Anatomic and Pathologic Studies in Ventricular Septal Defect

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In a necropsy study of 50 cases of ventricular septal defects, the anatomic position and relations of ventricular septal defects, the causes of and ages at death, and association of ventricular septal defects with other cardiovascular malformations were determined. The present availability of surgical closure of ventricular septal defects makes this information of practical significance.

The present availability of surgical closure of ventricular septal defects renders a number of questions particularly pertinent. Some of these may be answered by pathologic studies and clinicopathologic correlations. Such studies are proper even though there is inherent selection of cases among those included in a pathologic series. These studies provide information concerning the anatomic position and relations of ventricular septal defects, the causes of and ages at death, and the association of ventricular septal defects with other cardiovascular malformations. The present report is a necropsy study of 50 cases of ventricular septal defect. Surgical procedures designed to close the defects had not been done in any of the patients. An attempt is made to throw additional light on these problems.

METHODS AND MATERIALS

A series of normal hearts was studied to determine the main anatomic landmarks of the ventricular septum.

A study then was made of 50 hearts that had defects of the ventricular septum. Forty were from patients dying at the Mayo Clinic and 10 were sent to the laboratory of pathologic anatomy from other sources. The series represented all specimens in our pathologic collection with ventricular septal defects in which it was the only congenital malformation of the heart and great vessels or in which other anomalies, such as atrial septal defect or anomalies of the aortic-arch system, were coincidental. Not included in this study were cases in which a ventricular septal defect was part of a recognized complex of related anomalies, such as the tetralogy of Fallot, persistent truncus arteriosus, complete transposition of the great vessels, or subaortic stenosis with bi-ventricular origin of the pulmonary trunk.

Each specimen was classified on the basis of the location of the ventricular septal defect according to the scheme to be presented in the next section of this paper.

The diameter of the defect and the diameter of the aorta at the level of the valve were measured in each specimen. The ratio of their relative sizes was useful in defining the size of a given ventricular septal defect irrespective of the age of the patient and the size of the heart.

The cause of death in each case was designated as either related or unrelated to the congenital malformation of the heart. The immediate causes of death in the former group were heart failure and bacterial endocarditis. Although heart failure was considered to have affected both ventricles, the cases with this complication could be subdivided further according to the predominant picture: predominantly left ventricular failure was considered to be manifested in the cases showing pulmonary congestion and edema, whereas predominantly right ventricular failure was considered to exist in cases having peripheral edema, serous effusion, and chronic passive congestion of the liver.

The results of the pathologic studies are presented in 2 sections. The first involves those cases in which the ventricular septal defect was not associated with other cardiovascular anomalies (group A). The second section deals with those cases in which the ventricular septal defect was associated with other coincidental, congenital malformations of the heart or great vessels (group B).
VENTRICULAR SEPTAL DEFECT

ANATOMIC CONSIDERATIONS

The 50 hearts included in this study were classified according to the region of the ventricular septum involved by the defect into 2 major groups. In the first group, the defects involved regions of the ventricular septum related to the ventricular outflow tracts; in the second group, the involved regions were not in the ventricular outflow tracts. Lesions in the first group are commoner and, therefore, of greater surgical interest.

Defects Related to the Ventricular Outflow Tracts

Of the 50 hearts, 40 had defects involving this region. The outflow portion of the right ventricle is defined in this study as that part which lies between the pulmonary valve above and the nearest portion of the tricuspid valve below. The inflow portion lies posterior and caudal to the outflow tract.

As seen from its right ventricular aspect, the portion of the ventricular septum related to the ventricular outflow tracts is convex and extends from the tricuspid ring inferiorly and posteriorly to the annulus fibrosus of the pulmonary valve superiorly and anteriorly. This becomes clearer if it is recalled that, as the heart lies in situ, this aspect of the ventricular septum, when viewed from its right ventricular side, rises anteriorly as well as cephalad from the tricuspid ring to the pulmonary valve.

Four major anatomic landmarks of the outflow tract of the right ventricle may be considered (fig. 1a). These are (1) the tricuspid ring, (2) the papillary muscle of the conus, (3) the crista supraventricularis, and (4) the annulus fibrosus of the pulmonary valve. It is apparent that nearly all of the septum viewed surgically through the usual incision for right ventriculotomy is related to the ventricular outflow tracts.

The papillary muscle of the conus may be defined as that point of the septal wall of the right ventricle into which insert the chordae tendineae corresponding to the left half of the anterior tricuspid leaflet and the anterior half of the septal leaflet of this valve. At this point is usually located a small broad-based papillary muscle that is readily identifiable, lying about at right angles to the long axis of the right ventricular outflow tract. In some hearts, particularly when the right ventricular chamber is dilated, the chordae tendineae appear to insert directly into the septal wall rather than into a recognizable specialized papillary muscle. It must be stressed, however, that a constant phenomenon is the convergence to the ventricular septum of the chordae tendineae corresponding to the left half of the anterior leaflet of the tricuspid valve and the anterior portion of the septal leaflet.

The crista supraventricularis may be described as a prominent muscular bundle that arches across the uppermost portion of the outflow tract of the right ventricle. Its right anterior limb originates in the anterior wall of the right ventricle approximately at the level of the tricuspid ring. From this point it arches upward and to the left, to pass across the upper wall of the outflow tract between the papillary muscle of the conus below and posteriorly and the pulmonary valve above and anteriorly. The left limb of the crista supraventricularis continues from under the pulmonary valve downward along the ventricular septum.

As seen from its left ventricular aspect, the portion of the ventricular septum related to the ventricular outflow tracts is concave and extends from the point where the anterior mitral leaflet joins the ventricular septum posteriorly to a point located below the midportion of the left aortic cusp* anteriorly (fig. 1b).

Along its entire upper border, the left ventricular aspect of the outflow portion of the ventricular septum is related to the aortic valves; therefore, regions in it can be described as the tissue lying beneath a given portion of the corresponding aortic cusp. The adjacent halves of the left and posterior aortic cusps are not related to the ventricular septum, being continuous with the anterior mitral leaflet.

It is helpful for the surgeon to recognize

* In this discussion, the right and left aortic cusps correspond to the aortic sinuses from which the right and left coronary arteries, respectively, arise. The posterior cusp is the noncoronary cusp.
anatomic features of the normal ventricular septum.

a. Right ventricular aspect. The septal leaflet of the tricuspid valve (S.T.V.) demarcates the junction of the right atrium (R.A.) and the right ventricle; retracted upward to show the membranous portion of the ventricular septum (hatched circle). Anterior and superior to this is the papillary muscle of the conus (P.M.C.). From this muscle, chordal tissue extends to the adjacent portions of the septal and anterior tricuspid leaflets. Superior and anterior to the papillary muscle of the conus lies the crista supraventricularis (C.S.). In a cephalad and anterior position lies the pulmonary valve. P.T. = pulmonary trunk; R.P.L. = right pulmonary leaflet; L.P.L. = left pulmonary leaflet; P.R.V. = posterior right ventricular wall; A.R.V. = anterior right ventricular wall; A.P.M. = anterior papillary muscle of the tricuspid valve. The dotted vertical line corresponds to the center of the right aortic leaflet, which lies beyond this level.

b. Outflow tract of the left ventricle and aorta. The membranous septum (M.) lies inferior to the commissure between the posterior (P.) and the right (R.) aortic leaflets and a portion of the posterior aortic leaflet. The membranous septum also lies anterior and in contact with the anterior face of the anterior mitral leaflet (A.M.). The left aortic leaflet (L.A.L.) has been sectioned in opening the aorta. P.M. = posterior mitral leaflet; A.L.V. = anterior left ventricular wall. L.C.A. = ostium of left coronary artery. P.T. = pulmonary trunk.

Defects Involving the Region Posterior to the Crista Supraventricularis. The region of the right ventricular outflow tract lying inferior and posterior to the crista supraventricularis deserves particular attention because it is most commonly involved by ventricular septal defects. The ventricular septal defect that most of the outflow tract of the right ventricle and the pulmonary valve lie more superior (cephalad) and anterior than do the outflow tract of the left ventricle and the aortic valve when the heart is in situ. For this reason, the left extremity of the tricuspid ring lies at approximately the same horizontal plane as does the aortic valve at the posterior aortic leaflet.

In its right ventricular aspect the outflow tract of the ventricular septum may be divided into 2 regions. One lies posterior and inferior to the crista supraventricularis and extends between it and the tricuspid ring, and the other extends superiorly and anteriorly from the crista supraventricularis to the annulus fibrosus of the pulmonary valve.
was in this region in 36* of the 50 hearts in this study.

These lesions are usually classified as "membranous ventricular septal defects," but it was apparent from this study that such a designation is not an adequate descriptive name. The membranous portion of the ventricular septum is seen from the left ventricle as a small zone lying beneath the commissure between the posterior and right aortic cusps and the adjacent portion of the posterior cusp. It cannot be seen when the interior of the right ventricle is viewed in the usual perspectives unless the tissue of the septal leaflet of the tricuspid valve is retracted upward.

While most of the defects are related to the membranous portion of the septum, it is exceptional for a ventricular septal defect to be restricted to this membranous portion. In almost all of our cases, the defect either did not involve the membranous portion of the ventricular septum at all or involved varying amounts of this region and, additionally, a proportionately larger zone of the muscular tissue lying superoanteriorly to the membranous septum. It is recognized that the defect in such cases may constitute a failure of union of the membranous and muscular septa rather than absence of these elements. The size of the defect itself was mainly related to the amount of the muscular portion of the ventricular septum that was malformed.

As seen from the right ventricle, the region of the ventricular septum lying immediately posterior and inferior to the crista supraventricularis is overhung by the left half of the anterior leaflet and the anterior half of the septal leaflet of the tricuspid valve. Most of the chordae of this valvular tissue converge toward the apex of the papillary muscle of the conus. The posterior boundary of this region on its right ventricular aspect is the tricuspid ring. The posterior boundary on its left ventricular aspect is the junction of the anterior mitral leaflet and the ventricular septum.

From the right side, the papillary muscle of the conus appears as a prominent landmark within the region being described and serves as a useful point of reference in estimating the size of a given ventricular septal defect. The right and left ventricular relations of defects involving this region are better understood if it is realized that a plane extending at right angles to the septum along the long axis of the papillary muscle of the conus of the right ventricle will run more or less vertically through the middle of the right aortic cusp on the left side and that the crista supraventricularis lies at a level corresponding to the commissure between the right and left aortic cusps. This relationship is noted clearly during open right ventriculotomy for the repair of ventricular septal defects.

In the 36 instances of ventricular septal defect involving the region posterior to the crista supraventricularis, the inferoposterior extremity of the defect was the tricuspid ring or identifiable portions of the membranous septum. The superoanterior extremity of the defect in 20 of these cases did not extend beyond the level of the chordae emanating from the papillary muscle of the conus (fig. 2). These defects were overhung by the septal tricuspid leaflet and were obscured either completely or partially from view unless the septal tricuspid leaflet was retracted superiorly. All except 1 of these defects were small, their diameter being less than the diameter of the aorta. From the left ventricular aspect, these smaller defects were confined to the tissue of the ventricular septum inferior to the right half of the posterior aortic cusp and varying amounts of the adjacent half of the right aortic cusp. Their anterior border did not extend anterosuperiorly beyond a line drawn through the midportion of the right aortic cusp.

In the other 16 of these 36 instances of defects involving the region posterior to the crista supraventricularis, the superoanterior extremity of the defect extended beyond the papillary muscle of the conus to involve the septal tissue lying between it and the crista supraventricularis (fig. 3). In all defects in this series involving tissue between the papillary muscle of the conus and the crista supraventricularis, the aforementioned ratio of the diameter of

* One heart had 2 ventricular septal defects, 1 in this category and the other in the inflow portion of the septum. This explains the total of 51 defects noted in these 50 hearts.
FIG. 2. Ventricular septal defects in relation to the membranous septum and lying behind the papillary muscle of the conus.

a. Right ventricular aspect in a 32-day-old girl. The defect lies partly hidden by the septal leaflet of the tricuspid valve (S.) and posterior to the papillary muscle of the conus (point of arrow). This defect involves the membranous septum and muscular tissue anterior to it.

b. Same case, the defect being viewed from the left ventricle anterior to the anterior leaflet of the mitral valve (M.) and inferior to the adjacent portions of the right (R.) and posterior (P.) leaflets of the aortic valve. The anterior extremity of the defect is beyond the membranous septum and involves muscular tissue in this region.

c. Right ventricular aspect in a 33-year-old woman. The defect lies posterior to the papillary muscle of the conus (point of arrow) and is partly hidden by the septal leaflet of the tricuspid valve (S.). d. Same case, viewed from the left ventricular aspect; the defect lies inferior to the right aortic leaflet (R.) and the commissure between the right and posterior (P.) leaflets. Membranous septal tissue is present between the defect and the anterior leaflet of the mitral valve (M.).

the defect to the diameter of the aortic orifice was 1.0 or more, indicating that the diameter of the defect was equal to or larger than the diameter of the aorta. From the left ventricular aspect, defects with these features involved the septal tissue that lies inferior to the right aortic leaflet and the adjacent half of the posterior aortic leaflet. Thus, these defects
involved the same regions as did the group of small defects previously considered, but also involved the septal tissue that lies between the papillary muscle of the conus and the crista supraventricularis on the right side, and beneath the anterior half of the right aortic cusp on the left.

These anatomic considerations may be
summarized as follows: From the right ventricular aspect, the papillary muscle of the conus lay superoanterior to all defects with small ratios; most defects with large ratios involved tissue extending both anterior and posterior to it. From the left ventricular aspect, most defects with large ratios involved septal tissue lying below the anterior half of the right aortic cusp, whereas no defects with small ratios involved tissue below the anterior half of the right aortic cusp, these lesions being restricted to tissue beneath the posterior cusp and the posterior half of the adjacent right aortic cusp.

In all instances in which the defect involved the septal tissue lying below the anterior half of the right aortic cusp, the aortic leaflets overhung the outflow tract of the right ventricle giving the impression of "dextroposition" of the aorta. This usually did not occur in defects of smaller ratios. In those cases in which the membranous portion of the ventricular septum was entirely lacking, the septal leaflet of the tricuspid valve and the anterior leaflet of the mitral valve became continuous across the posterior border of the defect.

**Defects Involving the Region Anterior to the Crista Supraventricularis.** The septal tissue that extends from the crista supraventricularis to the annulus fibrosus of the pulmonary valve on the right side corresponds on its left ventricular aspect to the tissue lying below the right half of the left aortic cusp. Four instances of defects involving this region were found among the 50 specimens in this study.

The main features of such defects are their close relationship to the pulmonary valve and their lack of extension inferiorly and posteriorly beyond the crista supraventricularis. The membranous portion of the ventricular septum was intact and normal in appearance in all instances. The upper border of the defect was formed by pulmonary valvular tissue, usually the left cusp. From the left ventricular

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**Fig. 3.** Defects related to the membranous septum and extending superior and anterior to the papillary muscle of the conus.

- **a.** Right side of heart from a 2-day-old boy. The defect is seen through the septal leaflet of the tricuspid valve (S.), where it involves the membranous portion of the septum and extends beyond the papillary muscle of the conus (point of arrow) to include the tissue between this region and the inferior edge of the crista supraventricularis (C.).

- **b.** Same case, left ventricle. The large defect involves the tissue inferior to the posterior aortic leaflet (P.) and the tissue inferior to the adjacent half of the right aortic leaflet (R.). The membranous septum is absent. The posterior boundary of the defect is formed by the continuous membrane representing the anterior leaflet of the mitral valve (M.) and that portion of the septal leaflet of the tricuspid valve that is seen through the defect from this view.

- **c.** Specimen from a 3-month-old boy. The defect is clearly seen between the crista supraventricularis (C.) and the papillary muscle of the conus (point of arrow); it extends posteriorly beyond this region but is obscured by the septal leaflet of the tricuspid valve. *P.V.* = pulmonary valve.

- **d.** Same case, left ventricle. The defect lies inferior to the adjacent halves of the right (R.) and posterior (P.) aortic leaflets. The membranous portion of the septum is intact, lying between the point of the arrow and the anterior leaflet of the mitral valve (M.). These cases illustrate that, when a defect involves the region between the papillary muscle of the conus and the crista supraventricularis, varying amounts of tissue posterior to the papillary muscle of the conus may be deficient, including the membranous septum, but in some instances, as seen in c and d, the membranous septum may be present.

- **e.** Right ventricle and pulmonary arteries from a 6-month-old girl in whom the defect was anterosuperior to the crista supraventricularis. The defect lies some distance from the papillary muscle of the conus (point of arrow) and is bounded by the crista supraventricularis (C.) below and the right (R.) and left (L.) pulmonary leaflets above. *A.* = anterior pulmonary leaflet. The probe is in a narrow patent ductus arteriosus; an atrial septal defect also was present.

- **f.** Same case. The left ventricular aspect shows the defect (*V.S.D.*) inferior to the left aortic leaflet (L.) and some distance from the posterior (P.) aortic leaflets, in contrast to cases in which the defect lies posteroinferior to the crista supraventricularis (figs. 3a to d). *P.T.* = pulmonary trunk; *M.* = anterior leaflet of mitral valve.
aspect, these defects lay immediately inferior to the left aortic leaflet and to varying amounts of the adjacent anterior half of the right aortic leaflet.

Comparison of the diameter of the defect and that of the aortic orifice showed that 3 of the defects involving this region had ratios of 1.0 and the fourth had a ratio of 1.3.

**Defects Involving Regions Not Related to the Ventricular Outflow Tracts**

Among the 50 hearts in this study, 11 had defects of this type (fig. 4). These defects

![Fig. 4. Defects involving regions not related to the ventricular outflow tracts.](image)

*a.* Right side of heart of a 51-year-old woman who also had a patent ductus arteriosus and mitral insufficiency. The defect (V.S.D.) lies in the muscular portion of the septum inferior to the septal leaflet of the tricuspid valve (S.) and far removed from the papillary muscle of the conus (point of arrow) and from the membranous portion of the ventricular septum (dotted circle).

*b.* Same case. The left ventricular aspect shows the defect in the muscular portion of the septum inferior to the posteromedial commissure of the mitral valve (M.). The membranous septum is above the point of the arrow. R. = right aortic leaflet; P. = posterior aortic leaflet.

*c.* Heart from a 5½-month-old boy. The defect is in the muscular portion of the septum at the junction of the inflow and outflow portions involving the tissue near the right ventricular apex. The papillary muscle of the conus is at the arrow. S. = septal leaflet of tricuspid valve.

*d.* Same case. From the left ventricular aspect, the defect is seen at the junction of the inflow and outflow portions of the left ventricle.
always were located entirely in the muscular wall of the ventricular septum and were related to the inflow or sinus portion of the ventricles. Two distinct groups could be distinguished.

**Defects Related to the Atrioventricular Valves.**

The defects in this first group were located in the basal portion of the muscular ventricular septum in close relation to the tricuspid and mitral valves. Six such defects were found. The ratios of the diameter of the defect to that of the aortic orifice were 0.4, 0.7, 1.0, 1.0, 1.2, and 1.6. From their right ventricular aspect, these defects opened into the right ventricle close to the tricuspid ring and under the posterior and septal leaflets of the tricuspid valve. From their left ventricular aspect, the defects were in close relation to the base of the posterior papillary muscle of the left ventricle and the posterior leaflet of the mitral valve.

**Defects Involving the Apical Portion of the Ventricular Septum.** These defects had 1 feature in common in that they were not closely related to any of the valvular structures of the heart. Five hearts had defects of this type, and the ratios were 0.3, 0.5, 0.7, 1.0, and 1.3.

**Pathologic Considerations**

**Group A—Defects Not Associated with Other Cardiovascular Anomalies**

Among the 50 cases included in this study were 34 in which the ventricular septal defect was the only cardiovascular congenital malformation. In this group 16 were female and 18 were male. The ages of the patients at the time of death ranged from stillbirth to 55 years, with a median of 2½ months.

**Cause of Death.** In 19 of the 34 cases in group A (56 per cent), death was attributed to the presence of the defect, whereas death in 15 cases (44 per cent) was considered to be caused either entirely or in part by conditions unrelated to the ventricular septal defect (table 1). For the purpose of this paper, death in such cases was not attributed to the septal defect.

Among the 19 patients dying as a consequence of the defect, 12 (63 per cent) were less than 1 year of age. Death occurred at 14 and 21 months, respectively, in 2 patients and at 5 years in another; the remaining 4 patients died at 14, 18, 33, and 55 years of age. The most frequent cause of death was cardiac failure, which was predominately left ventricular in type, with pulmonary congestion and edema; it was present in 15 of these 19 patients (79 per cent). These 15 patients included all 12 patients who died in less than 1 year of life. The remaining 3 patients who died with left ventricular failure were 14 months, 21 months, and 14 years of age at the time of death; the last patient also had aortic insufficiency. Two patients aged 5 and 18 years died of bacterial endocarditis, whereas 2 women aged 33 and 55 years died of chronic congestive heart failure.

**Types of Defects.** The most frequent type of ventricular septal defect in group A involved the outflow regions of the ventricles lying posterior to the crista supraventricularis; 29 of the 34 defects were in this region, 4 involved the inflow portion of the septum, and the

**Table 1.—Relationship of Death to Ventricular Septal Defects Not Associated with Other Cardiovascular Anomalies: Group A**

<table>
<thead>
<tr>
<th>Age at death*</th>
<th>Location of defects</th>
<th>Outflow tracts</th>
<th>Inflow tracts</th>
<th>Totals in each age group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Posterior to crista supraventricular</td>
<td>Anterior to crista supraventricular</td>
<td>Unrelated to death</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Related to death</td>
<td>Unrelated to death</td>
<td>Related to death</td>
</tr>
<tr>
<td>0-5 mo.</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>6-11 mo.</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1-9 yr.</td>
<td>3†</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10 yr. and more</td>
<td>4‡</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals of types of defects</td>
<td>17</td>
<td>12</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

* All deaths related to the ventricular septal defect were caused by left ventricular failure unless indicated otherwise.
† Unrelated to death.
‡ One patient died of bacterial endocarditis at 5 years of age.
§ Two patients died of chronic congestive heart failure at 33 and 55 years of age. One died of bacterial endocarditis at 18 years of age; 1 patient, aged 14 years, had aortic insufficiency associated with the ventricular septal defect; death was caused by left ventricular failure.
remaining lesion was in the outflow tract immediately below the pulmonary valve.

Among the 29 defects involving the region of the outflow tracts posterior to the crista supraventricularis, 18 were of the small type and 11 were of the large type. Of the 4 defects located in the inflow portion of the ventricular septum, 3 were in the apical region and 1 was basal in position, lying just beneath the mitral and tricuspid valves. The anatomic distribution of the defects was about the same in those patients dying of the defects as in those dying of unrelated causes.

Of the 19 patients in group A dying as a consequence of the defect, 7 were more than 1 year of age; 5 of 7 patients had the smaller-type defects in relation to the membranous septum, 1 had the larger type, and the seventh had an inflow defect in the apical region.

Size of the Defect. The median ratio of the diameter of the defect to the diameter of the aorta in the 34 cases comprising group A was 1.0, with a range of 0.2 to 1.7. The median ratio was 1.0 in those cases in which death was related to the ventricular septal defect, whereas it was 0.5 in those cases in which death was not related to the defect. The greatest median ratio (1.1) was noted in those cases in which death occurred before 1 month of age; the median ratio generally was smaller with increasing age at death, being lowest (0.3) at more than 10 years of age, with individual exceptions.

The defects with the largest ratios were those located in the outflow tracts posterior to the crista supraventricularis and involving the septal tissue between it and the papillary muscle of the conus. The median ratio for this type was 1.1, with a range of 1.0 to 1.5. Thus, the diameter of the defect in each of these cases was equal to or larger than the diameter of the aorta.

The defects in the outflow tracts restricted to the septal tissue lying posterior to the papillary muscle of the conus had ratios ranging from 0.2 to 1.7, with a median of 0.5. The largest defect in group A was of this type and was found in the woman who died at the age of 55 years of chronic congestive heart failure. However, most of these defects were small compared to the size of the aorta. The single case in group A in which the defect involved the region anterior to the crista supraventricularis had a ratio of 1.0. The defects involving the inflow or sinus portion of the ventricles had ratios ranging from 0.3 to 1.0, with a median of 0.7.

The 2 patients who died of bacterial endocarditis had relatively small defects, their ratios being 0.3 and 0.6; the 2 patients who died of chronic congestive heart failure had ratios of 0.7 and 1.7. The 15 patients who died of left ventricular failure had a median ratio of 1.0, with a range of 0.2 to 1.5. Three of them had ratios of 0.2, 0.3, and 0.5, while all the others had ratios of 1.0 or more.

Noncardiovascular Anomalies. The 34 patients in group A included 18 (53 per cent) who had some additional congenital malformation not involving the cardiovascular system. These noncardiovascular malformations were of serious nature and caused death in 10 patients; they were numbered among the 15 in group A in whom death was not attributed to the ventricular septal defect. Of these 10 patients, 5 had severe malformations of the central nervous system, 2 had tracheoesophageal fistulas, 1 had exstrophy of the bladder, 1 had a complicated omphalocele, and 1 had infected polycystic kidneys.

In the remaining 8 patients who had noncardiovascular anomalies, the associated lesions were of minor significance; they included supernumerary digits, imperforate anus, cleft palate, congenital hydronephrosis, clubfoot, bilateral double ureter with congenital dislocation of the hip, situs inversus of the spleen and stomach, and diaphragmatic hernia. Some patients had more than 1 malformation. Mongolism was present in 2 instances. Congenital absence of the spleen was not observed in any patient.

Group B—Defects Associated with Coincidental Cardiovascular Malformations

The 50 cases of ventricular septal defect in our series included 16 cases in which other cardiovascular anomalies were present (fig.
Fig. 5. Malformations associated with ventricular septal defects.

a. The heart and great vessels showing a widely patent ductus arteriosus (P.D.A.) in the 51-year-old woman whose ventricular septal defect is illustrated in figure 4a and b.

b. The right side of the heart from the 6-month-old girl with an atrial septal defect whose ventricular septal defect and patent ductus are illustrated in figure 3e and f. I.V.C. = inferior vena cava; A.S.D. = atrial septal defect; T.V. = tricuspid valve.

c. Heart and great vessels in a 10-day-old girl with a defect located in the muscle of the apical portion of the ventricular septum. Tubular hypoplasia of the aortic arch and a patent ductus arteriosus (P.D.A.) are shown.

d. Specimen from a 4-day-old infant with a tracheoesophageal fistula and two ventricular septal defects, which are shown from the right side. One defect involves the tissue in relation to the membranous septum and posterior to the crista supraventricularis. The second defect lies in the muscle in the posterior part of the septum and inferior to the tricuspid valve (T.V.). Probes are in the defects. The papillary muscle of the conus is at the point of the arrow.

e. Same case. From the left side, one defect is seen to be centered inferior to the right aortic cusp and the second lies in the muscle inferior to the posteromedial commissure of the mitral valve. A.M. = anterior mitral leaflet.
VENTRICULAR SEPTAL DEFECT

Table 2.—Data in Ventricular Septal Defects Associated with Coincidental Cardiovascular Malformations Together Not Forming Established Complexes

<table>
<thead>
<tr>
<th>Region involved by the defect</th>
<th>Case</th>
<th>Age</th>
<th>Ratio*</th>
<th>Associated cardiovascular malformation</th>
<th>Cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outflow tract</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior to crista supraventricularis</td>
<td>1</td>
<td>21 yr.</td>
<td>0.3</td>
<td>Vascular ring†</td>
<td>Bacterial endocarditis</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Stillborn</td>
<td>1.0</td>
<td>Atrial septal defect</td>
<td>Premature stillborn</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1 day</td>
<td>1.0</td>
<td>Atrial septal defect</td>
<td>Unrelated to cardiac malformation</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3 mo.</td>
<td>0.5</td>
<td>Vascular ring†</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5 mo.</td>
<td>1.2</td>
<td>Atrial septal defect</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2 yr.</td>
<td>1.0</td>
<td>Coarctation and patent ductus arteriosus</td>
<td>Right ventricular failure</td>
</tr>
<tr>
<td>Anterior to crista supraventricularis</td>
<td>7</td>
<td>3 days</td>
<td>1.3</td>
<td>Interruption of aortic arch</td>
<td>Right ventricular failure</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3 mo.</td>
<td>1.0</td>
<td>Coarctation of aorta</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>6 mo.</td>
<td>1.0</td>
<td>Atrial septal defect and patent ductus arteriosus</td>
<td>Right ventricular failure</td>
</tr>
<tr>
<td>Inflow tract</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Related to the atrioventricular valves</td>
<td>10</td>
<td>3 mo.</td>
<td>0.4</td>
<td>Patent ductus arteriosus</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>5 yr.</td>
<td>1.6</td>
<td>Vascular ring†</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>34 yr.</td>
<td>1.2</td>
<td>Patent ductus arteriosus</td>
<td>Right ventricular failure</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>51 yr.</td>
<td>1.0</td>
<td>Patent ductus arteriosus and anomalous insertion of chordae, with mitral insufficiency</td>
<td>Right ventricular failure</td>
</tr>
<tr>
<td>In the apical region</td>
<td>14</td>
<td>10 days</td>
<td>1.3</td>
<td>Tubular hypoplasia of aorta</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td>Two separate ventricular septal defects, one in the posterior outflow tract and the other in the postero-basal inflow tract</td>
<td>15</td>
<td>14 days</td>
<td>0.7</td>
<td>Coarctation of aorta</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>4 days</td>
<td>0.8</td>
<td>Second ventricular septal defect</td>
<td>Unrelated to cardiac malformation</td>
</tr>
</tbody>
</table>

* Ratio of diameter of defect to diameter of aortic orifice.
† Vascular ring characterized by a right aortic arch with retroesophageal segment and left-sided descending aorta. The ligamentum arteriosum was attached to the left pulmonary artery below and to a diverticulum of the aorta at the junction of the right arch and descending aorta above.

Three of these patients died of noncardiovascular causes, while 13 were considered to have died of the ventricular septal defect alone or in association with the additional cardiovascular malformation. The ages at the time of death of these 13 patients ranged from 3 days to 51 years, with a median age at death of 5 months, which is similar to that for the 19 patients in group A who died of the ventricular septal defect.

Pertinent data concerning the 16 patients in group B are given in table 2.

Noncardiovascular Anomalies. Only 2 patients in group B had noncardiovascular congenital anomalies, and death in both instances

5), but together these did not form established complexes.*
was attributed to their presence. One of these patients, who died at 1 day of age, had a large diaphragmatic hernia and congenital hypoplasia of the lung; the other patient died at the age of 4 days of respiratory obstruction after operation for a tracheoesophageal fistula.

**Discussion**

The ages of the majority of these patients who died as the result of ventricular septal defect with or without associated malformations and whose hearts formed the primary material for this study were strikingly low. As already noted, the ventricular septal defect was considered to be the lesion causing death in 19 of the 34 patients who did not have associated cardiovascular malformations. Twelve of these patients were less than 1 year of age at the time of death.

It was considered that death resulted from the cardiovascular anomalies in 13 of the 16 patients in whom the ventricular septal defect was associated with other significant cardiovascular malformations. Eight of these 13 patients were less than 1 year of age at death. Severe pulmonary edema and hemorrhage were common findings in these young patients.

A standard for measuring the size of the defects was desired in our study. Absolute measurements obviously mean little in comparing the heart of an infant with that of an adult. Therefore, we followed the suggestion of Selzer and compared the size of the ventricular septal defect with the caliber of the aorta. This comparison was expressed as the ratio of the diameter of the defect to the diameter of the aorta.

The patients who died early in infancy of ventricular septal defects had defects, as a group, with larger ratios than did patients who died later in life of bacterial endocarditis. The latter group of patients probably had a significant differential in pressure between the 2 ventricles, and the traumatizing influence of this left-to-right shunt contributed to the ultimate development of bacterial endocarditis. The comparatively small defect, allowing for a differential in pressure between the 2 ventricles and a relatively low pulmonary pressure, probably explains why these patients survived the period of infancy. The latter type of case in the past has been thought to be representative of ventricular septal defect. Even when allowance is made for differences in the percentage of postmortem examinations in different age groups, it is obvious from our studies that this benign type of defect is less common than are defects with larger ratios and in which the ages at death are usually low.

The commonest type of defect, in our experience, was that with a relatively large ratio of the diameter of the defect to the aortic diameter. The majority of patients with such anomalies died in infancy of pulmonary congestion and edema. Such patients probably are like those of other series in whom physiologic studies reveal large left-to-right shunts and various degrees of increased pulmonary arterial pressure. In emphasizing the malignant nature of certain ventricular septal defects, Selzer, Marquis, and Engle probably dealt with similar cases.

A small number of patients in our series had large ratios but did not have evidence of left ventricular failure; they usually were adults. In 1 of these patients, the 33-year-old woman without additional malformations in whom physiologic studies had been done, pulmonary hypertension was demonstrated and the right and left ventricular pressures were essentially equal. Bidirectional shunts of minor proportions had been present. In such cases, large left-to-right shunts and left ventricular failure probably are avoided by the presence of high resistance to pulmonary flow. Such patients might be said to have the Eisenmenger complex. We prefer the more recent approach in classification, as suggested by Selzer and Laqueur, categorizing these cases as instances of large ventricular septal defect with pulmonary hypertension and bidirectional shunts.

The position of the defect appears to make little difference in the behavior of the cardiovascular system. The size of the defect, however, is important.

It is apparent from our study that there is a relatively high incidence (30 per cent) of cardiovascular malformations associated with ventricular septal defects that do not consti-
tute established complexes of malformations. Not included among our 50 cases were examples of the tetralogy of Fallot, persistent truncus arteriosus, complete transposition of the great vessels, the Taussig-Bing complex, persistent common atroventricular canal, or the complex recently described in which a ventricular septal defect is associated with biventricular origin of the pulmonary trunk and subaortic stenosis. Likewise not included in this series are 2 hearts with ruptured aneurysms of the aortic sinus and ventricular septal defects. The common associated defects in our series were atrial septal defect, patent ductus arteriosus, coarctation or other stenosing lesions of the aortic arch, and vascular rings.

A patient with a ventricular septal defect may have certain physiologic and clinical features that are indistinguishable from those in a patient who has a ventricular septal defect associated with additional cardiovascular malformations. For instance, the association of a wide patent ductus arteriosus with a wide ventricular septal defect may yield a clinical and physiologic pattern indistinguishable from that in a patient who has only a wide ventricular septal defect. Recognition of the similarity between these 2 types of lesions is important in therapy, since it is obvious that treatment is different in these 2 instances.

The association of some type of obstruction in the region of the aortic arch in infants who have ventricular septal defects was strikingly common in our series. It will be recalled that 3 of the 50 patients had classic coarctation of the aorta, 1 had hypoplasia of the aortic arch, and a fifth had interruption of the aortic arch. In patients who have both coarctation of the aorta and ventricular septal defects, the coarctation probably increases the tendency for a left-to-right shunt over what might be expected in the absence of such an aortic obstruction. As in the association of patent ductus arteriosus with ventricular septal defect, it is recognized that the patient with a ventricular septal defect and coarctation may have certain clinical and physiologic features in common with patients having only ventricular septal defects. The essential differences in treatment also are important in such instances.

Three of our 50 patients with ventricular septal defects had an associated right aortic arch. This incidence of 6 per cent is relatively great, although it is less than the incidence of right aortic arch in the tetralogy of Fallot. Three of our patients had atrial septal defects of the usual variety associated with ventricular septal defects. Another patient had these 2 malformations associated with a patent ductus arteriosus. Under such conditions, cardiac catheterization probably would disclose the presence of highly oxygenated blood in both the right atrium and right ventricle. Such a combination of findings would lead to the justifiable consideration in the differential diagnosis of a persistent common atroventricular canal. Indeed, it might be difficult to distinguish that malformation from an ordinary ventricular septal defect associated with an ordinary atrial septal defect.

A strong tendency appears to exist for defects involving the region of the outflow tracts anterior and superior to the crista supraventricularis to be associated with some form of obstruction of the aortic arch. Two of the 4 patients in this study who had this type of defect also had either coarctation or interruption of the aortic arch. In each of 5 patients who are not part of this study and who are reported on elsewhere as having a complex of malformations, there was a ventricular septal defect anterior to the crista supraventricularis associated with biventricular origin of the pulmonary trunk, subaortic stenosis, and obstruction of the aortic arch. Thus, of 9 patients with defects anterior to the crista supraventricularis, 7 also had an obstructive aortic abnormality.

It is interesting to consider the types of ventricular septal defect encountered when obstruction of the aortic arch is also present. As already indicated, we have studied 10 hearts characterized by obstruction of the aortic arch (including typical coarctation, tubular hypoplasia of the aortic arch, and interruption of the aortic arch) associated with ventricular septal defects. The defect in 7 of
these 10 cases involved that portion of the ventricular outflow tracts anterior to the crista supraventricularis; the defects in 2 cases were in the apical region of the inflow portion of the septum, whereas the defect involved the region of the ventricular outflow tract posterior to the crista supraventricularis in the tenth case.

From our anatomic studies of ventricular septal defects, we are left with the concept that the term “membranous ventricular septal defect” often cannot be applied with accuracy. The greatest contribution to the area of a given ventricular septal defect involving the posterior region of the outflow portion of the septum usually is in the territory of a portion of the muscular ventricular septum, the membranous portion being partially or totally identifiable.

**Summary**

In 50 cases in which the hearts had ventricular septal defects studied at necropsy, this anomaly was the only cardiovascular malformation in 34 cases (group A); it was associated with 1 or more cardiovascular malformations in the remaining 16 cases (group B), but together these did not form traditionally recognized complexes.

Of the 19 patients of group A in whom death was related to the ventricular septal defect, 12 were less than 1 year of age at the time of death and each of these 12 died of predominantly left ventricular failure. Bacterial endocarditis and predominantly right ventricular failure were the principal causes of death in the patients who died beyond the period of infancy.

Among the 16 patients in group B, 13 were considered to have died of the cardiovascular malformations. Eight patients were less than 1 year of age at the time of death: 6 of them died of left ventricular failure and 2 of right ventricular failure.

Commonly associated cardiovascular malformations included atrial septal defect (4 cases), obstructive disease of the aortic arch (5 cases), patent ductus arteriosus (5 cases) and vascular rings (3 cases).

The 2 oldest patients at the time of death were a 55-year-old woman with only a ventricular septal defect and a 51-year-old woman with ventricular septal defect, patent ductus arteriosus, and anomalous insertion of the chordae tendineae with mitral insufficiency.

Each ventricular septal defect was classified according to the region of the ventricular septum it involved. By far the commonest type of defect was situated in the outflow regions of the ventricular septum.

**Summario in Interlingua**

In 50 casos in que le necropsia revelava de defectos ventriculo-septal del corde, 34 (gruppo A) habeva iste anomalia como le sol malformation cardiovascular, durante que 16 (gruppo B) habeva lo in association con un o plure alters. Le observate combinationes de malformaciones cardiovascular non representava complexos que es tradicionalmente recognoscite.

Inter le 19 patientes del gruppo A in qui le morte eseva relationate al defecto ventriculo-septal, 12 habeva minus que un anno quando illes moriva, e in omne iste 12 casos le causa del morte eseva predominante disfallimento sinistro-ventricular. Endocarditis bacterial e predominantemente disfallimento dextero-ventricular eseva le principal causas de morte in le patientes qui moriva post le periodo del prime infantia.

Inter le 16 patientes del gruppo B, le morte de 13 eseva considerate como resultato de malformationes cardiovascular. Octo patientes habeva minus que un anno de etate al tempore de lor morte. Sex de illes moriva per disfallimento sinistro-ventricular e 2 per disfallimento dextero-ventricular.

Malformationes cardiovascular de commun occurrentia associate eseva inter alters defecto atrio-septal (4 casos), morbo obstrutive del arco aortic (5 casos), patente ducto arterioso (5 casos), e annulos vascular (3 casos).

Le 2 plus vetule patientes al tempore del morte eseva un femina de 55 annos con solmente un defecto ventriculo-septal e un femina de 51 annos con defecto ventriculo-septal, pa-
tente ducto arteriose, e anormal insertion del chordas tendine e insufficientia mitral.

Omn'ie caso de defecto ventriculo-septal esseva classificate secunde le region del septo ventricular involvite in illo. Le per molto plus com-mun defecto esseva situate in le regiones de effluxo del septo ventricular.

REFERENCES


Medical Eponyms

By Robert W. Buck, M.D.

Austin Flint Murmur. Austin Flint (1812–1886), then Professor of the Principles and Practice of Medicine in the Bellevue Hospital Medical College, New York, first fully described this murmur in a paper “On Cardiac Murmurs” which appeared in the American Journal of the Medical Sciences 44 (new series): 29–54 (July), 1862.

“Now in cases of considerable aortic insufficiency, the left ventricle is rapidly filled with blood flowing back from the aorta as well as from the auricle, before the auricular contraction takes place. The distension of the ventricle is such that the mitral curtains are brought into coaptation, and when the auricular contraction takes place the mitral direct current passing between the curtains throws them into vibration and gives rise to the characteristic blubbering murmur. The physical condition is in effect analogous to contraction of the mitral orifice from an adhesion of the curtains at their sides, the latter condition, as clinical observation abundantly proves, giving rise to a mitral direct murmur of a similar character.

“A mitral direct murmur, then, may exist without mitral contraction and without any mitral lesions, provided there be aortic lesions involving considerable aortic regurgitation.”
Anatomic and Pathologic Studies in Ventricular Septal Defect
LUIS M. BECU, ROBERT S. FONTANA, JAMES W. DUSHANE, JOHN W. KIRKLIN, HOWARD B. BURCHELL and JESSE E. EDWARDS

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