Ultrasound Evaluation of Systolic Anterior Septal Motion in Patients With and Without Right Ventricular Volume Overload

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SUMMARY

Little information is available concerning the normal systolic pattern of movement of the interventricular septum in man. Accordingly, we studied 242 patients without clinical or catheterization evidence of right ventricular volume overload (RVVO) employing the ultrasound continuous recording technique. In the plane of the mitral valve, systolic anterior septal motion (SASM) was present in 111 patients; in 38 patients the septum did not move during systole while in 74 patients, septal motion was variably anterior and posterior during the same recording. Normal posterior septal motion occurred in only 19 patients. However, at or below the level of the chordae tendineae, 226 of the 242 patients (93%) had normal posterior septal motion. The other 16 patients had severely impaired left ventricular function.

In 56 patients with RVVO, 34 had abnormal septal motion at the level of the chordae tendineae (24 with SASM, 7 with variable motion and 3 with no movement).

To evaluate septal motion further, 100 normal subjects were studied using a phased multicrystal ultrasound system designed by Bom which provided a sagittal plane image of the cardiac structures. In all 100 subjects the superior septum moved anteriorly in systole with the aortic root, and the upper one-third of the septum acted as a 'hinge' for the lower two-thirds which moved posteriorly. In 8 of 21 patients with RVVO studied by the multicrystal method, the entire septum moved anteriorly during systole; variable patterns occurred in 7 patients, while normal septal motion was present in 6 patients.

We conclude that 1) normal septal motion consists of anterior movement of the superior segment of the septum during systole; 2) below a pivot point, the inferior two-thirds of the septum moves posteriorly during systole; 3) the normal pivot point of the septum frequently results in SASM when recordings are made in the plane of the mitral valve in patients with and without RVVO; and 4) paradoxical septal motion is not always present in patients with RVVO even when echocardiographic recordings are obtained at or below the level of the chordae tendineae.

Additional Indexing Words:
Echocardiography
Multicrystal echocardiography
Ultrasound cardiology
Atrial septal defect

ECHOCARDIOGRAPHY has gained considerable recognition as a safe, reliable, noninvasive method for the diagnosis of many forms of congenital heart disease.1-11 It has been suggested that in the presence of an enlarged right ventricular chamber, abnormal interventricular septal motion below the plane of the mitral valve is a specific finding in patients with right ventricular volume overload.12-19 However, there is little available information concerning the usual pattern of interventricular septal motion both in normal subjects and in patients with congenital and acquired heart disease. Using both conventional single crystal recording techniques and the complementary data provided by a new mul-

Dr. O'Rourke is the recipient of the teaching scholar award of the American Heart Association.

The opinions or assertions contained herein are those of the authors and are not to be construed as official or as reflecting the views of the Navy Department.

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Received January 17, 1974; revision accepted for publication April 19, 1974.

Circulation, Volume 50, August 1974

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ticrystal instrument,\(^\text{20}\) we have sought for the first time to
define in man the entire range of interventricular septal motion. An additional aim of this study was to
examine the specificity of the finding of ‘‘paradoxical’’
septal motion in patients with right ventricular
volume overload.

**Methods**

A total of 398 patients were studied either by a commer-
cially available ultrasound continuous recording device
(Picker Echoview II interfaced with a Honeywell strip chart
recorder) or by using a phased multicroystal echocardio-
graphic system. Group I consisted of 201 patients with
various forms of congenital or acquired heart disease but no
right ventricular volume overload; group II consisted of 141
normal subjects without heart disease; and group III in-
cluded 56 patients with right ventricular volume overload
(table 1). There were 216 females and 182 males whose ages
ranged from 2 months to 81 years.

Single crystal studies utilized a 2.25 MHz transducer for
adults and older children whereas a 3.5 MHz transducer was
employed for the younger children. Echocardiograms were
obtained with the transducer positioned along the left sternal
border directed posteriorly and recordings made in the
M-mode or ‘‘slow sweep’’ display. Airless contact between
transducer and skin was achieved with a water soluble gel.
The recording paper was calibrated for 1 cm anterior-
posterior distance and 0.5 sec horizontal duration and the
speed adjusted to provide the best quality in relation to each
patient’s heart rate.

Multiple crystal echocardiographic studies were per-
formed with an instrument designed by Bom and associates
at the University of Rotterdam\(^\text{21}\) (fig. 1). This system utilizes
a twenty element transducer at 4.5 or 2.25 MHz with a
frame rate of 80 per second. When fired sequentially, each
element generates an independent ‘‘A’’ mode echocar-
diogram which consists of two lines. A total of 40 lines is
displayed on an oscilloscope in an arrangement which
duplicates their physical distribution. Therefore, the
number one, or most superior element on the transducer
surface will generate the first two lines on the oscilloscope
cross-section. An electrocardiogram (ECG) is displayed
simultaneously on the oscilloscope. Recordings were ob-
tained both on videotape and on 8 mm motion picture film,
and photographs were recorded using an ECG-gated
Polaroid system. All patients were examined in the supine
position. The multiscan transducer was placed along the left
sternal border and positioned until a sagittal cross-section
incorporating the left ventricular body and outflow tract
and right ventricle was obtained. This position allowed good

**Table 1**

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>201</td>
<td>41</td>
<td>35</td>
</tr>
<tr>
<td>M</td>
<td>0</td>
<td>180</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>201</td>
<td>141</td>
<td>56</td>
</tr>
</tbody>
</table>

Abbreviations: TM = Time motion single crystal strip chart recording system; M = Multiple crystal echocardiographic system.

**Results**

Single Crystal Echo Evaluation

The single crystal echo continuous recording technique was used to study 277 patients, while 121
patients were studied by the multiple crystal system
(table 1). High quality recordings of the interven-
tricular septum were obtained in all 277 cases studied
by the single crystal method so that systolic septal
motion could be carefully assessed at two cross-sectional
levels: level (1) which included the mitral valve, and
level (2) in which septal motion was recorded at or
below the chordae tendineae. Four basic patterns of
systolic septal motion were identified: (A) anterior, (B)
flat, (C) variable and (D) posterior (fig. 2).

**Group 1 — Heart Disease, No Right Ventricular Volume Overload**

At the level of the mitral valve systolic anterior sep-
tal motion was recorded in 44% (89 of 201) of group I
patients. Eight percent (17 of 201) of patients in this
group exhibited the normal systolic posterior septal
motion (SPSM) when recordings were obtained at the
level of the mitral valve. At this level, 31% (62 of 201)
were noted to have systolic variable septal motion
(SVSM) and in the remaining 17% septal motion was
flat during systole. Upon directing the transducer in-
feriorly and laterally away from the mitral valve,
thereby aiming at the level of or below the chordae
tendineae, 92% of the patients (185 of 201) had nor-
mal systolic posterior septal motion. The remaining
8% consisted of the following: 1) 7 patients with a left
ventricular aneurysm who had paradoxical systolic
anterior septal motion; 2) 5 patients with mitral or
aortic valvular prostheses without interventricular
conduction disturbances in whom systolic variable
septal motion was noted; and 3) 4 patients with a car-
diomyopathy who exhibited no septal motion during
systole.

**Diagram of the multiple crystal echocardiographic system.**
Group II — Normals

Group II consisted of 141 normal subjects. Of the 41 subjects studied by the single crystal continuous recording technique at the level of the mitral valve, 22 (54%) demonstrated systolic anterior septal motion, 2 (5%) had systolic posterior septal motion, 12 (29%) exhibited systolic variable septal motion, and 5 (12%) revealed no motion during systole. However, all 41 subjects demonstrated normal systolic posterior septal motion when the recording was obtained at the level of or below the chordae tendineae. Systolic septal motion was observed to change in all normal subjects as the transducer was directed toward the aortic root, then inferiorly through the mitral valve and left ventricle during continuous strip chart recording. The upper portion of the septum adjacent to the anterior aortic root always moved anteriorly during systole. As the ultrasound beam was directed more inferiorly, the systolic septal motion was observed to change consistently, assuming variable or no motion during a transition point, and finally moving posteriorly. At times this systolic posterior septal motion occurred at the level of the mitral valve while in other instances this posterior movement did not occur until the recording was made in the plane of the chordae tendineae (fig. 3).

Group III — Right Ventricular Volume Overload

Group III comprised 56 patients who had right ventricular volume overload. Of this group 41 had atrial septal defects, 10 had Ebstein’s anomaly, and 5 had pulmonic regurgitation. Thirty-five patients in this group were studied with the single crystal continuous recording technique. When septal recordings were made in the plane of the mitral valve 80% (28 of 35) had systolic anterior septal motion; 6% (2 of 35) had systolic posterior septal motion; 11% (4 of 35) had systolic variable septal motion; and 3% (1 of 35) had no motion during systole. When septal recordings were obtained at or below the plane of the chordae

Figure 2

Diagrams and corresponding echocardiograms from different patients are presented to illustrate the four patterns of normal systolic interventricular septal motion. The arrows identify the contour of septal motion during systole in each panel. Panel A demonstrates that the upper septum above the “pivot” or “hinge” point moves anteriorly during left ventricular ejection. Panels B and C illustrate typical septal patterns when the echo beam passes through the “hinge” point. Panel B demonstrates the pattern of flat septal motion, while Panel C shows variable septal motion during systole. Panel D illustrates that normal septal motion below the “pivot” point is directed posteriorly, RS = right side of interventricular septum; LS = left side of septum; AML = anterior mitral leaflet; PML = posterior mitral leaflet; LA = left atrial wall; END = endocardium; EPI = epicardium.
ULTRASOUND AND SEPTAL MOTION IN RVVO

Figure 3

The upper panel shows the upper septum (S,) moving anteriorly during systole. When recording in the plane of the posterior mitral leaflet (PML), systolic septal motion becomes flat in the area of the septal pivot (S,), and finally the lower septum (S,) exhibits posterior motion during systole at the level of the chordae tendineae. Ao = aortic root. The lower panel is an example of a case in which the pivot or transitional point of the septum occurs at a higher level while still in the plane of the mitral valve. The arrow identifies the uppermost portion of the septum (S) moving anteriorly.

AAR = anterior aortic root; PAR = posterior aortic root.

tendineae in these 35 patients, 45.7% (16 of 35) exhibited paradoxical systolic anterior septal motion whereas 45.7% (16 of 35) had normal systolic posterior septal motion with the remaining 8.5% (3 of 35) revealing essentially no motion during systole. Among 10 ASD patients in whom the right ventricular diameter index (RDVI) could be calculated, it was increased in all cases (8 with a large shunt and 2 with a small shunt). However, in this small group no correlation existed between the right ventricular diameter index and the type of septal motion. The average right ventricular diameter index was 2.1 cm/m² (range of 1.3 to 3.2) compared to a normal range of 0.3 to 1.1 cm/m². Following the operative closure of the atrial septal defect, the right ventricular diameter index was reduced in all patients by an average of 31%.

Multicrystal Echo Evaluation

In all of 100 normal subjects studied with the multiple crystal echocardiographic system, the superior portion of the septum moved anteriorly during systole along with the aortic root. A consistent finding was that the septum “hinged” or pivoted at the junction of its upper one-third and lower two-thirds (fig. 4). During systole the lower two-thirds of the interventricular septum moved posteriorly, i.e., toward the anteriorly moving posterior left ventricular wall. This pivot point, which in all 100 cases was located within the upper one-third of the septum, was in the plane of the mitral valve. By contrast, systolic posterior septal motion was observed in all areas below the plane of the mitral valve.

Among the 21 patients with right ventricular
Normal septal motion as recorded in the sagittal plane by the multicrystal echocardiographic system. The panel at the top left is a schematic representation of the structures illustrated in the remaining five panels. The small insert in the top left panel depicts the position of application of multicrystal transducer in relation to the heart and great vessels. At the beginning of systole the anterior mitral valve leaflet moves posteriorly (right panel, top). As left ventricular ejection proceeds, the inferior portion of the septum moves toward the posterior left ventricular wall and the superior portion of the septum moves anteriorly with the aortic root. RVD = right ventricular dimension; Ao = aorta; aMVL and MV = anterior mitral valve leaflet; S = septum; LV = left ventricle; LVD = left ventricular dimension; pMVL = posterior mitral valve leaflet; LA = left atrium; LVPW = left ventricular posterior wall.

volume overload studied by the multicrystal echo system normal septal motion was observed in 6; the entire septum moved anteriorly, i.e., paradoxically during systole in 8, and variable patterns were noted in 7 cases (table 2). Among these 21 patients 10 had ostium secundum atrial septal defects, 6 of whom had a small left to right shunt (pulmonary to systemic flow ratio < 2:1), while the other 4 had a large shunt (pulmonary to systemic flow ratio > 2:1). None of the six patients with a small atrial septal defect had true paradoxical septal motion whereas two of the four patients with a large shunt demonstrated paradoxical septal motion and two had variable septal motion during systole. Among the five patients with pulmonic regurgitation no particular type of systolic septal motion predominated. Two of this group had normal motion, 2 paradoxical motion and 1 variable motion. In the latter 3 cases considerable valvular regurgitation was present while the two patients with normal septal motion had only mild regurgitation. None of the 6 patients with Ebstein's anomaly had normal septal motion (4 paradoxical and 2 variable). In these patients however, there was no correlation between the type of septal motion and the magnitude of the right ventricular volume overload.

**Table 2**

Multicrystal Echocardiographic Findings of Septal Motion in Right Ventricular Volume Overload

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of cases</th>
<th>Normal</th>
<th>Flat or variable</th>
<th>Paradoxical</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Atrial septal defect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qp/Qs* &gt; 2:1</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Qp/Qs &lt; 2:1</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2. Pulmonic regurgitation</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3. Ebstein's anomaly</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

*Qp/Qs is the ratio of pulmonary to systemic blood flow.

Discussion

Previous studies have focused on abnormalities of interventricular septal motion in patients with right ventricular volume overload. Popp and associates were the first to suggest that atrial septal defects could
be diagnosed with ultrasound by measurement of the mean right ventricular dimension index.\textsuperscript{13} In the same paper they also reported that if the mitral valve were included in the recording, the "septal echo motion would be seen to change at times." Therefore, to avoid the problem of evaluating changing septal motion, they recommended that the sound beam be directed inferiorly and laterally away from the mitral valve. Diamond and co-workers described two abnormal forms (Types A and B) of interventricular septal motion which they suggested are specific for right ventricular volume overload (RVVO).\textsuperscript{13} It has been proposed that a normal echocardiogram is sufficiently accurate to exclude any possibility of an atrial septal defect.\textsuperscript{14} Although Tajik and associates observed paradoxical septal motion in a group of children with right ventricular volume overload, they described a total of seven patients with right ventricular volume overload who had normal septal motion during systole.\textsuperscript{15-17} In five of these seven patients the left to right shunt was small with pulmonary to systemic flow ratio of less than 2:1. Kerber and co-workers reported that five of twenty patients with an atrial septal defect had normal septal motion.\textsuperscript{19} In the same series, fifteen of sixteen patients who had surgical correction of the atrial septal defect continued to demonstrate paradoxical septal motion, but these investigators did not describe other factors in addition to right ventricular volume overload which were important in the pathogenesis of the abnormal motion. In this study we sought to define for the first time the types of interventricular septal motion found in normal subjects as well as to reassess the reliability of systolic anterior septal motion as an indicator of right ventricular volume overload.

When compared to Polaroid images, the continuous recording technique is distinctly more accurate for evaluating interventricular septal motion. The advantages of this method have already been emphasized for studying cardiac anatomy and performance in newborn infants.\textsuperscript{21, 22} By directing the ultrasound beam through the aortic root, then sweeping inferiorly and laterally through the mitral valve and sweeping inferiorly through the interventricular septum at different levels, it is possible to appreciate sequential alterations in septal motion. Our data indicate that systolic septal motion at the level of the mitral valve may be anterior, posterior, variable or flat depending on whether the ultrasound beam traverses the septum above, below or at the pivot point. Therefore, in order to assess septal motion accurately, the transducer must be directed at or below the level of the chordae tendineae. In a number of illustrations reproduced in the published literature, this criterion was not met (fig. 2;\textsuperscript{13} fig. 1, left panel;\textsuperscript{19} fig. 8;\textsuperscript{19} fig. 5).\textsuperscript{19} Patients without right ventricular volume overload who exhibited abnormal septal motion at this level include those with cardiomyopathies, left bundle branch block, valvular prostheses, and dyskinetic segments or aneurysms involving the interventricular septum. Patients with right ventricular volume overload may demonstrate either normal or paradoxical septal motion. Thus, systolic anterior septal motion, although frequently found in the presence of right ventricular volume overload, is not a specific finding in such patients. In this connection, McCann et al. emphasized that abnormal septal motion is not present in all patients with an increased right ventricular volume index or an elevated pulmonary to systemic flow ratio.\textsuperscript{29} Our findings are in agreement with these observations.

It should be emphasized that the variable septal motion pattern may differ from patient to patient. It appears that the findings vary depending on the posi-

### Table 3

<table>
<thead>
<tr>
<th>Qp/Qs Ratio</th>
<th>No. of Cases</th>
<th>Normal</th>
<th>Flat or Variable</th>
<th>Paradoxical</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2:1</td>
<td>18</td>
<td>4</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>&lt; 2:1</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

*Qp/Qs is the ratio of pulmonary to systemic blood flow.*

### Figure 5

A. Normal septal motion in a patient with a small atrial septal defect (< 2:1 shunt). B. Paradoxical septal motion in a patient with a large atrial septal defect (> 2:1 shunt). S = interventricular septum; SL = left side of septum; END = endocardium; EPI = epicardium; RV = right ventricular wall; C = chordae tendineae.
tion of the septal “pivot” or “hinge” point. Paradoxical anterior septal motion occurs in systole when the pivot point is low in the interventricular septum. As shown in table 3 there was a correlation between true paradoxical septal motion inferior to the plane of the mitral valve as recorded by the single crystal continuous recording technique in patients with an atrial septal defect and a large left to right shunt. Figure 5 illustrates normal septal motion contrasted to paradoxical motion in two patients who had a small and a large left to right shunt, respectively.

The multiscrystal echo system displays the entire interventricular septum in a sagittal plane, thereby enabling visualization of the “hinge” or “pivot” point of the septum. The multiscan provides a cross-sectional visualization of the patterns of both septal and posterior wall motion. Normal septal motion consists of anterior movement of the superior segment of the septum during systole. Below a pivot point, the inferior two-thirds of the septum moves posteriorly during systole. We believe that the term “paradoxical septal motion” should be reserved exclusively for those instances in which the interventricular septum at or below the level of the chordae tendineae moves anteriorly during systole.

In patients with right ventricular volume overload the pivot point of the interventricular septum may be displaced inferiorly or not be present at all. This accounts for the variable appearance of systolic anterior septal motion at different septal levels in patients with right ventricular volume overload. In our patients with right ventricular volume overload who were examined both by the multiscrystal and single crystal continuous recording systems, true paradoxical septal motion was present less frequently than previously reported and appeared to occur only in the presence of the more severe instances of right ventricular volume overload.

We conclude that the position of the pivot or hinge point of the interventricular septum determines the pattern of its systolic motion. Thus, whether right ventricular volume overload is present or absent, recordings obtained only in the plane of the mitral valve frequently reveal systolic anterior septal motion. Further, even when recordings are performed at or below the level of the chordae tendineae, paradoxical septal motion may not be a consistent echocardiographic finding in patients with right ventricular volume overload.

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Circulation. Volume 59, August 1974
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_Circulation_. 1974;50:248-254
doi: 10.1161/01.CIR.50.2.248

_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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