Transatrial Resection of the Obstructed Right Ventricular Infundibulum

L. Henry Edmunds, Jr., M.D., Naresh C. Saxena, M.B.B.S., Sidney Friedman, M.D., William J. Rashkind, M.D., and Paul F. Dodd, M.D.

SUMMARY Obstructions of the right ventricular infundibulum were resected through the orifice of the tricuspid valve in 21 patients, 15 of whom had tetralogy of Fallot. At operation the systolic pressure difference between the right ventricle and pulmonary artery after repair averaged 18 mm Hg (range 0–40 mm Hg). In patients with tetralogy, cardiac index four hours after operation averaged 2.8 L/M²/min. One patient with tetralogy and severe pulmonary hypertension died. Twelve patients with tetralogy were recatheterized 10 to 186 days after operation. The mean systolic pressure difference between right ventricle and pulmonary artery was 23 mm Hg. Residual obstructions were in the pulmonary valvular annulus. Cineangiograms did not show paradoxical motion of the right ventricular wall. Transatrial resection of right ventricular infundibular obstructions carries with it none of the consequences that often follow right ventriculotomy and this surgical approach satisfactorily relieves infundibular obstructions.

A TRANSVERSE OR VERTICAL INCISION in the right ventricle is generally used to resect muscular or fibrous obstruction of the infundibulum.1, 2 An incision in the right ventricle reduces myocardial contractility,3, 4 may be associated with complete right bundle branch block,5 and causes necrosis of adjacent myocardium.6, 7 In a few patients a major coronary arterial branch may be transected8 or the right ventricular free wall may develop akinesis9 or become aneurysmal.10–12 An especially long ventriculotomy,4 the addition of an outflow patch,13 or creation of pulmonary insufficiency further impairs right ventricular performance after surgical correction of infundibular fibromuscular obstructions.

This report describes our experience with a technique for resecting infundibular obstructions through a right atriotomy and the orifice of the tricuspid valve. The technique is an extension of methods developed for transatrial closure of high ventricular septal defects.3, 14 Our initial experience with 21 patients, 15 of whom had tetralogy of Fallot, is reported.

Operative Technique

The operation is performed through a median sternotomy using conventional cardiopulmonary bypass, hemodilution, and hypothermia to 28–30°C. The right atrium is incised and the left ventricle is vented through the fossa ovalis or right superior pulmonary vein if a ventricular septal defect is present. The pulmonary valve is exposed through a longitudinal arteriotomy and the valvular obstruction is relieved.

The anterior leaflet of the tricuspid valve is retracted cephalad and anteriorly. Chordae attached to the papillary muscle of the conus are retracted caudally. An incision is made in the crista supraventricularis parallel to the plane of the ventricular septum. This incision is carried laterally toward the aortic annulus and anteriorly beneath the retracted anterior leaflet of the tricuspid valve into the endocardium of the free right ventricular wall. With scissors, the surgeon establishes a plane of dissection between the fibromuscular obstructing tissue and the aorta and free right ventricular wall. Fingers of the left hand partially invaginate the anterior-right lateral portion of the right ventricular infundibulum as the dissection proceeds cephalad to the pulmonary annulus. The free right ventricular wall is left approximately 4–7 mm thick.

Hypertrophied septal bands are resected similarly. The left lateral portion of the crista supraventricularis is incised in the plane of the ventricular septum. This incision is extended caudally and laterally to the base of the anterior papillary muscle of the tricuspid valve. The incision then curves anteriorly into the endocardium of the free right ventricular wall. A plane of dissection is established with

25. Carrel
26. Bailey CP, Glover pulmonary insufficiency 'the addition of
stenosis based on two cases. Thorax 17: 154, 1962
25. Carrel A: On the experimental surgery of the thoracic aorta and the
26. Bailey CP, Glover RP, O'Neill TJE, Redondo Ramirez HP: Experiences
with the experimental surgical relief of aortic stenosis: a preliminary
scissors and extended cephalad, laterally and anteriorly toward the pulmonary annulus. Fingers of the left hand invaginate the free right ventricular wall. The dissection is never carried deep to the plane of the ventricular septum. As the dissection proceeds cephalad, the pulmonary valvular annulus is invaginated into view and fibromuscular tissue at the valvular annulus is incised or excised from below.

After completing the infundibular resection, Hegar dilators are inserted from below to size the pulmonary annulus. If the annulus is inadequate (less than 0.5 of aortic diameter) the pulmonary arteriotomy is extended a short distance across the annulus into the right ventricular infundibulum and a patch is inserted. The ventricular septal defect is closed transatrially with a dacron patch. After bypass is stopped, pressures in the body of the right ventricle and main pulmonary artery are measured through an 18 gauge needle.

Clinical Experience

Between January and September, 1975, 21 patients were treated by transatrial resection of infundibular pulmonary stenosis. Fifteen patients had tetralogy of Fallot, four had valvar and infundibular pulmonary stenosis with an intact ventricular septum, and two had infundibular pulmonary stenosis with ventricular septal defects.

Tetralogy of Fallot

Ages of these patients ranged between three and 18 years and body weight ranged between 12.7 and 48 kg (fig. 1). All had cyanosis and exercise intolerance. Five patients had had no previous shunt operations, two had aortic-right pulmonary arterial (Waterston) anastomoses and eight had either left or right subclavian-pulmonary arterial (Bialock-Taussig) anastomoses. One patient had anomalous origin of the left anterior descending coronary artery (patient 8, table 1). All had preoperative cardiac catheterizations (table 1). The diameter of the main pulmonary artery exceeded 0.5 of the aortic diameter in all except two patients.

Mean time spent on cardiopulmonary bypass was 107 min. However, bypass averaged 114 min for the first five patients and 94 min for the last five.

The pulmonary artery was opened in all except three patients. A pericardial patch was placed across the pulmonary annulus and extended 0.5 cm and 1.5 cm into the free right ventricular wall in two patients.

The mean peak systolic pressure difference between the right ventricular body and main pulmonary artery measured during operation averaged 20 mm Hg after repair (fig. 2). The ratio of peak right ventricular to systemic arterial systolic pressures ranged between 0.22 to 0.85 (mean 0.48).

One of the 15 patients died. This four-year-old girl had had a Waterston anastomosis ten months previously. Three months before open heart surgery, episodic cyanotic spells returned and her continuous murmur disappeared. At catheterization, two months before operation, the Waterston anastomosis was functioning without obstruction to either pulmonary artery. Aortic saturation was 83%, left pulmonary arterial pressure was 100/70, and peak pulmonary arterial pressure was 0.9 of peak ventricular and aortic systolic pressures. The ratio of pulmonary to systemic resistance was estimated to be 0.6 to 0.8. However, since the Waterston anastomosis had been present only a short time, operation was undertaken in spite of the high risk.18 She died

![Figure 1](http://circ.ahajournals.org/) Age (A) and weight (B) ranges of patients with tetralogy of Fallot. Horizontal bars indicate means.

![Figure 2](http://circ.ahajournals.org/) Peak systolic right ventricular pressure minus pulmonary arterial systolic pressure before operation (pre-op), after repair of tetralogy of Fallot at operation and postoperatively (post-op).
Table 1. Hemodynamic Measurements before, during, and after Transatrial Resection of the Right Ventricular Infundibulum Obstructions in Patients with Tetralogy of Fallot

<table>
<thead>
<tr>
<th>Pt</th>
<th>Wt (kg)</th>
<th>Previous shunt</th>
<th>Ao O₂ SAT %</th>
<th>RV pressure (mm Hg)</th>
<th>PA pressure (mm Hg)</th>
<th>RV-PA pressure (mm Hg)</th>
<th>PA/Ao</th>
<th>RV patch</th>
<th>RV pressure (mm Hg)</th>
<th>PA pressure (mm Hg)</th>
<th>Systolic RV-PA*</th>
<th>RV/Art.*</th>
<th>Days after operation</th>
<th>RV pressure (mm Hg)</th>
<th>PA pressure (mm Hg)</th>
<th>RV-PA* (mm Hg)</th>
<th>RV/Art.*</th>
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<td>107</td>
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*Peak systolic pressures

1RV/Art. is derived from peak systolic pressures.

Abbreviations: Pt = patient; Wt = weight; Ao O₂ SAT = arterial oxygen saturation; RV = right ventricle; PA = pulmonary artery; Press = pressure; Art = systemic arterial; Pulm insuff = pulmonary insufficiency; VSD = ventricular septal defect; RB-T = right Blalock-Taussig procedure; LB-T = left Blalock-Taussig anastomosis; W = Waterston aortic-right pulmonary arterial anastomosis; sl = slight; sm = small; mod = moderate; NE = not entered.

Figure 3. Angiographic photographs of the right ventricular outflow tracts and pulmonary arteries at operation (table 1). Arrows indicate pulmonary valve and dacron patch over ventricular septal defect. Note absence of infundibular resection and thickening of right ventricular outflow tract.

During a cardiac catheterization on the third postoperative day, exercise electrocardiogram confirmed the adequacy of the infundibular resection.
mm Hg and averaged 23 mm Hg (table 1, fig. 2). Pullback pressure measurements show that residual stenoses are located at the pulmonary valve annulus in all of the patients studied. Two patients have significant right ventricular hypertension (90 mm Hg), which is in part due to peripheral pulmonary stenosis. Right ventricular end-diastolic pressures are normal in eight patients (0–6 mm Hg) and slightly elevated in four patients (7–10 mm Hg). Peak systolic right ventricular-systemic arterial pressure ratios range from 0.25 to 0.90 (mean 0.48).

Three patients have trivial residual ventricular septal defects detected by cineangiography but not by oxygen saturations.

One child who has a pulmonary annular patch and significant pulmonary insufficiency has tricuspid insufficiency of mild degree. With the catheter transversing the tricuspid valve, right ventricular injection shows some reflux of contrast material into the right atrium. However, the right atrial v wave exceeds the a wave by only 1 mm Hg and mean right atrial pressure is 6.5 mm Hg. No evidence of tricuspid insufficiency was detected in other patients.

Cineangiograms indicate successful relief of infundibular obstruction in all patients (fig. 6). Cineangiograms in the lateral projection show contraction of the free right ventricular infundibular wall during systole in most patients. No patient had paradoxical motion of the free right ventricular infundibular wall.

**Infundibular Pulmonary Stenosis with Ventricular Septal Defect**

Two patients aged 8 and 9 years had ventricular septal defect associated with infundibular pulmonic stenosis. Both patients were acyanotic. Ventricular pressures were equal in one patient; peak right ventricular systolic pressure was 15 mm Hg lower than peak left ventricular systolic pressure in the other. The pulmonary valve was normal in both as determined by preoperative cineangiograms and direct visualization from below at operation. Obstructing infundibular fibrous tissue was excised and the ventricular septal defects were closed transatrially during 72 and 90 min of cardiopulmonary bypass. Pressure measurements at operation are listed in table 2. Postoperative (4 hours) cardiac indices were 3.8 and 4.3 L/M²/min; catecholamines were not administered. One child developed right bundle branch block and the other did not.

**Infundibular and Valvular Pulmonic Stenosis with an Intact Ventricular Septum**

Four patients aged 5 to 28 years had both valvular and infundibular pulmonic stenosis. Preoperative peak systolic pressure differences between the right ventricle and pulmonary artery ranged from 70 to 142 mm Hg (table 2). All had stenotic tricuspid pulmonic valves which were incised through a pulmonary arteriotomy. One patient had discreet fibromuscular obstruction of the infundibulum and two patients had severe muscular hypertrophy so that transatrial resection of the infundibular obstruction was planned preoperatively. The fourth patient had transatrial resection of hypertrophied infundibular muscular obstruction when the right ventricular pressure failed to decrease after pulmonary valvotomy. Three patients developed right bundle branch block postoperatively.

**Discussion**

Transatrial resection of infundibular fibromuscular obstruction is technically feasible and safe. Transatrial infundibular resection requires no more retraction of the tricuspid valve leaflets than exposure of membranous ventricular septal defects. No injuries to the valve chordae, coronary vessels, or ventricular septum occurred. The relief of obstruction is adequate and comparable to that produced by resections through transverse or vertical ventriculotomies. In patients with tetralogy, residual right ventricular-pulmonary arterial pressure differences were localized to the pulmonary annulus which was not enlarged in 87% (13 of 15) of patients. Initially, transatrial resection required more operative time than transventricular resections; however, with experience this time differential disappeared. A pulmonary arteriotomy is not always required but is helpful in obtaining maximal relief of valvular stenoses and in preserving pulmonary valvular competence in the majority of patients.

The transatrial approach is applicable to most patients with infundibular obstructions who do not have tetralogy of Fallot. In these patients the infundibulum is well developed and an adequate blood channel is easily obtained. The
operation is also feasible in many patients with tetralogy of Fallot. However, to date we have not used the transatrial approach in infants less than 12 kilograms because of difficulties in working through the small tricuspid orifice and because of the desirability of a large outflow patch in the majority of these patients. Transventricular resections are also recommended when the right ventricular infundibulum and pulmonary arteries are very hypoplastic and require a large patch to produce a channel at least one-half the diameter of the ascending aorta. During the period of this study only two patients had transventricular repair of tetralogy of Fallot. One patient was a six kilogram infant and the second patient had severe diffuse infundibular and pulmonary arterial hypoplasia and required a very large patch.

Transatrial repair of infundibular obstructions offers several advantages over transventricular resections. Postoperative depression of myocardial performance due to the ventriculotomy is avoided. Myocardial necrosis, which generally involves 1 cm of tissue on each side of a ventriculotomy, does not occur. The free wall of the right ventricular infundibulum contracts normally rather than paradoxically and dilatation which occurs in up to 25% of patients is avoided. The approach is particularly important in the 2% of patients with tetralogy who have an anomalous major coronary artery that crosses the right ventricular infundibulum. In the past the mortality of corrective operations in these patients was 15 to 30%. In patients with valvular pulmonary stenosis, transatrial resection offers an attractive solution to the dilemma of whether or not to resect the hypertrophied muscle if the residual pressure difference between the right ventricle and the pulmonary artery remains elevated above 60–70 mm Hg.

While further experience is needed, transatrial resection of the infundibular obstruction in patients with tetralogy of

Table 2. Hemodynamic Measurements before and at Operation after Transatrial Resection of Right Ventricular Infundibular Obstructions in Patients with Tetralogy of Fallot

<table>
<thead>
<tr>
<th>Patient</th>
<th>Wt (kg)</th>
<th>VSD</th>
<th>Pulm Valv sten</th>
<th>Aortie O2 SAT</th>
<th>Pre-operative</th>
<th>Operative</th>
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<tr>
<td></td>
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<td>PA press (mm Hg)</td>
<td>RV-PA press (mm Hg)</td>
<td>RV press (mm Hg)</td>
<td>PA press (mm Hg)</td>
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Abbreviations: Pulm valv sten = pulmonary valvular stenosis; for other abbreviations see table 1.
Fallot may offer additional advantages over transventricular procedures. Myocardial performance and cardiac output immediately after operation may be improved. While mean indices of early postoperative cardiac function in this series did not differ significantly from published data after transventricular repair,¹ ² eight patients in the second half of the series who did not have outflow patches generally required no catecholamines and had higher cardiac indices than patients in the first half of the series and those published. The relatively low incidence of the need for insertion of outflow tract patches may be advantageous,¹² ²⁸ however, there is little published data to indicate that pulmonary insufficiency more severely depresses myocardial performance at rest or during exercise than does minimal residual pulmonary annular stenosis.¹³ ¹⁴ Nevertheless the reduced length of outflow patches with the transatrial approach should reduce the likelihood of aneurysmal dilatation of the patched right ventricular outflow tract.¹² ¹⁴

One final finding is of interest. All patients with tetralogy of Fallot and four of six patients with infundibular fibromuscular obstruction developed right bundle branch block. The exact location of the bundle branch interruption was not studied, but the observation indicates that full thickness, right ventriculotomy is not the most common cause of right bundle branch block following correction of tetralogy of Fallot.⁶

References

Transatrial resection of the obstructed right ventricular infundibulum.
L H Edmunds, Jr, N C Saxena, S Friedman, W J Rashkind and P F Dodd

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