RADIOLOGY

The Natural History of the So-Called Aneurysm of the Membranous Ventricular Septum in Childhood


SUMMARY

Fifty-six children with isolated membranous ventricular septal defect (VSD) included in the National Natural History Cooperative Study for Congenital Heart Disease were studied at the Johns Hopkins Hospital Center to determine the occurrence and natural history of an associated "aneurysm of the membranous septum" (AMS). These patients represented a wide range of ages and VSD size. Each child was evaluated by two cardiac catheterizations four years apart, with regular clinical examinations in the interval. The diagnosis of AMS was based on angioGraphic criteria, and as such may encompass several distinct anatomic lesions.

Twenty children had AMS at the first catheterization; all were over age two, and all but one had a pulmonic-to-systemic flow ratio (Qp/Qs) of less than 2.0, with normal intracardiac pressures. Four years later, repeat catheterization revealed only minor changes in Qp/Qs and angiographic appearance of the aneurysms in this group. Twelve new cases of AMS were also demonstrated at the second study; seven of these children underwent a significant diminution in Qp/Qs during the period in which the aneurysm was formed. No cases of spontaneous anatomic closure were observed in the course of our study, nor were there any serious complications which could be attributed to the presence of an aneurysm. Overall, AMS was found in 32 of 56 patients (57%), and in 31 of 44 (70%) of those with a Qp/Qs less than 2.0.

These findings suggest that AMS is common among children with small membranous VSD, and that its course in childhood is usually stable and asymptomatic. Although anatomic closure of the VSD was not observed during this four year study, our data support suggestions that aneurysm formation may play an important role in some cases of spontaneous diminution in the functional size of an associated membranous VSD.

Additional Indexing Words:
Congenital heart disease
Spontaneous closure of ventricular septal defect
Phonocardiography

The so-called aneurysm of the membranous portion of the ventricular septum (AMS) has been an interesting and controversial subject for many years. Although recent attention has focused on the observation that functional diminution or spontaneous closure of a membranous ventricular septal defect (VSD) may be accompanied by formation of aneurysm-like tissue,1-8 the natural history of this entity is largely undefined.9 The present study was designed to provide longitudinal information on the occurrence of AMS and its subsequent course in the child with isolated membranous VSD.

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Received June 22, 1973; revision accepted for publication September 18, 1973.
Aneurysm of the membranous septum (AMS) in a six year old boy. A ventricular septal defect forms the base of the aneurysm, while contrast enters the right ventricle through a trivial defect at its apex. Pulmonary-to-systemic flow ratio \((Qp/Qs)\) was 1.0. This and other cineangiograms which follow are selective left ventricular (LV) injections, with the patient in the left anterior oblique projection. \(Ao = \) aorta.

**Figure 1**

**Definition**

For the purpose of this study, aneurysm of the membranous septum is defined as angiographic evidence of any alteration or deposition of tissue around the margins of a membranous VSD, producing a structure with distinct margins which protrudes into the right ventricle with each systole and seems to partially or completely occlude the flow of blood through the associated defect (fig. 1).

This is an angiographic definition, since the clinical nature of our study does not permit anatomic correlation of our findings, with the exception of the few cases examined during open heart surgery. We are aware that anomalies of the tricuspid valve, including pouches and maladherent leaflets, resemble aneurysms of the membranous septum and may yield a similar angiographic appearance. Within the present confines, this definition does not allow us to distinguish between the types of aneurysmal tissue in the area of the membranous septum, nor does it include any aneurysms which did not have an associated membranous VSD.

**History**

Since the case described by Laennec in 1826,\(^1\) an extensive bibliography of AMS has accumulated,\(^1-43\) documenting its association with a multitude of congenital cardiac anomalies,\(^1\), 11–22 arrhythmias,\(^4\), 14, 21–24 and conduction defects.\(^25\), 26, 27 A variety of complications have been attributed to its presence.\(^4\), 12, 14, 15, 17, 20–22, 24, 28, 29 Many theories concerning the origins of this malformation have been proposed. In his review, Mall (1912)\(^35\) concluded that most of these aneurysms occurred when the membranous septum, congenitally weakened by a mildly dextroposed aorta, was misplaced into a more or less horizontal position. This theory was further supported and enlarged upon by Lev and Saphir (1938),\(^32\) who reported two cases and reviewed the 70 cases in the literature. Other authors have been unable to document an abnormal position of the membranous septum or aortic root in their patients with AMS.\(^1\), 17

Aneurysm of the membranous septum was first diagnosed during life by Steinberg in 1957,\(^36\) who reported the angiographic demonstration of an aneurysm in a 60-year-old housewife. Over the next decade, numerous reports were published dealing with the angiographic appearance of these lesions and their complications.\(^1\), 4, 15, 17, 19–21, 24, 25, 28, 29 It became clear that the most common associated cardiac anomaly was the small membranous VSD.\(^2\), 4, 7, 17, 19, 28, 37, 38 Several authors during this period suggested that these aneurysms might be related to spontaneous closure of an associated membranous VSD.\(^1\), 2, 4, 7 In 1969, angiographic proof of spontaneous closure of a small membranous VSD in a child previously shown to have an aneurysm surrounding the defect was presented from this institution.\(^5\) More recently, we have

**Table 1**

*Unpublished data, National Natural History Cooperative Study for Congenital Heart Disease.

**Classification of Ventricular Septal Defect, According to the Protocol of the National Natural History Study**

<table>
<thead>
<tr>
<th>Severity of VSD</th>
<th>Flow ratio ((Qp/Qs))</th>
<th>Pressure ratio ((Pp/Ps))</th>
<th>Resistance ratio ((Rp/Rs))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&lt;1.4</td>
<td>&lt;0.5</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.4–2.2</td>
<td>&lt;0.5</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt;2.2</td>
<td>&gt;0.5</td>
<td>0.3–0.75</td>
</tr>
<tr>
<td>Inoperable</td>
<td>&gt;1.5</td>
<td>1.0</td>
<td>&gt;0.75</td>
</tr>
</tbody>
</table>

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described typical auscultatory and phonocardiographic findings in children with small membranous VSD accompanied by aneurysm formation. Others have confirmed these findings. Methods and Materials

Patient Selection and Evaluation

Fifty-nine children with isolated membranous VSD were entered into the prospective portion of the National Natural History Cooperative Study for Congenital Heart Disease at the Johns Hopkins Hospital Center from October 1966 to June 1969. Each patient underwent an initial cardiac catheterization upon entry into the study and a follow-up catheterization four years later; additional studies were performed when warranted. Three children were excluded from the present study because of incomplete angiographic data at their final catheterization. The remaining fifty-six patients comprise our study group; many of these children are among patients reported in previous communications from this institution.

The 56 patients in our study group ranged in age from one month to 13 years (mean 4.8 years) at the time of their initial catheterization; 14 of these were studied in the first year of life. There were twenty-seven males and twenty-nine females. Tables 1 and 2 present the severity classification of the VSD and the distribution of our patients into these categories on admission to the study.

Clinical examinations, standard 13-lead electrocardiograms (ECG), and chest radiographs were obtained prior to each catheterization, and at least yearly between studies. Phonocardiograms were performed on all patients just prior to the final catheterization, using techniques previously described by Pieroni and associates.

Cardiac Catheterization

All children were sedated about 45 min before the procedure with a mixture of meperidine, promethazine, and chlorpromazine at a dosage previously reported. Right heart catheterization was performed according to the protocol of the National Natural History Cooperative Study for Congenital Heart Disease (unpublished data), except in infants, in whom the approach to the left heart was retrograde. After hemodynamic data were obtained, cineangiograms were filmed at 60 frames/sec during pressure injection of contrast material (1.5 ml/kg), with the child in the left anterior oblique projection. Selective left ventricular injection was performed in all but a few patients in whom the left ventricle was visualized during the levophase of a pulmonary artery injection.

Aneurysm of the membranous septum was only considered to be present when the angiographic appearance was that previously described in our definition. In the rare cases of ambiguous angiographic findings, AMS was not diagnosed.

Results

Catheterization Data

The pulmonary-to-systemic flow ratio (Qp/Qs) was determined by cuvette oximetry and, as in a previous communication, the severity of the VSD was assessed using the arbitrary criteria of the Natural History Study (table 1).

Table 2 presents the distribution of our patients at the time of their first catheterization and notes the incidence of AMS in each severity category. Over-all, an aneurysm was demonstrated in 20 of 56 children (36%) at the first study. All patients with AMS in this group were two years of age or older (range two to 13 years, mean 7.1 years), and all but one had a Qp/Qs of less than 2.0 (range 1.0 to 2.3, mean 1.3). Intracardiac pressures were within normal limits in these patients. We could not demonstrate AMS in 36 patients at the first study; these children ranged in age from one month to 13 years (mean 3.5 years). Mean Qp/Qs for this group was 2.2, with a range of 1.0 to 5.2.

Table 3 presents the hemodynamic and angiographic findings at the final catheterization, four years after the first study. At that time, 32 of 56 children (57%) had AMS. Thus, 12 additional cases of AMS were demonstrated at this study. Of the 23 children with Qp/Qs of 1.4 to 2.2 on the first catheterization, six were randomly selected, subject to informed consent, for surgical closure of their defect, according to the protocol of the Natural History Study. Three of these six children had an AMS and a Qp/Qs in each case of 1.4. Seven children with a Qp/Qs greater than 2.2 on the first

Table 2

<table>
<thead>
<tr>
<th>Severity</th>
<th>Overall</th>
<th>With aneurysm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>18</td>
<td>10 (56%)</td>
</tr>
<tr>
<td>Moderate</td>
<td>23</td>
<td>9 (39%)</td>
</tr>
<tr>
<td>Severe</td>
<td>15</td>
<td>1 (6%)</td>
</tr>
<tr>
<td>Inoperable</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td>20 (36%)</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Severity</th>
<th>Overall</th>
<th>With aneurysm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>22</td>
<td>17 (77%)</td>
</tr>
<tr>
<td>Moderate</td>
<td>17</td>
<td>12 (71%)</td>
</tr>
<tr>
<td>Severe</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Inoperable</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Surgery</td>
<td>13</td>
<td>3 (23%)</td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td>32 (57%)</td>
</tr>
</tbody>
</table>

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Table 4

<table>
<thead>
<tr>
<th>Changes of Qp/Qs in Patients with Aneurysms</th>
</tr>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Mean age (yrs)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>20 patients with aneurysm visualized at 1st catheterization</td>
</tr>
<tr>
<td>12 patients with aneurysm visualized at 2nd catheterization</td>
</tr>
</tbody>
</table>

study were also treated surgically because of persistent congestive heart failure in spite of aggressive medical management. It is possible that some of these children might have developed AMS had they not undergone open heart surgery. It is of interest that 17 of 22 (77%) children with Qp/Qs of 1.0 to 1.3 and 12 of 17 (71%) with Qp/Qs of 1.4 to 2.2 had aneurysms at this final study. These data suggest a tendency for the small membranous VSD to have an associated AMS.

Table 4 demonstrates the changes in Qp/Qs from first to second catheterization in the 20 children found to have AMS on the first study, and in the 12 children who developed aneurysms between the two studies. Several of the latter 12 children experienced a significant reduction of Qp/Qs during the period in which their aneurysms were formed. In contrast, in the 20 children with AMS present at the first study, the hemodynamic data showed little change between studies, with a significant decrease of Qp/Qs in only one patient (2.3 to 1.6).

Spontaneous anatomic closure of the associated VSD was not observed in the course of our study. Although eight children with AMS and three without aneurysms had normal intracardiac pressures and no evidence of an intracardiac left-to-right shunt by oximetry data at the second catheterization, all were shown by left-ventricle-to-pulmonary-artery dye curves and angiography to have persistence of a trivial defect.

Angiographic Appearance

A wide spectrum of sizes and shapes of aneurysmal tissue was found among the 32 patients shown to have AMS by angiography (figs. 1-12). The morphology of the aneurysm remained unchanged in those we observed on serial studies (figs. 1-3). The aneurysms were best visualized by selective left ventricular angiograms in the left anterior oblique projection; the lepohase of a pulmonary arteriogram did not consistently provide adequate definition of the aneurysm.

Clinical Features

The presenting signs and symptoms of all patients, both with and without an associated AMS, were those of a ventricular septal defect. Twenty-five patients had a history of congestive heart failure in infancy. Of these, seven required surgery during the course of the study because of persistent failure, while ten experienced aneurysm formation along with spontaneous diminution in the size of the defect. We were unable to find features in the ECG or chest radiograph which would distinguish the VSD with an associated AMS from the isolated membranous defect without aneurysm formation. Certain auscultatory and phonocardiographic features, however, are most suggestive of an associated aneurysm.39-41 A "clicky" early systolic sound, usually heard best in expiration at a very localized area along the lower left sternal border, is a reliable sign that an aneurysm of the membranous septum is present. Because of its subtle and variable qualities, careful and repeated auscultation is often necessary to elicit this finding. Its presence may be confirmed by the phonocardiogram, which usually demonstrates an early systolic sound during the upstroke of an indirect carotid artery tracing, and 100-130 msec after the Q wave of a simultaneous ECG (fig. 13). An early systolic sound has been documented in 24 of the 25 (96%) patients with AMS in our study who have been examined since we became aware of the significance of this sign. Late systolic accentuation of the VSD murmur was also present in most of these cases.

Serious complications have been associated with or attributed to AMS, but these were rare during our period of observation. One patient in the present series had a chronic supraventricular tachycardia, first documented at three years of age.
Figure 2
Same patient as figure 1, at a repeat catheterization four years later. There is no significant change in the size or morphology of the aneurysm.

Figure 3
Left: Round, smooth-walled aneurysm with a narrow base in a six year old girl (Qp/Qs = 1.4). The aneurysm fills before the aorta, eliminating the possibility of a sinus of Valsalva aneurysm. Right: Repeat catheterization reveals little change in the appearance of the aneurysm (Qp/Qs = 1.2).

Upon entry into our study at age 13, she was shown to have an AMS associated with her small membranous VSD. Four patients, two with AMS, had frontal plane axes of $-15^\circ$ to $-60^\circ$, with a superiorly oriented, counterclockwise frontal vector loop. None of these four had angiographic evidence of an endocardial cushion defect, and the VSD appeared to be in the membranous portion of the ventricular septum in all cases. Three patients, two with AMS, had prolapse of the noncoronary aortic cusp. There was mild aortic insufficiency in two of these. Four patients with AMS had angiographic evidence of tricuspid insufficiency. In each case, contrast material was observed to enter the right atrium following a selective left ventricular injection. No patient in our series had significant right ventricular outflow obstruction (right-ventricle-to-
pulmonary-artery gradient greater than 12 mm Hg) which could be attributed to the presence of an aneurysm. There were no cases of rupture, thromboembolism, or infective endocarditis among our cases during the period of the study. One patient had an episode of endocarditis at the age of six, and upon entry into the study at ten years of age was found to have an aneurysm. It is not known whether the aneurysm was present prior to the episode of endocarditis.

Discussion

Although "aneurysm of the membranous septum" has been used since the earliest reports to describe a pouch of tissue in the area of the membranous septum, it has become increasingly evident that many of the lesions which bear this name are not truly aneurysms, nor do they, in many cases, derive their tissue from the membranous septum. Accessory endocardial cushion tissue and malformed or maladherent leaflets of the tricuspid valve which resemble aneurysms have been described by Edwards and his associates in autopsy specimens of
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Aneurysm of the membranous septum was initially believed to be of congenital origin, but a recent study has shown that some cases associated with a membranous VSD are acquired. During the course of our study, aneurysm formation was observed in 12 patients; in these, the AMS was shown to be an acquired lesion. In the remaining 20 children, the presence of an aneurysm at the initial catheterization makes it impossible to ascertain whether the lesion was congenital or acquired. The absence of AMS in any of the 18 patients studied prior to age two and similar findings in the literature suggest that most aneurysms associated with a membranous VSD are acquired. Aneurysms are not unique, however, to the child over age two, and we have seen clinical, angiographic, and anatomic evidence of this entity in infants.

Our data support earlier observations that diminution in the functional size of a membranous VSD is often accompanied by aneurysm formation. A hemodynamically large membranous VSD in infancy progressed to a functionally smaller defect with aneurysm formation later in childhood in several of the patients in our study. Of the 12 children known to have an acquired aneurysm, six had been shown at an earlier catheterization to have a Qp/Qs of greater than 2.0. In addition, five of the 20 children with small VSD and an associated AMS at the initial study had a history of

**Figure 10**

Thirteen year old boy; Qp/Qs = 1.0. Figure has been retouched.

patients with membranous VSD. These may be indistinguishable from the "true aneurysm" on angiography. Because of wide acceptance of the term, the limitations of a clinical study, and our own inability to provide more precise terminology, we have continued to use "aneurysm of the membranous septum" to describe a common angiographic appearance which undoubtedly encompasses several distinct anatomic lesions.

**Figure 11**

Eight year old boy; Qp/Qs = 1.4. Figure has been retouched.

**Figure 12**

Seven year old boy; Qp/Qs = 1.0. Figure has been retouched.
Phonocardiograms, indirect carotid artery pulse, and lead II electrocardiogram (EKG) recorded from a three year old boy with an aneurysm (Qp/Qs = 1.3). Phonocardiograms were recorded at low (25 cycles per second [CPS]), medium (100 CPS) and high (400 CPS) frequencies at the lower left sternal border. Auscultation in this patient revealed a “clicky” sound which occurred early in systole, was localized to the lower left sternal border and varied markedly with respiration. An intermittent early systolic sound (ESS) is recorded during the carotid upstroke and approximately 110 msec following the Q wave of a simultaneous EKG. Late systolic accentuation of the VSD murmur was also present, best seen in the high frequency phonocardiogram.

Figure 13

congestive heart failure in infancy, with a mid-diastolic flow murmur and severe growth retardation. Angiography may demonstrate a similar progression; the large VSD of infancy often appears at a later study to be surrounded by the aneurysm, whose tissue limits the regurgitant flow to one or more tiny streams. These observations are the basis for the suggestion that the aneurysm itself may be an important mechanism in reducing the functional size of the defect.

Spontaneous closure of a membranous VSD preceded by formation of aneurysmal tissue around the margins of the defect has recently been reported from this institution.10 Studies of large series of children with isolated VSD have shown a high rate of spontaneous closure of the defect in infancy, with a slower but significant rate continuing into adulthood. Hoffman9,10 has suggested that 40% of defects present at birth will close in infancy, and up to 60% by age five; other authors have shown similar results.5, 8, 49-51 Bloomfield has estimated that 25% of the defects persisting after infancy will close later in childhood or adulthood.52-53 In these studies, the rate of spontaneous closure was much higher in patients with a small VSD, although occasional cases of spontaneous closure of large defects have been reported.5, 51, 52, 54 There is also some suggestion that the rate of closure for membranous defects might be significantly less than that for VSD in general, when position of the defect is not taken into account.8, 55

We did not observe spontaneous anatomic closure over a four year period in any of the 56 children included in our study. Most of our patients were studied after infancy, and thus during a time in which spontaneous closure is less common.46, 49, 52 Similarly, most patients we studied in infancy had large defects, a group in which closure is also less frequent. Six of the 11 patients previously discussed with normal hemodynamic data at the second catheterization might clinically have been considered to have undergone spontaneous functional closure of their defect, on the basis of a questionably organic murmur and an otherwise normal cardiac examination, ECG and chest radiograph,5, 46, 54 but each was shown on angiography to have persistence of a trivial shunt. It is likely, in light of studies of the natural history of small VSD, that several of the children in our study group will eventually undergo spontaneous anatomic closure of their defect in the future.

Our study period was also too brief to provide a definitive picture of the frequency and scope of complications which may be seen over an extended period in children with AMS. Several of the complications which have been associated with AMS are also well-known complications of the isolated VSD. Arrhythmias, bundle branch block, aortic cusp prolapse, and infective endocarditis may all be seen in the small membranous VSD, and have not been shown to occur more frequently in

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children with an associated AMS. These complications did not show a predilection for children with AMS in our study, although more extensive studies will be necessary to determine whether the patient with AMS is at an increased risk.

Certain other complications, however, are probably directly related to the presence of aneurysmal tissue. Right ventricular outflow obstruction has been well-documented in patients with large, long aneurysms of the "windsock" variety.4, 20, 21, 29 This type of aneurysm was rare in our study, and there were no cases of significant outflow obstruction which could be attributed to the presence of an aneurysm. An aneurysm may cause tricuspid insufficiency, perhaps by deforming the overlying septal leaflet.15, 17, 22, 24, 28, 42 Trivial amounts of contrast material were observed to enter the right atrium during left ventricular injection in four patients, but the possibility that this was related to the pressure of injection and premature ventricular contractions makes this observation of questionable significance. None of these patients had evidence of a defect in the atrial portion of the membranous septum. None showed oxygen increments or large V waves in the right atrium, nor did they have murmurs suggestive of tricuspid regurgitation.

Most of our patients with AMS experienced a stable, asymptomatic course during the period of observation, very similar to that found in large clinical studies of the natural history of small VSD.48, 52 The use of the Natural History Study patients allowed us a unique opportunity to obtain longitudinal hemodynamic and angiographic data on large numbers of children with small membranous VSD who might otherwise have been followed only clinically. However, a great deal remains unknown about this entity, which is more common and more important than previously believed. Although left ventricular angiography remains the most accurate clinical means of establishing the diagnosis, the use of auscultatory and phonocardiographic criteria appears promising. Diagnostic ultrasound may also become a useful, noninvasive technique for the diagnosis and evaluation of AMS. Extended observations of patients with small membranous VSD and an associated aneurysm of the membranous septum will be necessary to define fully the history of this interesting entity.

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_Circulation_. 1974;49:375-384
doi: 10.1161/01.CIR.49.2.375

_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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