Problems in the Diagnosis and Surgical Treatment of Pulmonic Stenosis with Intact Ventricular Septum

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Obstruction to pulmonary blood flow may occur in the pulmonic valve, in the infundibulum or in both. Cardiac catheterization aids in the determination of the site of obstruction. Criteria for the differentiation at operation of valvular and infundibular pulmonic stenosis are enumerated, and the usefulness of accurate pressure tracings during operation is emphasized. The accurate identification of the site or sites of obstruction to pulmonary blood flow is essential to proper surgical management. A correctly selected operation must be carried out in as complete a manner as possible.

One of the significant contributions to the treatment of congenital heart disease has been the introduction of pulmonic valvotomy by Sellers1 and its extension by Brock,2 Blalock and Kieffer,3 Potts and associates4 and others. Nonetheless, certain problems remain in the surgical management of congenital pulmonic stenosis with intact ventricular septum.

The results of pulmonic valvotomy for the treatment of pulmonic stenosis with intact ventricular septum must depend upon two factors. First, they are related to the anatomic details of the pulmonic obstruction existing in a given case. Thus, if there is valvular pulmonic stenosis alone, one may anticipate a good result from a properly executed procedure. If on the contrary, there is some degree of obstruction produced by the configuration of the outflow tract of the right ventricle below the valve, there may be a less satisfactory result from the operation. Secondly, the extent of the opening which the operation produces in the stenotic pulmonic valve must directly influence the result of the procedure; that is, if the valve is incompletely opened, there may be a less satisfactory reduction in right ventricular pressure than if a complete opening of the valve is attained.

Unfortunately, in spite of the considerable literature now available upon this subject, it is somewhat difficult to obtain accurate information concerning the changes in right ventricular pressure which have been obtained by operation. The available literature on this matter, however, is summarized and discussed in conjunction with a discussion of the results in our group of cases. Furthermore, the anatomic details of the obstruction to pulmonary blood flow are not always clearly elucidated in the necropsy reports of the cases in the literature; however, these reports are reviewed and will be discussed in conjunction with a review of our own anatomic studies.

Anatomy of the Obstruction to Pulmonary Blood Flow

Pulmonic stenosis with intact ventricular septum may be the only anatomic defect present or it may be associated with an atrial septal defect or a patent foramen ovale.

There are basically three types of obstruction to pulmonary blood flow. The pathologic picture of pure valvular stenosis is strikingly constant. The pulmonic valves are fused and form a dome-shaped or conical diaphragm with a central aperture of variable size. In the second type, there is obstruction to pulmonary blood flow in the outflow tract or infundibulum of the right ventricle in the presence of a normal pulmonic valve. This obstruction may consist of a diffuse narrowing of the infundibulum or of a point of localized stenosis located in the

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outflow tract at either a high, intermediate or low position. A third type of obstruction may exist in which there is a combination of a stenotic valve and an infundibular stenosis.

The literature was reviewed in an attempt to tabulate the necropsied cases of pulmonic stenosis with intact ventricular septum with reference to the site and nature of the obstruction to pulmonary blood flow. Only cases in which adequate postmortem data were available were included. Detailed information, particularly relative to cases with infundibular stenosis, was frequently lacking. One hundred and thirty-seven cases with adequate data were found and are summarized in table 1. The infundibular stenosis was usually described as a narrowing of the outflow tract of the right ventricle or infundibulum, but in 11 cases, a localized stenotic area in the subpulmonic region was the only defect present.

To investigate further the nature of the obstruction to pulmonary blood flow in cases of pulmonic stenosis with intact ventricular septum, six hearts in our collection exhibiting this defect were re-examined (table 2). Of the six hearts available for examination, all showed marked pulmonic valvular stenosis, the pulmonic valve opening varying from 1.5 to 9 mm. in diameter. Infundibular stenosis without valvular stenosis was not encountered in this series.

Because our observations differ from published reports referred to above and because the anatomic features of the outflow tract may be of importance in the surgical management of these cases and the results to be expected, a

### Table 1.—Necropsied Cases of Pulmonic Stenosis With Intact Ventricular Septum (Review of Literature)

<table>
<thead>
<tr>
<th>Defect</th>
<th>Cases</th>
<th>Valvular stenosis</th>
<th>Infundibular stenosis</th>
<th>Valvular and infundibular stenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonic stenosis with patent foramen ovale</td>
<td>57 (42%)*</td>
<td>47 (83%)†</td>
<td>3 (5%)†</td>
<td>7 (12%)†</td>
</tr>
<tr>
<td>Pulmonic stenosis with intact atrial septum</td>
<td>80 (58%)*</td>
<td>55 (69%)‡</td>
<td>17 (21%)‡</td>
<td>8 (10%)‡</td>
</tr>
<tr>
<td>Total</td>
<td>137</td>
<td>102 (74%)*</td>
<td>20 (15%)*</td>
<td>15 (11%)*</td>
</tr>
</tbody>
</table>

* Per cent of 137. † Per cent of 57. ‡ Per cent of 80.

### Table 2.—Pulmonic Stenosis With Intact Ventricular Septum, Necropsy Series (Mayo Clinic)

<table>
<thead>
<tr>
<th>Age</th>
<th>Sex</th>
<th>Foramen ovale</th>
<th>Pulmonic valve orifice, mm.</th>
<th>Infundibulum</th>
<th>Cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mo</td>
<td>F</td>
<td>Probe-patent</td>
<td>3</td>
<td>Marked narrowing</td>
<td>Congestive failure</td>
</tr>
<tr>
<td>60 yr</td>
<td>F</td>
<td>Closed</td>
<td>7</td>
<td>No narrowing</td>
<td>Congestive failure</td>
</tr>
<tr>
<td>33 yr</td>
<td>M</td>
<td>Probe-patent</td>
<td>9</td>
<td>No narrowing</td>
<td>Carcinoma of kidney; Staphylococcus aureus septicaemia.</td>
</tr>
<tr>
<td>26 yr</td>
<td>M</td>
<td>Probe-patent</td>
<td>5</td>
<td>Marked narrowing</td>
<td>Cerebral abscess</td>
</tr>
<tr>
<td>3½ yr</td>
<td>F</td>
<td>Open; short valve of foramen ovale; perforation of valve</td>
<td>1.5</td>
<td>Slight narrowing</td>
<td>Postoperative</td>
</tr>
<tr>
<td>22 yr</td>
<td>M</td>
<td>Probe-patent</td>
<td>5</td>
<td>Marked narrowing</td>
<td>Postoperative</td>
</tr>
</tbody>
</table>
short discussion of the anatomic features of this area is warranted. In the right outflow tract of the normal heart there are two recognizable bundles of muscle which together form the shape of an inverted “V.” One bundle extends from under the pulmonic valve downward and to the right to join the anterior wall of the right ventricle and is frequently referred to as the crista supraventricularis. The other limb of the inverted “V” extends from under the pulmonic valve down along the ventricular septum. Chordae from the medial portion of the anterior tricuspid leaflet insert into this mass of muscle (fig. 1).

In the six hearts examined there was marked hypertrophy of the muscle of the right ventricle and particularly of the two bundles of muscle described in the preceding paragraph. In four of the six hearts, this hypertrophy was sufficient to produce significant narrowing of the outflow tract. This finding is in contrast to the scattered incomplete reports of infundibular stenosis in association with pulmonic valvular stenosis encountered in the literature. Undoubtedly, the attention of examiners is drawn primarily to the startling appearance of the pulmonic valve itself, and the anatomic features of the outflow tract are easily overlooked.

Two types of narrowing were seen in the four hearts exhibiting infundibular stenosis. One type is a diffuse narrowing of this region and is portrayed in figure 2 (case 6). Two hearts showed a definitely localized area of stenosis formed mainly by the two hypertrophied muscle bundles described previously. There was slight dilatation beyond the area of stenosis, the dilated portion being represented by the pulmonary valve inferior to the stenotic ostium in one case (fig. 3). Case 9 demonstrated a similar situation with the point of maximal stenosis occurring lower in the outflow tract, 2.3

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**Fig. 1.** Pulmonary valve and outflow portion of right ventricle in a normal heart. The anterior wall of the right ventricle has been incised parallel with the ventricular septum and deflected to the right (left side of illustration). From beneath the pulmonic valve two muscle bundles diverge, one of which (1) is the crista supraventricularis. The second (2) extends from the base of the pulmonic valve to the ventricular septum. In its inferior aspect this bundle continues to the anterior wall of the right ventricle as the moderator band. A set of chordae from the medial leaflet of the tricuspid valve insert into a specialized papillary muscle of the second bundle. This attachment is seen to left of the 2 in the illustration.

**Fig. 2.** Pulmonic stenosis with intact ventricular septum (case 6). Note the diffuse narrowing of the outflow tract in addition to the stenotic pulmonary valve.
cm. below the valve orifice (fig. 4). The infundibular stenosis encountered in the presence of valvular stenosis described previously may be considered as being due to the muscular hypertrophy associated with the valvular stenosis.

The surgical implications of these anatomic findings are significant. Division and dilatation of the stenotic valve in a case such as illustrated in figure 5, where the outflow tract is not narrowed, should produce a good physiologic result. On the other hand, where significant infundibular narrowing exists in association with valvular stenosis, simple division of the valve alone results in improvement, but right ventricular pressures may remain relatively elevated. In considering a further attack on the stenotic area in the infundibulum, the fact that the chordae from the medial portion of the anterior leaflet of the tricuspid valve cross the outflow tract and insert in the hypertrophied muscle bundle along the ventricular septum must be remembered. Injury to this structure could result in tricuspid insufficiency.

Fig. 3. Combination of valvular and infundibular stenosis. Note the localized area of stenosis in the outflow tract just inferior to the valve.

Fig. 4. Valvular and infundibular stenosis (case 9). A localized area of infundibular stenosis is present 2.3 cm. below the stenotic pulmonary valve.

Fig. 5. Pulmonic valvular stenosis. The outflow tract of the right ventricle is wide in this instance.

**Physiologic Demonstration of Variation in Sites of Obstruction**

Pulmonic stenosis can be diagnosed at cardiac catheterization by the demonstration of a high systolic pressure in the right ventricle and a low systolic pressure in the pulmonary artery.

Roentgenoscopic observation of the catheter tip, together with continuous monitoring of the pressure being transmitted through the catheter, enables one to localize the region in the cardiac shadow at which the change occurs from high right ventricular pressure to low pulmonary arterial pressure. Under ideal circumstances, one can determine whether this change occurs abruptly in the region of the pulmonic valve or whether it is first detected at a position in the outflow tract of the ventricle, some distance proximal to the valve.

If an abrupt change in systolic pressure can
be demonstrated with certainty to occur at the valve, it is an indication that a valvular type of stenosis exists (figs. 6 and 7). In cases of infundibular stenosis, it is frequently possible by careful manipulation of the catheter during its withdrawal from the pulmonary artery to detect an intermediate zone of pressure in the outflow tract of the right ventricle. This finding is characteristic of infundibular pulmonic stenosis (figs. 6 and 7).

FIG. 6. Schematic representation of different types of pulmonic stenosis and associated pressure recordings that might be obtained during slow withdrawal of tip of catheter through stenotic region. (A) Valvular stenosis; (B) infundibular stenosis with normal valve; (C) combined valvular and infundibular stenosis. The type of pressure recording theoretically expected on withdrawal of the catheter from pulmonary artery to right ventricle is seen under each diagram.

In figure 6, the three types of obstruction to pulmonary blood flow are diagrammed, together with the types of pressure tracing theoretically expected. In the upper diagram, the stenosis exists solely at the valve, and, on withdrawal of the catheter, an abrupt change from low systolic pulmonary arterial pressure to the typically high systolic ventricular pressure is obtained, no matter how slowly the withdrawal is carried out. In the middle diagram, the stenosis exists in the outflow tract of the right ventricle and the pulmonic valve itself is normal. Under such circumstances, when the catheter is withdrawn slowly from the pulmonary artery to the right ventricle, an intermediate zone of pressure may be detected in the region of the outflow tract of the ventricle. The intermediate zone is characterized by a low systolic pressure equal to pulmonary arterial systolic pressure and a low diastolic pressure equal to the right ventricular diastolic pressure in contrast to the higher diastolic pressure in the pulmonary trunk. In the lowermost diagram of figure 6, an obstruction is present in the outflow tract of the right ventricle, but, in addition, a valvular pulmonic stenosis is present. Under such circumstances,
a low pressure exists beyond the stenosed pulmonic valve and an intermediate zone of pressure exists in the infundibular region; however, under these conditions, the systolic pressure in the infundibular region will exceed that in the pulmonary artery. The actual pressure tracings from patients with these different types of stenosis are shown in figure 7.

**TYPES OF PULMONIC STENOSIS IN WHICH NO INTERMEDIATE PRESSURE ZONE MAY BE DETECTED AT CARDIAC CATHETERIZATION**

1. Isolated Valvular Stenosis

2. Valvular Stenosis with a mild degree of infundibular Stenosis

3. Normal Pulmonic valve, with localized infundibular Stenosis close to valve

![Schematic representation of different types of pulmonic stenosis.](image)

Fig. 8. Schematic representation of different types of pulmonic stenosis in which no intermediate pressure zone may be detected during slow withdrawal of the catheter tip from pulmonary artery to right ventricle. (1) Valvular stenosis; (2) valvular stenosis with a mild degree of infundibular stenosis; (3) normal pulmonic valve with localized infundibular stenosis close to valve.

If the degree of infundibular stenosis is not severe relative to the degree of stenosis existing at the valve, the pressure in the infundibular region may approach the right ventricular pressure in magnitude, and the presence of infundibular stenosis may not be recognized at catheterization (fig. 8).

**Surgical Considerations**

A. Identification of Site of Obstruction. The identification at the operating table of the type of obstruction present is unquestionably exceedingly important in the management of patients with pulmonic stenosis. The difficulty in recognizing accurately the nature of the obstruction is apparent from the disagreement that exists as to the incidence of valvular pulmonic stenosis in the tetralogy of Fallot; however, it is also to be stressed that by careful examination of the outflow tract of the right ventricle and of the pulmonary artery, a good appraisal of the nature of the obstructing lesion may be made.

Two criteria exist, of which the more important, in our opinion, is the location of the thrill which is always present in these cases. If the thrill originates precisely at the orifice of the pulmonic valve, valvular pulmonic stenosis very probably exists. The diagnosis of valvular pulmonic stenosis is made nearly certain by noting the presence of a palpable, domelike, stiff pulmonic valve. These two criteria, the presence and location of the thrill and the palpable valve, are most important in our opinion.

It has been said that the sinuses of Valsalva are absent in valvular pulmonic stenosis. This may be true, but we have, in well-verified cases of valvular stenosis, seen a slightly bluish, thin-walled, localized area in the base of the pulmonary artery which is indistinguishable from the appearance of a sinus of Valsalva. In most cases of valvular pulmonic stenosis there is poststenotic dilatation of the pulmonary trunk. This may be present, however, in cases of infundibular stenosis and is, therefore, not a satisfactory criterion for distinguishing between these two types of obstruction.

The typical thrill may in some cases be felt to originate proximally to the junction of the outflow tract of the right ventricle and the pulmonary trunk. In such a case, it is highly probable that the obstruction is in the outflow tract of the right ventricle either alone or in combination with valvular pulmonic stenosis.

Unfortunately, the presence of the criteria enumerated for the diagnosis of valvular pulmonic stenosis does not exclude the possibility of an associated obstruction in the outflow tract of the right ventricle. It is our opinion that knowledge concerning this secondary obstruction is important, and it is for this reason that we believe that pressure recordings during the operation are of extreme value to the surgeon treating this type of malformation. By such pressure tracings, one can identify the location of the primary obstruction and can identify a second obstruction if it is
present. By the same token, cases in which the more important site of the obstruction is in the outflow tract of the right ventricle may have an associated but less apparent valvular stenosis. In such instances, the gross criteria might lead one to the conclusion that only infundibular stenosis is present, whereas accurate pressure recordings during the operation would advise one of the associated presence of valvular stenosis.

In figure 9 is illustrated the type of tracing obtained during operation in a patient (case 10) with pulmonic stenosis and intact ventricular septum but with an atrial septal defect. This clinical diagnosis was confirmed at the time of cardiac catheterization, but no evidence of an infundibular stenosis was obtained. At operation, gross examination of the heart suggested the presence of infundibular stenosis, the typical dome of a stenotic pulmonic valve could not be felt, and the thrill began several centimeters proximal to the valve. With the more exact control of the catheter tip possible when the cardiac catheter was introduced directly into the right ventricle during operation, it was apparent from the pressure recording obtained during withdrawal of the catheter from the pulmonary trunk that the stenosis was a combined valvular and infundibular type.

In figure 10 are shown further recordings during operation in two patients (cases 8 and 9) with valvular and infundibular stenosis, one of whom had intact septa whereas the other had an atrial septal defect. In both, the diagnosis at operation, on the basis of examining the heart, was pulmonic valvular stenosis. In each of these patients prior to the incision and dilatation of the stenosed valve, the pressure recorded in the infundibular region approached closely that recorded in the low right ventricle. This finding indicated that the stenosis in the infundibular region was relatively mild compared with that existing at the valve. After incision and dilatation of the stenosed valve in each of these cases, a relative increase in the stenosis in the outflow tract was apparent as seen by the marked fall in pressure in the infundibular region while the right ventricular pressure was not reduced to the same degree.

B. Execution of a Complete Operation. In this, as in all operative undertakings, it is important that the maximal improvement in the anatomic defect be attained by the operative procedure. This means that in cases of valvular pulmonic stenosis a vigorous attack must be made upon the stenotic pulmonic valve and that this attack must be continued until a very adequate opening is obtained. A complete opening may be obtained without the aid of pressure recordings during operation, providing the surgeon is diligent and persistent in his maneuvers; however, it has been of great assistance to us to have pressure recordings available during the operation.

Figure 11 illustrates continuous pressure recordings taken during operation in case 7 and shows the effect of successive incision and dilatations of the stenosed pulmonic valve. After the first incision and dilatation, which was thought to be adequate, a significant reduction in right ventricular pressure was achieved; however, since this was not of the degree desired, further dilatations of the valve were performed. After each dilatation, a further fall in pressure resulted and a more satisfactory end result was achieved than would have been the case had one been content with
the initial, apparently satisfactory, incision and dilatation of the valve.

C. Representative Surgical Results. Figures 12 and 13 show the type of operative results, stenosis (case 6) and atrial septal defect with an associated marked degree of peripheral arterial desaturation at rest. During the operation, recordings were made of both the right

![Graph](image)

**Fig. 10.** Recordings obtained at operation in two patients with combined valvular and infundibular stenosis (a, case 8; b, case 9). Patient 9 had, in addition, an atrial septal defect. In each instance pressure in the cavity of the right ventricle was recorded by means of a catheter inserted through a needle placed into the lower part of the ventricle. Recordings in the outflow tract of the ventricle were made by means of a catheter inserted through the operative incision. Note that in each instance the systolic pressures in the infundibular region and right ventricle proper differ by about 40 mm. Hg before valvotomy. In each case, however, after incision and dilatation of the valve, the initial rise in pressure when the catheter tip is drawn through the valve is much less than before, indicating a marked degree of relief of the valvular stenosis. On the other hand, only a moderate decrease in the right ventricular pressure is evident in each, indicating that a gross degree of subvalvular stenosis still persists.

as detected by pressure studies during operation, which can be achieved when relief of the stenosis has been almost complete. Figure 12 illustrates such findings in a child with valvular ventricular pressure and the peripheral arterial oxygen saturation. Three minutes after the incision of the stenosed valve and two minutes after its dilatation, the peripheral arterial
oxygen saturation had increased from 49 to 86 per cent. After operation, the right ventricular systolic pressure had decreased to 45 mm. Hg from its preoperative level of 150 mm. Hg. A very satisfactory relief of the pulmonic stenosis was achieved, as demonstrated by the pressure studies during operation and on examination of the operative result on the valve.

at necropsy. It was a bitter disappointment that this patient died of bilateral bronchopneumonia in the postoperative period.

Figure 13 shows a similar degree of surgical relief of the valvular stenosis (case 12). Preoperatively, it was felt that the stenosis resided mainly in the valve, although a relatively mild degree of subvalvular stenosis was suspected by reason of the recording of a slightly lower pressure in the immediate subvalvular region than was present in the right ventricle proper. This suspicion was confirmed at operation by the presence of an intermediate zone of pressure of 180 mm. Hg systolic for a distance of not more than 5 mm. proximal to the stenosed valve compared with the right ventricular pressure of 250 mm. Hg. Valvotomy and dilatations of the valve ring were followed by an immediate reduction of right ventricular systolic pressure from 250 mm. Hg to 70 mm. Hg. The intermediate zone of pressure, still measurable over the same very short distance

![Diagram](http://circ.ahajournals.org/)

**Fig. 11 (case 7).** Effects of incision and successive dilatations of the pulmonic valve on right ventricular pressure in a patient who had pulmonic stenosis without septal defect. In each panel the upper tracing is the electrocardiogram (lead II) and the lower tracing is the right ventricular pressure. The first and last panels show, with a paper speed of 25 mm. per second, the initial and final right ventricular pressures, respectively. The second, third and fourth panels, recorded with paper speeds of 10, 5 and 5 mm. per second, respectively, are continuous tracings of right ventricular pressures during incision and successive dilatations of the valve. Note the irregularities and artefact in the electrocardiogram during dilatations of the valve and the abrupt decrease in right ventricular pressure after this procedure.

of less than 5 mm., decreased from 180 to 50 mm. Hg while the pulmonary artery pressure increased from 18/10 to 25/15 mm. Hg.

It has been found that pressures recorded from the right ventricle during operation do not always correspond to those found at preoperative and postoperative cardiac catheterization. In many instances, probably due to increase in cardiac output during operation, the right ventricular systolic pressure recorded during operation was as much as 50 per cent greater than the resting value obtained at preoperative cardiac catheterization. Nevertheless, such pressure recordings during opera-
tion do give a good immediate index of the degree of relief of the stenosis which has been produced by the surgical procedure.

D. Problems in Surgical Management. In some instances, valvotomy may not give a good result in cases with coexisting valvular and infundibular obstruction. In such patients with combined valvular and infundibular types of stenosis, the magnitude of the abrupt pressure change at the pulmonic valve gives some measure of the degree of valvular stenosis, while the height of the right ventricular pressure gives a measure of the total stenosis.

In case 9, the right ventricular pressure recorded at operation, before valvotomy, was 254/15 while the pressure recorded immediately below the pulmonic valve was 220/15. After valvotomy, the right ventricular pressure was still very high, 200/15, but the height of the pressure recorded on withdrawal of the catheter through the valve was 50/15 mm. Hg. These findings suggested that an adequate valvotomy had been performed but that a marked degree of subvalvular stenosis still persisted. Because of this severe residual stenosis, the patient died 18 hours postoperatively. Examination of his heart at necropsy, as described earlier, showed that an adequate valvotomy had been done but that a severe degree of subvalvular stenosis persisted, causing the maintained elevation of right ventricular pressure after valvotomy.

![Figure 13](case 12). Changes in pulmonary arterial and right ventricular pressures following incision and dilatation of stenosed pulmonic valve. The electrocardiogram, radial arterial, and catheter pressure recorded during withdrawal of the catheter tip from the pulmonary artery to the right ventricle before incision and dilatation of the valve are shown in the upper panel; similar recordings after valvotomy are shown in the lower panel. As a result of valvotomy an appreciable decrease in right ventricular pressure from 248/8 to 72/5 mm. Hg was obtained, although some degree of valvular pulmonic stenosis remains. Note the intermediate zone of pressure which was demonstrated in the subvalvular region by the slow and controllable withdrawal of the catheter tip which was possible during operation. This intermediate pressure zone was detectable only over a distance of less than 5 mm., between the sites at which typical pulmonary arterial and right ventricular pressures, respectively, were recorded.

It is interesting to compare here the findings in case 10, in which there was also a combined valvular and infundibular stenosis. It was appreciated at operation that a considerable degree of subvalvular stenosis persisted following valvotomy, but it was felt that some benefit should follow the valvotomy. Cardiac catheterization six months postoperatively showed that a considerable fall in right ventricular pressure had taken place in spite of the persistence of the subvalvular stenosis after operation.

We have previously reported a case 69, case 5
in which pulmonic valvotomy was done for what was assumed to be pure valvular pulmonic stenosis with intact ventricular septum and without an atrial septal defect. An unsatisfactory result was obtained and reoperation was effected. At the time of the second operation, it was recognized with the aid of pressure studies that the obstruction was now primarily in the outflow tract of the right ventricle. A type of plastic procedure was done upon this obstructing area with improvement as judged both by clinical evidence and by an increase in cardiac output. Thus, on some occasions in patients with pulmonic stenosis and intact ventricular septum some procedure other than the routine valvotomy must be considered.

Results of Operation

There were two fatalities in this group of 12 cases. One was in the case outlined in an earlier paragraph in which the pulmonic stenosis was of such a type that we were unsuccessful in relieving it (case 9). This patient died without doubt because of unrelieved pulmonic stenosis. The second fatality occurred, as noted, because of bilateral bronchopneumonia (case 6).

All of the 10 patients in the group surviving the operation reported subjectively that they were “much improved.” A similar result is reported by most authors in the literature. It is our belief, however, that the interpretation of such subjective results is fraught with many difficulties and that we must in this condition turn to more objective measurements.

Studies of such a nature have been reported in occasional cases, and a fall in right ventricular pressure, a rise in pulmonary arterial pressure and a rise in arterial oxygen saturation have been noted after valvotomy. The most thorough and informative physiologic study was that recently published by Soulié and associates concerned with nine cases. Right ventricular pressures fell rapidly in the immediate postoperative period and more slowly thereafter. The fall was more marked in individuals whose initial right ventricular pressure was greater than 150 mm. Hg than it was in those with initial pressures of 100 mm. Hg or less. These authors emphasized the fact that normal pressure values are not usually attained. They postulated that certain inherent factors in the congenital defect, particularly right ventricular hypertrophy with narrowing of the outflow tract, might continue to act as an obstruction to pulmonary blood flow postoperatively and explain the results observed.

The physiologic data obtained in our cases are presented in order that we may discuss the results of the operation in our group (tables 3, 4 and 5).

The ultimate benefit resulting from operation on patients with pulmonic stenosis can be judged best by postoperative cardiac catheterization. The immediate findings at operation are extremely valuable, but the results are, as noted previously, not strictly comparable with those observed at preoperative and post-

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Table 3.—Pressure Studies During Operation*

<table>
<thead>
<tr>
<th>Case</th>
<th>Pressure, mm. Hg, before valvotomy</th>
<th>Pressure, mm. Hg, after incision and dilatation of valve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pulmonary artery</td>
<td>Infundibular region</td>
</tr>
<tr>
<td>4</td>
<td>23/14</td>
<td>93/8</td>
</tr>
<tr>
<td>5</td>
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</tr>
<tr>
<td>11</td>
<td>15/18</td>
<td>50/5</td>
</tr>
<tr>
<td>12</td>
<td>18/10</td>
<td>108/10</td>
</tr>
</tbody>
</table>

* Such studies were not done in cases 1, 2 and 3.
operative cardiac catheterization in the unanesthetized patient.

There is no doubt that the best results can be achieved in patients with valvular stenosis as an isolated lesion. This can be understood by a study of the findings at operation in cases 6, 7 and 12 and from the preoperative and postoperative catheterization data in case 1.

A considerable degree of diminution in right ventricular pressure on occasions can be obtained after an adequate valvotomy in patients who have a combined valvular and infundibular stenosis. Further detailed studies over a prolonged period are necessary before one can determine whether subvalvular hypertrophy of the ventricular musculature diminishes following valvotomy in such patients. However, it does appear as if the right ventricular pressure after valvotomy decreases progressively for a prolonged period as is seen in case 10.

The present series includes only two patients who had infundibular stenosis as an isolated lesion (cases 3 and 4). No dramatic diminution in right ventricular pressure followed dilatations of the infundibular stenosis but, in each instance, a moderate fall in right ventricular pressure followed operation. In case 3, a further fall in right ventricular pressure was found at cardiac catheterization 10 months after operation.

The studies on patient 11 are incomplete and evaluation of the effect of valvotomy must await postoperative cardiac catheterization.

Patient 2 was one of the first patients who

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<table>
<thead>
<tr>
<th>Case</th>
<th>Diagnosis</th>
<th>Preoperative</th>
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<tbody>
<tr>
<td></td>
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<td>Pulmonary artery</td>
<td>Infundibular region</td>
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<tr>
<td>1</td>
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<td>Valvular stenosis</td>
<td>15/10</td>
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<td>3</td>
<td>Infundibular stenosis</td>
<td>20/12</td>
</tr>
<tr>
<td>7</td>
<td>Valvular stenosis</td>
<td>12/8</td>
</tr>
<tr>
<td>10</td>
<td>Combined valvular and infundibular stenosis</td>
<td>20/10</td>
</tr>
<tr>
<td>11</td>
<td>Combined valvular and infundibular stenosis and atrial septal defect</td>
<td>159/9</td>
</tr>
<tr>
<td>12</td>
<td>Combined valvular and infundibular stenosis and atrial septal defect</td>
<td>19/9</td>
</tr>
</tbody>
</table>

* Relative right ventricular outflow resistance = Systolic pressure gradient, mm. Hg
Pulmonary blood flow, L/min.

† Reported in detail elsewhere.40
‡ Paroxysmal auricular tachycardia developed during preoperative and postoperative cardiac catheterization.
§ Cardiac catheterization carried out at another institution, data made available.
underwent operation for pulmonic stenosis. Such a patient would not be operated on now but would be observed at intervals during adolescence. In general, it is now our practice not to operate on asymptomatic patients whose right ventricular systolic pressure is less than 70 to 75 mm. Hg.

For adequate interpretation of preoperative and postoperative pressure recordings at cardiac catheterization, details of flow should also be obtained so that the resistance to flow through the valve can be estimated. Comparative cardiac outputs are not always obtained under similar circumstances since the patient may be more apprehensive at the time of one cardiac catheterization than at another time of catheterization. Determination of right ventricular pressure and cardiac output following a period of exercise probably gives a better comparison of preoperative and postoperative values. As far as pulmonary artery and right ventricular pressures are concerned, pulmonary flow is the important variable, not systemic output. A "relative right ventricular outflow resistance" value has been included in tables 4 and 5. This value was obtained by dividing the systolic pressure gradient between right ventricle and pulmonary artery by the pulmonary artery flow (in liters per minute).
Summary

1. The three types of anatomic obstruction to blood flow from the right ventricle to the pulmonary artery in patients with pulmonic stenosis and intact ventricular septum are discussed. Valvular stenosis in such cases may occur either alone or in combination with varying degrees of infundibular stenosis. Uncommonly, the latter may occur alone.

2. Physiologic data, gathered from patients with pulmonic stenosis and intact ventricular septum, are detailed. These again demonstrate that, in certain cases, valvular pulmonic stenosis is associated with some degree of infundibular stenosis.

3. Criteria for the differentiation at operation of valvular and infundibular pulmonic stenosis are enumerated.

4. The usefulness of accurate pressure tracings during operation is emphasized.

5. The accurate identification of the site or sites of obstruction to pulmonary blood flow is essential to proper surgical management. A correctly selected operation must be carried out in as complete a manner as possible.

6. Subjective and physiologic data are analyzed in the 12 cases reported.

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SUMARIO ESPAÑOL

Obstrucción a la circulación pulmonar puede ocurrir en la válvula pulmonar, en el infundíbulo o en ambos. Cateterismo cardíaco ayuda a determinar el sitio de la obstrucción. El criterio para la diferenciación durante la operación entre estenosis infundibular o valvular se enumera y el uso de trazados exactos de la presión durante la operación se recalca. La identificación exacta del sitio o sitios de obstrucción a la circulación pulmonar es esencial para el manejo quirúrgico apropiado. Una operación correctamente seleccionada se debe conducir en la manera más completa posible.

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Problems in the Diagnosis and Surgical Treatment of Pulmonic Stenosis with Intact Ventricular Septum
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