Late Hemodynamic Response to Correction of
Isolated Pulmonary Stenosis by Open Operation
during Pulmonary Bypass

By C. Walton Lillehei, Ph.D., M.D., Robert L. Simmons, M.D.,
and David B. Todd, M.D.

SURGICAL treatment of pulmonary stenosis has advanced to the point where a choice
of several operative technics is available. This study constitutes a comparative
review of the late recatheterization results in the open versus closed method of pulmonary
valvuloplasty.

Doyen reported an unsuccessful attempt to relieve pulmonary stenosis by transventricular
valvulotomy in 1913.1 In 1948, Sellors reported a successful transventricular valvulotomy;2 and
Brock reported three successful cases of pulmonary valvulotomy.3 The transventricular
valvulotomy, commonly called the Brock procedure, has been used extensively. Varco in-
roduced pulmonary valvulotomy under direct vision by a transarterial approach, inflow oc-
clusion, and normothermia.4 Swan, combining hypothermia and inflow occlusion,5 increased
the length of time available in correcting valvular stenosis by direct vision. With total
cardiopulmonary bypass, anatomically precise valvulotomy, deliberate infundibular resection
when necessary, and repair of associated defects can be done.

There are several reports of disappointing results following closed procedures for pul-
monary stenosis because of failure to relieve the obstruction.5-11 In 1956 we reported the
preoperative and postoperative right ventricu-
lar systolic pressures in 20 patients who had
closed valvulotomy for pulmonary stenosis.9
The purpose of this study is to compare the
results in our previous report with 25 patients
all of whom have been catheterized post-
operatively and who have had correction of
pulmonary stenosis by open technics with car-
diopulmonary bypass.

Materials and Methods

Twenty-five consecutive patients have had follow-up catheterizations after surgical treatment
for pulmonary stenosis by the open technic. Their
anatomic types are listed in table 1. The ventricu-
lar septum was intact in all of these patients.

The age ranged from 4 to 39 years at the
time of surgery, the diagnoses, valvular, infundib-
ular, or combined stenosis are postoperative.
Resection of significantly hypertrophied infundib-
ular areas was done in all cases designated as
having infundibular stenosis; two patients re-
quired an outflow patch. A tight fibromuscular
ring was present in the two patients with isolated
infundibular stenosis.

Only three of the patients had repair of the
atrial septal defects, the remainder of those
designated as atrial septal defect were probe-
patent foramen ovale defects. Postoperative
cardiac catheterization was done at varying in-
tervals from 9 to 36 months. The average period
between surgery and follow-up catheterization

<table>
<thead>
<tr>
<th>Site of obstruction</th>
<th>No. patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valvar</td>
<td>11</td>
</tr>
<tr>
<td>Valvar with atrial septal defect</td>
<td>5</td>
</tr>
<tr>
<td>Combined valvar and infundibular</td>
<td>4</td>
</tr>
<tr>
<td>with atrial septal defect</td>
<td></td>
</tr>
<tr>
<td>Combined valvar and infundibular</td>
<td>3</td>
</tr>
<tr>
<td>Pure infundibular</td>
<td>2</td>
</tr>
</tbody>
</table>

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was 13 months. Right ventricular pressures and pulmonary artery pressures were recorded. With the exception of four patients, right ventricular pressures were also taken in the operating room after repair of the stenosis. History, physical examination, electrocardiography, and cardiac fluoroscopy were also obtained.

Results

There was clinical improvement in all of the patients. Those who were symptomatic preoperatively demonstrated an increased exercise tolerance and less fatigue at the time of follow-up. None of the patients had symptoms related to cardiac decompensation. Five of the patients who had a distinctly palpable thrill preoperatively had a notable decrease in its intensity. There was a lessening in the intensity of systolic murmur in all of the patients. Two patients developed an early diastolic murmur over the left sternal border, which was consistent with pulmonary valve incompetence. These two patients were asymptomatic and right ventricular systolic pressures were 30 and 38 mm. Hg, with a diastolic range from 0 to + 4 mm. Hg.

Changes in heart size and pulmonary vascularity as determined by roentgenography were not striking. Eighteen of the patients showed a decrease in the amplitude of the R wave in V1. The level of the right ventricular systolic pressure correlated quite well with these R-wave changes.

The right ventricular systolic pressure showed a significant decrease in all of the patients. Consistent with the experience of others,12 the right ventricular systolic pressure taken in the late postoperative period showed significant reductions from the readings in the operating room. In addition, three of the patients did not have a satisfactory reduction in the right ventricular pressure at the time of operation but later had significantly lower pressures (fig. 1). The average right ventricular systolic pressure before operation in the group done by open technic (table 2) was 124 mm. Hg, following surgery the

Table 2

<table>
<thead>
<tr>
<th></th>
<th>Average, mm. Hg</th>
<th>Average decrease mm. Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed operation (20 patients)* (Previous report†)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>56</td>
<td>60</td>
</tr>
<tr>
<td>Open operation (25 patients)†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>35</td>
<td>89</td>
</tr>
</tbody>
</table>

*Five patients showed no postoperative pressure fall. †All patients showed postoperative pressure fall.

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

**Figure 1**

Correction of pulmonary stenosis by open operation.

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average value was 35 mm. Hg, a mean decrease of 89 mm. Hg. In a previously studied 20 patients who had Brock-type closed valvulotomy, the average decrease in the right ventricular systolic pressure was 60 mm. Hg. Five of the patients with closed transventricular valvulotomy did not have a decrease in the pulmonary valve gradient, but all of those done by the open technic had a favorable change in their right ventricular pressures.

**Discussion**

These studies indicate that the open operation under direct vision has given significantly superior physiologic results when compared to closed or blind transventricular valvulotomy. Moreover, the direct vision operation makes it possible to open the stenotic valve with incisions precisely placed in the anatomic commissures when these are present, as they often are. A greatly lessened incidence of pulmonary valvular incompetence is thereby achieved when comparison is made with patients having closed or blind transventricular procedures. All of these open operations were done with use of the pump oxygenator.

Open pulmonary valvulotomies can readily be done under inflow stasis without bypass. We have had considerable experience with this technic in the past, but have abandoned it in favor of the open operation with bypass for several important reasons. The one exception to the above statement is emergency or urgent valvulotomies in newborn or neonatal infants with pulmonary atresia or severe stenosis where palliation rather than cure is the immediate goal.

The open bypass operation will yield a lower mortality and a higher percentage of postoperatively hemodynamically normal or near normal patients. Whereas perfection in the preoperative diagnosis is the goal of all, it obviously cannot be reached in all cases. The open bypass approach allows the surgeon to ascertain and deal with these unanticipated findings safely and definitively. Moreover, even in the uncomplicated case operation under inflow stasis at normothermia or moderate hypothermia places such a premium on these few minutes (4 to 5 minutes maximum) that the need to hurry may result in less adequate valvuloplasties with the added risk that a technical misadventure such as a tear in the pulmonary artery may result in death from hemorrhage. Lastly, the use of disposable pump oxygen-

![Figure 2](image)

*R.K., No. 920178. Valvular stenosis without infundibular obstruction. The infundibulum relaxes very well in diastole. There is classical poststenotic dilatation of the main pulmonary artery. Transarterial valvulotomy on total cardiopulmonary bypass was successfully performed.*

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ators\textsuperscript{14–16} and a non-blood prime\textsuperscript{17–19} adds little if any complexity to the bypass operation. There is little doubt that the delayed progressive decrease in right ventricular systolic pressure which follows successful valvulotomy is the result of a regression of secondary infundibular hypertrophy. However, true organic infundibular obstruction may coexist with valvular stenosis; in these patients it is essential to resect the infundibular obstruction as well as to carry out valvuloplasty. Moreover, with the more severe degrees of combined

![Figure 3](image1)

\textit{Figure 3}

J.T., No. 941009. Interpretation was calcular stenosis with normal infundibulum, note the relaxation in diastole (center). However, at operation the infundibulum appeared to show considerable tubular narrowing about 3 cm. long and therefore both calcularotomy and infundibular resection were done. Preoperative R.V. pressures: high 84/3, low 90/6. Postoperative R.V. pressure at recatheterization was 29/9. This type of infundibular hypertrophy was definitely secondary to calcular stenosis, and calcularotomy alone might have been adequate.

![Figure 4](image2)

\textit{Figure 4}

S.S., No. 901490. Combined calcular and organic infundibular stenosis. The constricted infundibulum remains rigid throughout the cardiac cycle. Note the constant nature of the large filling defect in the right ventricular outflow tract (representing severe organic infundibular obstruction) during both systole and diastole. Preoperative pressure in the R.V. was 215/15, the postoperative recatheterization pressure in the R.V. was 45/25. An outflow roof was also required. Valculotomy without infundibular resection in this situation would likely be lethal.
valvular stenosis and infundibular hypertrophy it is essential to resect the infundibular element at the same time as valvuloplasty or the patient may not survive the immediate postoperative period. Early in our experience, two patients were encountered with right ventricular pressures above 200 mm. Hg. Valvulotomy without infundibular resection resulted in no fall in the right ventricular pressures recorded in the operating room, and both patients succumbed in the immediate postoperative period due to right heart failure with low cardiac output.

We have found preoperative selective right ventriculography to be essential in determining whether infundibular resection will be necessary (figs. 2 to 6), since it has proved considerably more accurate than observations made at operation, even when the heart was open. Any patient with questionable evidence supporting the diagnosis of infundibular obstruction, should be operated upon with cardiopulmonary bypass. Careful evaluation of preoperative angiocardiograms and the pressure determinations will usually provide adequate criteria for indicating preoperatively which patients need ventriculotomy and infundibular resection, but not invariably (fig. 3).

From the fatal result in the two patients with markedly elevated pressures that did not recede some immediately after valvulotomy, we have learned that if the preoperative level is above 140 to 150 mm. Hg, one should have an immediate significant drop (at least 1/3 to 1/2 reduction) in right ventricular systolic pressure on the operating table. If valvulotomy alone does not accomplish this goal, then infundibular resection with or without an outflow patch is necessary. This modus operandi has reduced operative risk to under 1 per cent.

Summary

A group of 25 patients was studied by cardiac catheterization before and after open operation for isolated pulmonary stenosis by direct vision with use of cardiopulmonary bypass. Organic infundibular obstruction, when present, was resected. The hypertrophied infundibulum, when it constitutes a severe obstruction, must also be resected. The average right ventricular systolic pressure preoperatively was 124 mm. Hg and postoperatively it was 35 mm. Hg.

The average gradient across the pulmonary valve preoperatively was 99 mm. Hg and postoperatively it was 17 mm. Hg, a mean decrease of 82 mm. Hg.

Figure 5

N.C., No. 992609. Severe isolated infundibular stenosis 4 to 5 cm. below a normal pulmonary valve. A 4-mm. diameter orifice was increased to 2 cm. by muscular resection together with an outflow roof of Teflon (17918) for reconstruction. The lateral views did not show the area of obstruction as well as the posteroanterior shown here. Preoperative R.V. pressure was 200/0 and dropped to 35/5 in the operating room immediately after correction.
The long-term hemodynamic response was distinctly superior in this group of patients operated upon under total bypass when compared with a similar series operated upon by us with a closed transventricular approach.

The specific diagnosis of lesions causing obstruction to the outflow of the right ventricle is particularly crucial in selecting an operative approach if open operation by inflow stasis is utilized.

Careful review of the selective right ventriculograms is an excellent preoperative guide in determining whether infundibular obstruction is present and hemodynamically significant.

Patients having severe valvular stenosis, with right ventricular pressures above 140 to 150 mm. Hg should have an immediate one-third to one-half decrease in their right ventricular systolic pressures at the time of surgery, or infundibular resection should be done to reduce postoperative mortality.

References


The Pulmonary Circulation. Michael Servetus—1511-1553

"... It is not said that the divine spirit is principally in the walls of the heart, or in the body of the brain or of the liver, but in the blood, as is taught by God Himself in Gen. 9, Levit. 8, Deut. 12.

"In this matter there must first be understood the substantial generation of the vital spirit which is composed of a very subtle blood nourished by the inspired air. The vital spirit had its origin in the left ventricle of the heart, and the lungs assist greatly in its generation. It is a rarefied spirit, elaborated by the force of heat, reddish-yellow (flavo) and of fiery potency, so that it is a kind of clear vapor from very pure blood, containing in itself the substance of water, air, and fire. It is generated in the lungs from a mixture of inspired air with elaborated, subtle blood which the right ventricle of the heart communicates to the left. However, this communication is made not through the middle wall of the heart, as is commonly believed, but by a very ingenious arrangement the subtle blood is urged forward by a long course through the lungs; it is elaborated by the lungs, becomes reddish-yellow and is poured from the pulmonary artery into the pulmonary vein. Then in the pulmonary vein it is mixed with inspired air and through expiration it is cleaned of its sooty vapors. Thus finally the whole mixture, suitably prepared for the production of the vital spirit, is drawn onward to the left ventricle of the heart by diastole."—André Courtand, M.D. Circulation of the Blood. Edited by Alfred P. Fishman, M.D., and Dickinson W. Richards, M.D. New York, Oxford University Press, 1964, pp. 21 and 22.
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