary stenosis; PV = pulmonary valve; Anterior leaflet = patients in whom both the anterior and posterior pulmonary valve leaflets were recorded.

**References**

SUMMARY We have identified pericardial effusion by echocardiography in 174 patients. Seventeen had cardiac tamponade which was not always clinically obvious. Right ventricular narrowing or compression, occurring in the minor axis at end diastole and end expiration, to 7 ± 2 mm or less, was strongly associated with tamponade in patients with effusion. Right ventricular compression and signs of tamponade abated with pericardiocentesis. One patient was in tamponade without obvious right ventricular narrowing. Nonetheless, he demonstrated serial increases in right ventricular dimensions which paralleled hemodynamic improvement. Diminished left ventricular end-diastolic dimension, "swinging heart," electrical alternans, reciprocal respiratory variations in right and left ventricular end-diastolic dimensions and variation in amplitude of the mitral D-E slope were nonspecific for tamponade. Evaluation of right ventricular dimensions may be clinically useful to diagnose and monitor cardiac tamponade.

ECHOCARDIOGRAPHY IS THE PRIMARY noninvasive tool to detect the presence and estimate the size of pericardial effusion. A recent report of three cases suggests that echocardiography may be helpful in identifying hemodynamically significant pericardial effusion.

It became clear early in our experience with pericardial effusion that the patient with tamponade differed echocardiographically from the larger population. We believed that subsequent prospective analysis of these echocardiographic differences would allow us to identify patients in tamponade, a condition that was not always obvious because its symptoms and signs were frequently overshadowed by those of the patient’s primary condition. We investigated the echocardiographic characteristics of the tamponade patient to test their specificity and to understand better the pathophysiology of the condition.

Methods

Three thousand consecutive echocardiographic studies were examined at the time of study for the presence or absence of pericardial effusion. Effusion was identified by the presence of an echo-free space between the epicardium and pericardium posteriorly, either alone or accompanied by a similar space anteriorly. Where possible, recordings were made with the patient both in the recumbent and left oblique positions.

Transducer location was usually in the fourth intercostal space near the left sternal border. The transducer was pointed superiorly and medially and swept inferiorly and laterally to provide images of all intracardiac chambers and valves. End-diastolic and end-systolic dimensions of the ventricles were measured in the minor axis, defined as the level of the superior margin of the mitral valve chordae tendineae. This level was slightly more basal than that suggested by Hagan and associates as being most accurate for evaluating septal motion. Right ventricular dimensions were also measured in the outflow tract at the level of the aortic valve leaflets. The right ventricular posterior wall was considered to be the anterior surface of the interventricular septum. Maximal right ventricular dimensions were obtained at both end inspiration and end expiration at end diastole with the patient in the left oblique position and with the transducer in a medical location. Left ventricular dimensions and the motion of the mitral valve (D-E excursion and E-F slopes) were routinely recorded.

The quantitation of right ventricular dimensional changes, limited by the resolution of the echocardiographic technique, at times was made more difficult by the prevailing clinical conditions. The studies were always performed in...
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