Hemodynamic Studies in Pectus Excavatum

By Clifford S. Reusch, Capt. USA MC

The presence of abnormal cardiac auscultatory findings of no diagnostic significance in pectus excavatum (funnel chest) has been repeatedly emphasized. However, published hemodynamic data in this condition are limited to 42 cases. It is the purpose of this paper to report eight additional cases with cardiac catheterizations that originally were diagnosed as organic heart disease.

Method of Study

The patients reported in this series were seen as routine referrals to the cardiac clinic of the City of Hope Medical Center during the course of one calendar year. In each instance, the patient was thought by his referring physician to have organic heart disease.

In addition to routine 14-lead electrocardiograms, each patient had a vectorcardiogram made with 3-lead systems (Kimura, Grishman, and Frank), a phonocardiogram, and a cardiac fluoroscopic examination.

Cardiac catheterization was performed on each patient. An Electronics-for-Medicine multichannel photographic recorder was employed for a permanent pressure record. Oxygen saturation data were recorded on Enasco and Waters indirect oximeters, and were checked at intervals during the procedure with Van Slyke gasometric determinations. Five minutes of exercise on a bicycle ergometer at the rate of 30 ergs per minute was carried out in most instances.

In each case dye-dilution curves were obtained with multiple injection sites throughout the right heart and recorded by continuous sampling from the radial artery. Indocyanine green was the dye indicator employed. Cardiac output was determined by the method of Fick, as well as from the dye indicator-dilution curves with the method of Hamilton and Stewart et al. Cardiac index was calculated from the cardiac output derived by the Fick principle. Total peripheral resistance (TPR) was calculated by the formula:

$$TPR = \frac{\text{mean arterial pressure} \times 1332 \times 60}{\text{cardiac output ml./min}}.$$

Selective angioangiograms were made in two cases.

In all instances the cardiac catheterization was performed under local anesthesia, with hydroxyzine or a combination of secobarbital, promethazine hydrochloride, and codeine as premedication.

Case Reports

Case 1

A 25-year-old Caucasian woman without symptoms was examined because of a murmur first discovered at the age of 5 years. Her blood pressure was 125/76, pulse rate was 82. A mild pectus excavatum was largely obscured by breast tissue. The chest was normal to auscultation and percussion. On cardiac examination the aortic second sound equaled the pulmonary second sound. A grade-III systolic murmur was heard at the second and third left intercostal spaces; a grade-IV systolic murmur was heard at the apex. A thrill was also felt at the apex. The tentative diagnosis was mitral insufficiency.

Case 2

A 32-year-old Caucasian man was examined because of palpitations and dizziness. He had a history of murmur present from age 12 years. The blood pressure was 180/90, the pulse was 90 and regular. The chest was normal to auscultation and percussion. There was a moderate pectus excavatum of the anterior chest. On cardiac examination the point of maximum impulse was in the fifth intercostal space at the midclavicular line. The pulmonary second sound was equal in intensity to the aortic second sound and closely split. In the sitting position, there was a grade-III systolic murmur at the apex, and a thrill was present. In the recumbent position, the apical murmur was grade I in intensity, and the thrill was absent. The tentative diagnosis was mitral insufficiency.

Case 3

A 3-year-old Caucasian boy was examined because of easy fatigue on exertion. A murmur was known to be present since the age of 6 weeks. Blood pressure was 75/50, and the pulse was 100 and regular. The chest was normal to auscultation and percussion. There was a mild pectus
excavatum. On cardiac examination the point of maximum impulse was in the fifth intercostal space, 1 cm, to the left of the midelavicular line. The pulmonary second sound was equal in intensity to the aortic second sound and closely split. There was a grade IV systolic murmur at the fourth left intercostal space, and a thrill was present in this area. The tentative diagnosis was interventricular septal defect.

Case 4

A 6-year-old Caucasian boy without symptoms was examined because of a murmur known to have been present since age 3 months. The blood pressure was 100/65, the pulse was 90 and regular. Auscultation and percussion of the chest were normal, and a moderate pectus excavatum was present. On cardiac examination the point of maximum impulse was in the fifth intercostal space at the midelavicular line. The pulmonary second sound was equal in intensity to the aortic second sound and closely split at the pulmonary area. There was a grade-IV high-pitched blowing systolic murmur at the fourth left intercostal space. A thrill was present in the left fourth intercostal space. The tentative diagnosis was interventricular septal defect versus an interatrial septal defect.

Case 5

An 8-year-old Caucasian girl was examined because of frequent upper respiratory infections and a murmur known to have been present since age 6 months. The blood pressure was 110/70, the pulse was 88 and regular. Auscultation and percussion of the chest were normal. There was a mild pectus excavatum deformity of the anterior chest. On cardiac examination the pulmonary second sound was equal in intensity to the aortic second sound and closely split in the pulmonary area. There was a grade-III systolic murmur at the fourth left intercostal space, which was referred to the apex and the aortic area. An indefinite thrill was also present in the fourth left intercostal space. The tentative diagnosis was interventricular septal defect.

Case 6

A 32-year-old Caucasian woman was examined because of fatigability and a murmur discovered 3 months previously during psychiatric hospitalization. The blood pressure was 120/70, the pulse was 70 and regular. Auscultation and percussion of the chest were normal; there was a pectus excavatum deformity of the anterior chest obscured by breast tissue. On cardiac examination the point of maximum impulse was in the fifth intercostal space at the midelavicular line. The pulmonary second sound was equal in intensity to the aortic second sound. There was a grade-III systolic murmur at the third left intercostal space. No thrill was present. The tentative diagnosis was interatrial septal defect.

Case 7

A 20-year-old Caucasian man without symptoms was examined because of a murmur discovered on military pre-induction physical examination. Blood pressure was 116/80, the pulse was 82 and regular. Auscultation and percussion of the chest were normal. There was a mild pectus excavatum deformity of the anterior chest wall. On cardiac examination the point of maximum impulse was in the fifth intercostal space at the midelavicular line. The pulmonary second sound was equal in intensity to the aortic second sound and widely split in both areas. There were a grade-III systolic murmur and a thrill at the fourth left intercostal space. A variable third heart sound was heard at the fourth intercostal space. The tentative diagnosis was interatrial septal defect.

Case 8

A 12-year-old Caucasian boy without symptoms was seen for the evaluation of a murmur known to be present since the age of 11 years. The blood pressure was 100/65, the pulse was 86 and regular. Auscultation and percussion of the chest were normal. There was a moderate pectus excavatum.

Figure 1

Superimposed pressure tracings (redrawn) on Cases 8 and 3. The center calibration column indicates right heart pressure in both cases. Outside calibration columns indicate arterial pressures. The time interval is one second.
pectus excavatum

Table 1

Hemodynamic Data from Cardiac Catheterizations Performed on Eight Patients with Pectus Excavatum

<table>
<thead>
<tr>
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<tr>
<td>Age</td>
<td>25</td>
<td>22</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>22</td>
<td>20</td>
<td>12</td>
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<td>Right atrial mean pressure</td>
<td>5</td>
<td>7</td>
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<td>4</td>
<td>3</td>
<td>5</td>
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<td>4</td>
</tr>
<tr>
<td>Right ventricular pressure</td>
<td>33/4</td>
<td>17/5</td>
<td>24/2</td>
<td>27/0</td>
<td>35/2</td>
<td>23/2</td>
<td>21/3</td>
<td>28/3</td>
</tr>
<tr>
<td>Right ventricular end-diastolic pressure</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Pulmonary artery pressure</td>
<td>33/14</td>
<td>18/12</td>
<td>26/14</td>
<td>27/10</td>
<td>35/15</td>
<td>18/6</td>
<td>21/10</td>
<td>17/8</td>
</tr>
<tr>
<td>Pulmonary artery mean pressure</td>
<td>20</td>
<td>14</td>
<td>20</td>
<td>17</td>
<td>22</td>
<td>13</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Pulmonary wedge pressure</td>
<td>16/10</td>
<td>Not Obt</td>
<td>Not Obt</td>
<td>13/8</td>
<td>9/7</td>
<td>12/5</td>
<td>9/7</td>
<td>13/8</td>
</tr>
<tr>
<td>Peripheral arterial pressure</td>
<td>120/65</td>
<td>110/66</td>
<td>102/48</td>
<td>117/60</td>
<td>123/70</td>
<td>115/63</td>
<td>130/70</td>
<td>120/68</td>
</tr>
<tr>
<td>Cardiac output ml./min.</td>
<td>5,600</td>
<td>7,500</td>
<td>6,100</td>
<td>2,800</td>
<td>4,700</td>
<td>3,200</td>
<td>4,500</td>
<td>7,600</td>
</tr>
<tr>
<td>Cardiac index L./min./M.²</td>
<td>3.4</td>
<td>3.6</td>
<td>8.5</td>
<td>3.4</td>
<td>4.5</td>
<td>2.0</td>
<td>2.7</td>
<td>5.6</td>
</tr>
<tr>
<td>Peripheral resistance</td>
<td>1,270</td>
<td>846</td>
<td>864</td>
<td>2,100</td>
<td>1,680</td>
<td>2,000</td>
<td>1,670</td>
<td>860</td>
</tr>
<tr>
<td>Total pulmonary resistance</td>
<td>286</td>
<td>148</td>
<td>184</td>
<td>480</td>
<td>332</td>
<td>250</td>
<td>252</td>
<td>147</td>
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deformity of the lower sternum with a "flat chest." On cardiac examination the point of maximum impulse was in the fifth intercostal space at the midclavicular line. The pulmonary second sound was split and greater in intensity than the aortic second sound. There were a grade-IV systolic murmur and a thrill present in the second and third left intercostal space. The tentative diagnosis was mitral insufficiency.

Results

The hemodynamic data are summarized in table 1. Superimposed pressure tracings obtained at the time of cardiac catheterization are presented in two cases in which minor abnormalities were found (fig. 1). Phonocardiograms and right precordial electrocardiographic leads are shown for all cases (fig. 2). Vectorcardiograms of four of these cases are presented (fig. 3). A photograph of case 8 (fig. 4) demonstrates a "moderate" degree of pectus excavatum.

The hemodynamic data of our eight cases are not grossly abnormal. In case 3 there was a mild diastolic gradient across the tricuspid valve, which was associated with an abnormally high cardiac index and resting cardiac output. This small gradient across the tricuspid valve may come from the increased flow rather than a direct effect from the pectus excavatum. In two cases there was a small gradient across the pulmonic valve, 11 mm. of mercury in one case, and 5 mm. in the other. Again, in the first of these two, there were a relatively large cardiac output and cardiac index. This finding is not at variance with previously reported transpulmonic gradients in normal individuals, especially with slight increases of cardiac output. Dye-dilution curves were normal in all cases.

In cases 1, 2, and 6 exercise was performed during the cardiac catheterization. In the first two, there was a substantial increase in cardiac output with a resultant drop in the pulmonary and systemic resistances, and no essential change in the intracardiac pressures. In case 6 cardiac output determinations were
Figure 2

Phonocardiograms and right precordial electrocardiograms on all cases.

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not made during exercise. However, pressure relationships remained normal. In addition, case 1 had a left heart catheterization that failed to reveal any abnormality.

Discussion
The incidence of pectus excavatum in the population as a whole is not low. Lang reported its occurrence in 2.2 per cent of boys and a 2.5 per cent of girls in a series of German school children.
Schaub and Wegmann, in a review of 137 cases of pectus excavatum, found cardiac auscultatory abnormalities in 57 per cent. Systolic murmurs were heard in 33 per cent, and the remainder had splitting of heart sounds or third heart sounds. In reported cases with hemodynamic data, the point has been re-emphasized that the evaluation of auscultatory findings in the presence of a pectus excavatum must be carried out with great caution. In addition to the previously described benign findings of splitting of the second sound and parasternal systolic murmurs, six of the present cases had a slight systolic thrill.

The presence of a benign thrill has not been mentioned previously among the diagnostic peculiarities of pectus excavatum in the absence of hemodynamically significant cardiac disease. This is of relatively great importance, as the presence of a thrill is usually considered a diagnostic sign par excellence of organic heart disease.

The electrocardiographic abnormalities in pectus excavatum are relatively constant. Dressler and Roesler pointed out that there is a persistence of the juvenile pattern with inversion of the T waves across the right-sided precordial leads. Incomplete right bundle-branch block and right axis shift or deviation are also common. Both persistent juvenile pattern and incomplete right bundle-branch block occur in the absence of any discernible abnormality, however, and may be normal variants.

In the past, much of this electrical pattern has been attributed to physical change produced by pressure of the sternum against the right ventricle. The vectorcardiographic evidence presented by Wachtel, Ravitch, and Grishman, as well as our own tracings, indicates that the abnormalities are more likely on the basis of a displacement of the heart toward the left. A relative difference in position of the precordial electrode on the deformed precordium in relationship to the cardiac vectors, rather than a rotation of the heart, per se, results in the pattern described.

Figure 3
Frontal and horizontal vectorcardiograms (Kimura lead system). All frontal depolarization progresses in a clockwise direction. All horizontal depolarization is counterclockwise.
Of interest regarding the electrocardiographic changes seen in pectus excavatum was the disappearance of the incomplete right bundle-branch block in 62 per cent of the cases following surgery.20

The radiographic findings are proportional to the displacement of the sternum posteriorly. The findings consist of leftward displacement of the cardiac shadow and increasing prominence of the pulmonary artery segment.21 On occasion, the obliteration of the retrosternal free space may be erroneously attributed to right ventricular hypertrophy, as it was initially in three of our own cases. The lateral radiogram may be most helpful, as it was in one of our female patients in whom the minimal pectus deformity was obscured by an ample amount of breast tissue. In this instance, the slight deviation of the lower sternum posteriorly was recognized only at the time of lateral chest films.

Physicians in general practice often have an opportunity to witness the familial characteristics of this condition. In most of the cases presented here other members of the family were examined. In one instance three members of the same family had a pectus excavatum. One patient described both his father and grandfather as having similar chest contours. A family studied by Elisberg22 demonstrated 50 per cent transmissability through four generations.

Currently 42 cases of pectus excavatum have been reported with hemodynamic data.2-8 Four of these cases had congenital heart disease in addition to pectus excavatum; all four cases were reported by Fabricius et al.4 In six of the remaining 38 catheterized patients with pectus excavatum, minor abnormalities were found. In three cases, small systolic gradients were found across the pulmonary valve, similar to those mentioned by Callahan et al.12 in normal individuals. In two instances, there was elevation of the end-diastolic pressure in the right ventricle and an abnormal diastolic pressure curve, similar to that seen in constrictive pericarditis. In four instances, there was some elevation of mean atrial pressure with a pressure gradient between the right atrium and right ventricle.

Respiratory abnormalities associated with pectus excavatum have been mentioned on several occasions, the most extensive study being that by Brown and Cook.23 They consistently found a reduction of the maximum breathing capacity and increased residual volume, while other measures of pulmonary function remained within normal limits.

McKusick,24 who emphasized the importance of pectus excavatum in the Marfan syndrome, pointed out that several cases of cardiac disease seen with pectus excavatum have subsequently been found to have the Marfan syndrome. He also noted that a diastolic murmur has not been reported as part

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**Figure 4**

Lateral photograph of case 8 demonstrating a moderate degree of pectus excavatum.
of the auscultatory abnormality in pectus excavatum and, when present, indicates a need for vigorous cardiac evaluation.

How a pectus excavatum deformity of the anterior chest wall is produced remains in question. The histologic studies of Chin\textsuperscript{25} have fortified Brodkin's original hypothesis that this represents a developmental abnormality of the anterior portion of the diaphragm. Their work is entirely compatible with the observed congenital and hereditary nature of the defect and stands as the most attractive evidence in favor of this hypothesis.

In addition to the obscure etiology of this condition, the genesis of the symptomatology also remains in question. On the basis of clinical evidence, pectus excavatum has been implicated in the production of congestive heart failure and severe cardiac embarrassment. This assumption has not been supported by hemodynamic data. In one of the cases reported by Wachtel et al.,\textsuperscript{2} cardiac output was reduced after exercise. Observations made on angiography by Howard\textsuperscript{26} tend to show some encroachment on the right ventricular cavity by the depressed sternum. These findings, however, are isolated and limited to severe deformities. In angiocardiograms performed on two of the patients in the current series, no reduction of the right ventricular chamber by compression between the left ventricle and anterior chest wall was demonstrated.

In the eight cases presented here, little in the way of symptomatology needs to be discussed, but the dramatic auscultatory findings do require explanation. Inasmuch as pulmonary systolic murmurs have been reported in thin individuals with no abnormal hemodynamic findings, it would appear that reducing the space between the pulmonary artery and the auscultating device would intensify these sounds. If the pulmonary artery segment or outflow track of the right ventricle were in apposition with the anterior chest wall, the observed thrill might result. This may be considered an exaggeration of a normal occurrence rather than an obscure pathologic mechanism.

Conclusions and Summary

Eight cases of mild to moderate pectus excavatum have been reviewed. Electrocardiographic and phonocardiographic tracings, hemodynamic data obtained from cardiac catheterization, and physical findings are presented. All eight individuals are considered to have a normal hemodynamic pattern despite the fact that auscultatory findings had led to a presumptive diagnosis of organic heart disease. A brief discussion of the incidence and significance of pectus excavatum is presented with reference to the available published hemodynamic data.

References


It is with the symptoms of disease that the patient, and that the doctor mainly, contends; and the symptoms of heart disease may be said to derive almost exclusively from faults in function. Therefore, in managing our patients, our thoughts must be chiefly set in terms of function and not of structure. To whom I fail to teach this first simple, but essential, lesson I have nought to teach.—Sir Thomas Lewis. Diseases of the Heart. New York, The MacMillan Company, 1933, p. vii.
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