Tetralogy of Fallot

Clinical and Hemodynamic Spectrum of Combined Pulmonary Stenosis and Ventricular Septal Defect

By Malcom C. McCord, M.D.,† Jack van Elk, M.D., and S. Gilbert Blount, Jr., M.D.

The considerable body of clinical and physiologic data in patients with the tetralogy of Fallot that has been accumulated over the past 15 years now indicates that the original concept of the lesion as a single, fairly narrowly limited entity is no longer valid. The tetralogy can now be demonstrated to occupy a broad spectrum in the field of congenital cardiac anomalies, representing widely varying forms. While the entity has been termed a tetralogy, only 2 features, namely the pulmonary stenosis and the ventricular septal defect, are essential in the determination of the clinical and physiologic pattern that patients with this defect portray.

The tetralogy of Fallot is a commonly occurring malformation that is perhaps the most familiar of all cyanotic congenital cardiovascular anomalies, and has occupied a salient position in the field of congenital heart disease. It was one of the first congenital cardiac lesions to be described in the pathologic literature with reports appearing in the seventeenth and eighteenth centuries. It was also one of the first to receive clinical definition, mainly as a result of Fallot's descriptions in the latter part of the nineteenth century, and it was the first of the cyanotic congenital cardiac anomalies to prove amenable to surgical correction. The success of the Blalock-Taussig procedure was a major factor in initiating the present era of widespread interest in diagnosis and therapy of congenital heart disease.

The recent period of extensive investigation of congenital heart disease has resulted in the accumulation of a considerable body of clinical and physiologic data in patients with the tetralogy. This evidence indicates that the original concept of the lesion as a single, fairly narrowly limited entity, is no longer valid. The tetralogy of Fallot can now be shown to occupy a broad spectrum in the field of congenital cardiac anomalies presenting in widely varying forms.

This wide range occupied by the tetralogy of Fallot is more complex than that of the other common congenital cardiac lesions owing to the combinations of the anatomic defects constituting this anomaly. The complexity can be simplified by identifying the dominant anatomic features of the anomaly. It is obvious that right ventricular hypertrophy, one of the classic components of the tetralogy, is a purely secondary phenomenon and can consequently be eliminated as a significant element.

The role played by dextroposition of the aortic root is more difficult to assess. It is the opinion of the authors that this element of the tetralogy is not a dominant factor in determining the hemodynamic pattern. The concept, that an aortic root overriding the right ventricle is often more of an apparent nature than an actual anatomic malposition, has received increasing support in recent years.

The infundibular stenosis and the ventricular septal defect thus remain as the essential elements determining the clinical and physiologic patterns in patients with the tetralogy of Fallot.

The present report consists of an effort to define the widely varying forms of the tetralogy on the basis of variation in the severity of these 2 elements. The categories formed by combinations of the 2 defects in varying grades of severity are described and patients studied at this center are presented as examples.

Classification

A classification of the tetralogy of Fallot is proposed based on the possible combinations

From the Cardiovascular Laboratory, University of Colorado School of Medicine, Denver, Colo.

This study was supported by a United States Public Health Service grant H-1208.

† Deceased, May 26, 1956.
McCORD, VAN ELK, AND BLount

737

Type I: Extreme Tetralogy

The anatomic elements underlying this form of the anomaly consist of extreme pulmonary stenosis or complete atresia of the pulmonary artery associated with a large ventricular septal defect. The resulting hemodynamic characteristics include a large right-to-left shunt, a severely reduced or nonexistent pulmonary blood flow from the right ventricle, and equalization of pressures in the left and right ventricles. Clinically the typical features are cyanosis from birth, marked symptomatology, evidence of collateral circulation to the lungs, and frequently fatal termination in infancy or early childhood. Taussig has suggested the term "extreme tetralogy" to identify this lesion.5, 6 "Pseudotruncus arteriosus" is also used to designate this severe form, particularly when pulmonary atresia is present.

Excellent descriptions of this well-known variant of the classic tetralogy are present in the literature.5, 6 Additional cases are therefore not presented. The hemodynamic aspects of the extreme tetralogy are similar to those of the classic tetralogy but reveal more marked peripheral arterial unsaturation. The arterial oxygen saturation levels are low at rest and are further reduced to astonishingly low levels on activity. Clinically the course of patients with the extreme tetralogy is marked by frequent episodes of paroxysmal hypoxia, which may be fatal, and severe limitation of exercise tolerance. Occasionally patients may develop extensive collateral circulation and live into adulthood. However, the usual course terminates in infancy or childhood. Auscultation reveals a systolic murmur along the left sternal border, which is considerably less intense than that accompanying the classic tetralogy, and on occasion no murmur is audible. The second heart sound at the base arises entirely from the closure of the aortic valve and at times, due to the relative position of the aorta, this second sound may be accentuated over the pulmonary area. A diagnostic auscultatory feature is a continuous cardiac murmur arising from the collateral circulation to the lungs.5, 7 This murmur, produced by blood flow through bronchial and mediastinal arteries, is usually well heard over the back.

The electrocardiogram invariably demonstrates a pattern of right ventricular hypertrophy. The roentgenologic aspects of this lesion have been well described.6, 8 The over-all heart size tends to be increased in contrast to the normal heart size usually present in the classic tetralogy. The collateral vessels produce a characteristic nodular hilar pattern and may indent the barium-filled esophagus.

The severe tetralogy may closely resemble tricuspid atresia in its clinical and radiologic aspects. The electrocardiogram is of considera-

Fig. 1. A spectrum of the tetralogy of Fallot. The direction and the volume of shunting of blood through the ventricular septal defect are demonstrated schematically with the associated right ventricular and pulmonary artery pressures.
ble importance in this differentiation as evidence of left ventricular dominance is usually present in the latter. A single ventricle with transposed great vessels and pulmonary stenosis produces a physiologic derangement similar to the severe tetralogy and may be difficult to differentiate. A true truncus arteriosus may also enter into the differential diagnosis should the pulmonary blood flow be greatly reduced.

A significant feature of the extreme tetralogy that segregates this lesion from the classic tetralogy is the unsatisfactory response to surgical measures. The hypoplasia of the main and at times of the right and left pulmonary arteries renders the establishment of a systemic anastomosis a very difficult or impossible technical procedure. Moreover, exploration of the hilar areas in search of a suitable vessel for anastomosis frequently results in destruction of the naturally occurring collateral vessels on which the life of these patients is dependent. Direct procedures relieving the pulmonary stenosis are of little benefit, since the pulmonary artery itself is decreased in size or atretic. Taussig and Bauersfield\(^8\) reported a 26 per cent mortality in 27 patients considered to represent an extreme tetralogy. Operation was uniformly fatal in all 4 patients with pulmonary atresia described by Allanby and associates.\(^7\)

**Type II: Classic Tetralogy**

The anatomic constituents of the classic tetralogy may be defined as severe pulmonary stenosis and a large ventricular defect. The hemodynamic changes resulting from the combination are a large right-to-left shunt and a small left-to-right shunt may also be present.\(^9\)-\(^11\) The pulmonary blood flow is decreased with a lowered pulmonary artery pressure.

The physiologic abnormalities occurring in the classic tetralogy are well described in the reports by various authors.\(^9\), \(^11\), \(^12\) The pattern described conforms with the features outlined above.

The clinical characteristics of patients with this typical tetralogy have been lucidly presented by Taussig.\(^6\) Early cyanosis, squatting, and episodes of paroxysmal dyspnea constitute an almost diagnostic triad. The physical examination reveals cyanosis and the features accompanying cyanosis, such as clubbing, hypertrophied gums, a "geographic" tongue, and injection of the conjunctivae. Auscultation reveals a systolic murmur at the left sternal border that may vary considerably in location and intensity from one patient to the next. A grade IV, harsh systolic murmur in the left third intercostal space might be considered the most common finding. The second heart sound in the pulmonary area probably arises from the aortic valve closure and may be normal or increased in intensity and is pure in quality.

Clinically patients with the classic form of tetralogy show cyanosis beginning early in childhood, a fairly severe limitation of exercise tolerance, and if untreated usually do not survive beyond childhood or adolescence.

The electrocardiogram demonstrates right ventricular hypertrophy.

Radiologic examination reveals a decreased vascularity of the lung fields, small and quiet right and left pulmonary arteries, and an absent or inconspicuous main pulmonary artery. The over-all heart size is characteristically within normal limits. However, the configuration of the heart reveals the classic “coeur en sabot” silhouette and indicates hypertrophy of the right ventricle. An additional characteristic radiologic feature is the occurrence of a right aortic arch. This abnormality occurs in approximately one fourth of patients with the tetralogy of Fallot. The angiocardiographic studies of Kjellberg and associates\(^12\) have demonstrated clearly the dynamic radiographic features of the tetralogy. This classic form of the tetralogy has been well described over a period of many years. Case reports are therefore not included at this time.

Operative therapy can be said to be indicated in all patients with the classic tetralogy of Fallot. However, at the present time the decision as to the type of surgical therapy and the time at which such therapy should be instituted is difficult. Five years ago the management of these patients was relatively simple. An arterial anastomosis was the only form of therapy and was established either by the Blalock-Taussig method or by the Potts' technic. Marked symptomatic relief and un-
questionable prolongation of life have been achieved in many patients by this palliative procedure. However, development of the technic of pulmonary valvulotomy or infundibulotomy has now reached the stage where the mortality rate and the degree of symptomatic improvement is equal to or may exceed that of the shunt procedures. Since the relief of pulmonary stenosis is a curative rather than a purely palliative approach, it has been recommended by some authors as the method of choice. At times, however, when the relief of the infundibular stenosis has been complete, or nearly so, an abrupt change in the hemodynamics may occur. Thus a significant left-to-right shunt has been noted with the development of rapidly increasing heart size and congestive failure. The most recent phase of surgical therapy in the tetralogy consists of the complete correction of both the pulmonary stenosis and the ventricular defect. This ideal, totally corrective form of therapy is still accompanied by a rather high operative mortality. A conservative course at the present time might be to defer surgery whenever possible, pending further improvement in the truly corrective techniques and to carry out a shunting procedure only on those patients whose clinical course permits no delay.

Type III: Mild Tetralogy

The third suggested subdivision of the spectrum of the tetralogy of Fallot is composed of acyanotic patients with minimal symptoms. The anatomic elements defining this type consist of pulmonary stenosis of a mild or moderate degree accompanying a ventricular septal defect of small or moderate size. This combination of anatomic features frequently results in an evenly balanced pattern with one defect governing the hemodynamic effects of the other. Shunting of blood through the ventricular defect due to its size is limited to relatively small volumes in either a right-to-left or left-to-right direction. The right ventricular pressure may be equal to or less than the left ventricular pressure and the pulmonary arterial pressure may be normal (patients 3, 4, 7, 8) or slightly elevated (table 2, patients 5, 6). Examples of this lesion are found in the rapidly expanding recent literature describing an increased pulmonary blood flow in the presence of pulmonary stenosis and have been termed atypical tetralogy of Fallot. A further source of illustrative cases from the literature is found in the description of patients with the classical form of the tetralogy who have had surgical relief of the pulmonary stenosis. Obliteration of a right-to-left shunt and the appearance of a mild left-to-right shunt have been documented in such patients.

Data from 7 patients are presented in tables 1 and 2 as additional examples of this form of the atypical tetralogy. Patients 3 through 8 represent naturally occurring forms of the anomaly, while patient 1 illustrates the development of a type III pattern following direct infundibular resection in a patient with the classical form of the tetralogy.

Patients in this group present a uniform pattern of mild symptomatology and absence of cyanosis. The physical examination reveals a loud systolic murmur with a palpable thrill along the left sternal border in all patients. The area of maximum intensity of this murmur varied from the second to the fourth left intercostal space at the sternal border. A short middiastolic murmur was audible at the apex in 2 patients. The second heart sound in the pulmonary area was variable in intensity and degree of reduplication. The electrocardiogram revealed a similarly inconsistent pattern, as it varied from an essentially normal tracing in 1 patient, to right ventricular hypertrophy in 1 patient, and combined right and left ventricular hypertrophy in at least 1 patient (fig. 2, table 1). Fluoroscopic features of patients in this group also varied widely. The vascularity of the lung fields varied from normal to slightly increased. The size and the amplitude of pulsation of the main and of the right and left pulmonary arteries also varied. The heart size was enlarged in all but 2 patients (table 1).

At cardiac catheterization the pressures in the right side of the heart varied considerably in this group of patients; in 3 patients the right ventricular pressure was equal to the left ventricular pressure and in the other 3 patients the right ventricular pressure was definitely lower than in the left ventricle (table 2).
### Table 1.—Clinical Data in Eleven Patients with Various Forms of the Tetralogy of Fallot

<table>
<thead>
<tr>
<th>Class</th>
<th>Case number</th>
<th>Age and sex</th>
<th>Impairment of exercise tolerance</th>
<th>Physical examination</th>
<th>EKG</th>
<th>Radiology</th>
<th>Overall cardiac enlargement</th>
<th>RVH</th>
<th>LVH</th>
<th>Aortic arch</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1 preop.</td>
<td>8 M</td>
<td>Mild</td>
<td>Absent</td>
<td>Absent</td>
<td>Decreased</td>
<td>Normal size Quiet</td>
<td>Absent</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>3</td>
<td>1 post-op.</td>
<td>8 M</td>
<td>None</td>
<td>Absent</td>
<td>Absent</td>
<td>Normal size and pulations</td>
<td>Small Slight</td>
<td>Present</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 preop.</td>
<td>20 F</td>
<td>Moderate</td>
<td>Definite</td>
<td>Absent</td>
<td>Increased in size and plications</td>
<td>Increased in size and plications</td>
<td>Present</td>
<td>Present</td>
<td>Left</td>
</tr>
<tr>
<td>4</td>
<td>2 post-op.</td>
<td>20 F</td>
<td>Initially severe, later moderate</td>
<td>Definite</td>
<td>Present</td>
<td>Increased in size and plications</td>
<td>Increased in size and plications</td>
<td>Present</td>
<td>Present</td>
<td>Left</td>
</tr>
<tr>
<td>3</td>
<td>3 F</td>
<td>3 F</td>
<td>Mild</td>
<td>Present</td>
<td>Decreased</td>
<td>Increased in size and plications</td>
<td>Increased in size and plications</td>
<td>Slight</td>
<td>Present</td>
<td>Left</td>
</tr>
<tr>
<td>3</td>
<td>4 F</td>
<td>6 F</td>
<td>None</td>
<td>Present</td>
<td>Increased</td>
<td>Increased in size and plications</td>
<td>Increased in size and plications</td>
<td>Moderate</td>
<td>Present</td>
<td>Left</td>
</tr>
<tr>
<td>3</td>
<td>5 F</td>
<td>8 F</td>
<td>None</td>
<td>Present</td>
<td>Increased</td>
<td>Increased in size and plications</td>
<td>Increased in size and plications</td>
<td>Moderate</td>
<td>Present</td>
<td>Left</td>
</tr>
<tr>
<td>3</td>
<td>6 F</td>
<td>11 F</td>
<td>Mild</td>
<td>Present</td>
<td>Increased</td>
<td>Increased in size and plications</td>
<td>Increased in size and plications</td>
<td>Normal</td>
<td>Present</td>
<td>Left</td>
</tr>
<tr>
<td>3</td>
<td>7 F</td>
<td>4 F</td>
<td>None</td>
<td>Present</td>
<td>Increased</td>
<td>Increased in size and plications</td>
<td>Normal</td>
<td>Present</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8 F</td>
<td>7 F</td>
<td>None</td>
<td>Present</td>
<td>Increased</td>
<td>Increased in size and plications</td>
<td>Normal</td>
<td>Normal</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>9 F</td>
<td>14 F</td>
<td>None</td>
<td>Present</td>
<td>Decreased</td>
<td>Normal in size and plications</td>
<td>Normal in size and plications</td>
<td>Moderate</td>
<td>Present</td>
<td>Left</td>
</tr>
<tr>
<td>4</td>
<td>10 F</td>
<td>4 M</td>
<td>Moderate</td>
<td>Present</td>
<td>Increased</td>
<td>Increased in size and plications</td>
<td>Increased in size and plications</td>
<td>Moderate</td>
<td>Present</td>
<td>Right</td>
</tr>
<tr>
<td>5</td>
<td>11 F</td>
<td>20 F</td>
<td>Moderate</td>
<td>Present</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Small</td>
<td>Moderate</td>
<td>Present</td>
<td>Right</td>
</tr>
</tbody>
</table>
### Table 2. Hemodynamic Data in Eleven Patients with Various Forms of the Tetralogy of Fallot

<table>
<thead>
<tr>
<th>Class</th>
<th>Case number</th>
<th>Age and sex</th>
<th>Pressures in mm. Hg</th>
<th>Blood oxygen saturation in % (average of multiple samples)</th>
<th>Pulmonary flow (L/min)</th>
<th>Left-to-right shunt (L/min)</th>
<th>Ratio left-to-right shunt/pulmonary flow</th>
<th>Systemic flow (L/min)</th>
<th>Right-to-left shunt (L/min)</th>
<th>Ratio right-to-left shunt/systemic flow</th>
<th>Surface area in M²</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1 preop.</td>
<td>8 M</td>
<td>7/3</td>
<td></td>
<td>66.2</td>
<td>68.8</td>
<td>66.6</td>
<td>63.4</td>
<td>82.5</td>
<td>3.0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1 postop.</td>
<td>8 M</td>
<td>8/6</td>
<td></td>
<td>66.9</td>
<td>68.4</td>
<td>80.4</td>
<td>78.0</td>
<td>94.5</td>
<td>5.3</td>
<td>2.1</td>
</tr>
<tr>
<td>2</td>
<td>2 preop.</td>
<td>26 F</td>
<td>10/5</td>
<td></td>
<td>58.3</td>
<td>60.1</td>
<td>59.4</td>
<td>60.5</td>
<td>81.3</td>
<td>3.2</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>2 postop.</td>
<td>26 F</td>
<td>17/6</td>
<td></td>
<td>58.6</td>
<td>55.8</td>
<td>78.2</td>
<td>78.5</td>
<td>89.3</td>
<td>9.1</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3 F</td>
<td>7/5</td>
<td></td>
<td>60.1</td>
<td>60.4</td>
<td>74.7</td>
<td>69.0</td>
<td>84.2</td>
<td>2.6</td>
<td>0.7</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>6 F</td>
<td>2/0</td>
<td></td>
<td>75.5</td>
<td>71.8</td>
<td>82.6</td>
<td>84.1</td>
<td>88.8</td>
<td>12.2</td>
<td>5.4</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>8 F</td>
<td>13/4</td>
<td></td>
<td>66.4</td>
<td>58.1</td>
<td>77.9</td>
<td>78.1</td>
<td>89.2</td>
<td>5.1</td>
<td>2.1</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>11 F</td>
<td>10/0</td>
<td></td>
<td>69.9</td>
<td>69.5</td>
<td>81.9</td>
<td>76.6</td>
<td>92.7</td>
<td>6.7</td>
<td>2.9</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>4 F</td>
<td>7/3</td>
<td></td>
<td>60.2</td>
<td>66.5</td>
<td>67.4</td>
<td>72.2</td>
<td>87.8</td>
<td>5.4</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>7 F</td>
<td>4/1</td>
<td></td>
<td>66.2</td>
<td>68.6</td>
<td>80.4</td>
<td>81.5</td>
<td>99.5</td>
<td>5.3</td>
<td>2.6</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>14 F</td>
<td>7/3</td>
<td></td>
<td>73.8</td>
<td>69.4</td>
<td>83.8</td>
<td>84.0</td>
<td>94.0</td>
<td>13.7</td>
<td>6.6</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>4 M</td>
<td>16/4</td>
<td></td>
<td>67.4</td>
<td>60.0</td>
<td>84.1</td>
<td>85.1</td>
<td>89.5</td>
<td>10.7</td>
<td>7.4</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>20 F</td>
<td>17/4</td>
<td></td>
<td>57.3</td>
<td>56.2</td>
<td>55.4</td>
<td>66.0</td>
<td>91.6</td>
<td>3.2</td>
<td>0</td>
</tr>
</tbody>
</table>

* Aortic pressure.
Surgical intervention at this time in patients belonging to this group is seriously questioned, as removal of the pulmonary stenosis may eliminate the governing influence on the left-to-right shunt and thereby acutely create a great increase in the volume of the pulmonary blood flow that may result in dilatation and failure of the heart.

It is probably wise to postpone surgery for patients belonging to this category as long as possible and to wait until such time that the operative risk of combined closure of the ventricular septal defect and infundibulectomy is more acceptable.

**Type IV: Dominant Ventricular Septal Defect**

This variant is defined by the presence of mild infundibular stenosis with a large ventricular septal defect. Physiologically it is characterized by a large left-to-right shunt at the ventricular level with an increased pulmonary blood flow. The pressure in the right ventricle is usually equal to the left ventricular pressure, but may be lower. The infundibular stenosis, although mild, varies in degree as does the volume of the pulmonary blood flow, consequently the pressure gradient across the valve is of varying magnitude. The pressure in the pulmonary artery may be normal, but will usually be elevated. As the shunting of blood is from left to right, the peripheral arterial oxygen saturation is normal.

The salient clinical features of this atypical form of the tetralogy are the absence of cyanosis, symptoms of slight to moderately decreased exercise tolerance with increase in heart size and increased vascularity of the lung fields, and right and left ventricular hypertrophy.

This form of the tetralogy is less common and less well documented in the literature than the previous types. The 4 children described by Rowe and associates are considered as representative examples of this variant of the tetralogy. Two of the patients described by Broadbent and associates, with pulmonary blood flows of 12 and 12.9 L., might also be included in this category.

Two patients, 9 and 10, presented at this time, are considered to fall in this category, one of whom will be described in detail (tables 1 and 2).

Patient 10 was a well developed, acyanotic, active, 4-year-old boy who was initially thought to have a large ventricular septal defect with pulmonary hypertension. Later it was noted that the boy had a right aortic arch, and then the diagnosis was changed to a tetralogy of Fallot with a left-to-right shunt. The roentgenogram of the heart is presented in figure 3. Catheterization revealed a considerable left-to-right shunt with an increment in oxygen content of 2.6 volumes per cent in the right ventricle; the pressure in the right ventricle was 89/7 mm. Hg, while the pressure in the pulmonary artery was 55/21 mm. Hg. The pressure tracing (fig. 4) obtained on withdrawal of the catheter from the pulmonary artery to the right ventricle suggested the presence of an infundibular chamber.

At operation a mild infundibular stenosis was noted with a small infundibular chamber. The ostium infundibulum was estimated at the time of surgery to be 10 mm. in diameter. This was removed at surgery and a ventricular septal defect was also closed. The operation was without event, however the patient suddenly died 6 hours postoperatively. At post-
mortem examination the ventricular septal defect was found to be completely closed and to measure 18 mm. in diameter. The infundibular chamber was 16 mm. in depth. The pulmonary valve was not stenotic, but was abnormal, as there were only 2 cusps present, 1 large cusp that occupied about two thirds of the valvular ring, and 1 smaller cusp that occupied the remainder of the ring. The aortic arch was on the right side (figs. 5 and 6).

The classical form of tetralogy may be transformed into the type of tetralogy under discussion at this time when the infundibular stenosis is largely removed without closure of the ventricular septal defect. Two such patients demonstrating this transformation have been previously reported. They developed a sudden and excessive increase in pulmonary blood flow following removal of the obstruction in the right ventricular outflow tract. Physiologic studies obtained before and after operation in 1 of these patients clearly document a large left-to-right shunt at the ventricular level postoperatively.

An additional patient, no. 2, in whom infundibular resection was performed, was a well developed 26-year-old woman who was markedly cyanotic and moderately restricted in her activities. She was operated upon, and under hypothermia and circulatory occlusion the infundibular stenosis was resected adequately. Postoperatively her color greatly improved; however, she developed exertional dyspnea, orthopnea, and dependent edema. She was digitalized and placed on full therapy for congestive failure, which responded and cleared over a period of 3 months. At the present time, although her heart has increased in size, she no longer requires medication. There is no evidence of cyanosis and her exercise tolerance has markedly increased over her preoperative status.

Thus these patients demonstrate the inability of the left ventricle to compensate for the acute load that develops with the creation of a large left-to-right shunt. Similar postoperative excessive left-to-right shunts were mentioned by Sell and associates. Thus depending upon the extent of the removal of the infundibular stenosis in patients operated upon by the direct infundibular approach the patient may be transformed into a mild tetralogy or the type of tetralogy under discussion at this time.

The problem of relative pulmonary stenosis must arise at this time. Experience with atrial septal defects associated with large pulmonary flows has revealed that considerable systolic pressure gradient may be present between the right ventricle and pulmonary artery in the absence of anatomic pulmonary stenosis. It is reasonable to assume that this phenomenon may also occur in patients with a ventricular septal defect and an increased pulmonary blood flow. However, studies of isolated ventricular defects have not shown functional pressure gradients comparable to those occurring in atrial septal defects. The possibility of functional stenosis might arise in patient 10, in
whose systolic pressure in the pulmonary artery was 55 mm. Hg and in the right ventricle 89 mm. Hg. However, the withdrawal pressure tracing from the pulmonary artery to the right ventricle suggested an infundibular chamber, and such a chamber was found at the time of operation and postmortem examination, as previously described.

The previously mentioned accessory diagnostic features of the tetralogy are also helpful in the differential diagnosis. A right aortic arch, which was present in patient 10, and in 1 of Rowe's patients, is significant. Only rarely is a right aortic arch noted in patients with an isolated ventricular septal defect.

This group again offers evidence indicating the minor role played by an "overriding" aorta. In the autopsied patient of Rowe the overriding of the aorta was described as "considerable" and "little different from the classic case of the malformation." In patient 10, the aorta also appeared to override the defect and yet the shunting occurred exclusively in a left-to-right direction; in addition, there was no problem whatsoever in closing this defect at the time of operation.

Relative to surgery, patients with this type of the tetralogy are to be evaluated as patients with an isolated ventricular septal defect. Thus, if they have shown a large left-to-right shunt, an enlarged heart, and relatively low pulmonary vascular resistance, closure of the defect might be considered. The removal of the mild infundibular stenosis is of secondary importance and creates a minor additional problem if surgery is undertaken. However, inasmuch as the mortality and morbidity stemming from closure of the ventricular septal defect is still quite high, a conservative approach is recommended for the time being.

**Type V: Dominant Pulmonary Stenosis**

This variation consists of a combination of severe right ventricular outflow obstruction and a small ventricular septal defect. The systolic pressure in the right ventricle may greatly exceed that in the left ventricle. The consequent right-to-left shunt, however, is limited in magnitude by the size of the defect. This is an uncommon form of the tetralogy and little information is available in the literature regarding its characteristics. Clinically these patients are often considered to have valvular pulmonary stenosis with an intact ventricular septum. Patient 11 is an example of this form and will therefore be discussed in detail.
Patient 11 was a 20-year-old white girl. A heart murmur was heard at the time of birth. She had led a relatively normal life; however, she had experienced slight to moderate shortness of breath and fatigue on prolonged exertion for as long as she could remember. She had noted an increase in shortness of breath and fatigue with episodes of mild ankle edema during the past year, and at the time of examination she could walk only a few blocks at a slow pace, and could not climb a flight of stairs without having to stop because of dyspnea and fatigue.

Physical examination revealed an alert, well developed young lady. No cyanosis or clubbing was present. Distinct a-waves were noted in the deep neck veins. There was a slight precordial bulge and precordial activity was diffuse. The apex beat was just outside the left midclavicular line, and a right ventricular lift was felt beneath and just to the left of the lower sternum. Palpation also revealed a systolic thrill along the upper left sternal border that was maximum in the second left intercostal space. A grade IV, harsh systolic murmur was heard along the left sternal border, also maximum in the second left intercostal space, but loud in the third and fourth interspaces, and louder in the third than in the first. The second heart sound in the left second intercostal space was decreased in intensity.

Fluoroscopy revealed the pulmonary vascularity to be at the lower limits of normal. The main pulmonary artery was not prominent. The heart was moderately enlarged with prominence of the right ventricle and right atrium. The aortic arch was on the right and the aorta also descended on the right (fig. 7).

The electrocardiogram revealed evidence of severe right ventricular hypertrophy and right atrial enlargement (fig. 8).

The patient had been referred with the diagnosis of isolated valvular pulmonary stenosis. However, because of the right aortic arch, and the location of the murmur, it was thought that she had an atypical form of the tetralogy of Fallot. This latter diagnosis was confirmed by the information obtained at cardiac catheterization (table 2). The oxygen saturation of the peripheral arterial blood was within normal limits for this altitude, thus indicating that there was no significant right-to-left shunting of blood, and there was no evidence of a left-to-right shunt. The catheter was passed from the right ventricle through a ventricular septal defect into the aorta. The right ventricular pressure was 220/10 mm. Hg, while the pressure in the aorta was 120/76 mm. Hg. The pressure in the pulmonary artery was only 12.8 mm. Hg. The pressure record on withdrawal of the catheter from the pulmonary artery to the right ventricle suggested an infundibular

![Fig. 7. Roentgenogram of patient 11, with a dominant infundibular stenosis and a right aortic arch.](image)

![Fig. 8. Electrocardiogram of patient 11, with dominant infundibular stenosis. This tracing has been interpreted as demonstrating right ventricular hypertrophy.](image)
Tetralogy of Fallot

Fig. 9 Top. Pathologic specimen of patient 11. A wooden probe is passed through the small ventricular septal defect which is covered by a tricuspid leaflet.

Fig. 10 Middle. Pathologic specimen of patient 11. The infundibular chamber is opened and the narrow fibrous ostium infundibulum (which has been removed partially at surgery) is seen.

Fig. 11 Bottom. Pathologic specimen of patient 11. The ventricular septal defect (indicated by arrow) is seen beneath the aortic valve.

chamber. The right atrial pressure was 17/4 mm. Hg, giant a-waves being present.

Infundibulectomy was performed without event, but complications developed post-operatively and the patient died on the third postoperative day. At postmortem examination the findings were as expected. There was a small, short infundibular chamber with a fibrous ring forming a very narrow ostium infundibulum, which had been partially excised at surgery. The ventricular septal defect was very small, being but 5 mm. in diameter, and in addition the tricuspid valve leaflet was positioned in such a manner that it tended to close the defect. The right ventricle was markedly hypertrophied, being 18 mm. in thickness (figs. 9, 10, and 11).

A similar patient was demonstrated by Goetzsche and associates with a figure showing a "drawback" from aorta to the right ventricle with a higher systolic pressure in the right ventricle than in the aorta. A possibly similar case is a patient of Brock and Campbell in whom an excessively high right ventricular pressure was recorded.

This type lesion thus masquerades as an isolated pulmonary stenosis, either valvular or infundibular. It is quite probable that many patients diagnosed as isolated infundibular stenosis may actually not have an intact ventricular septum, but have a small, physiologically insignificant defect in the septum.

The surgical approach to patients with this lesion should be directed at complete removal of the infundibular stenosis. The ventricular septal defect is small and thus one would not be concerned with the development of a significant left-to-right shunt, should the pulmonary stenosis be completely removed.

Summary

The tetralogy of Fallot is the most common cyanotic congenital cardiac defect that is compatible with the maintenance of life beyond infancy and early childhood. It was the first cyanotic congenital lesion amenable to the furtherance of life expectancy by operative intervention. Interest in this lesion was also the main stimulus for the development of our present fund of knowledge relative to congenital cardiac defects.

However, because of this early experience with the classic tetralogy and the so-called "blue baby operation," we have in general come to consider that the patient with tetralogy
of Fallot must be cyanotic and markedly incapacitated. Otherwise, the diagnosis of tetralogy of Fallot is not seriously entertained.

The considerable body of clinical and physiologic data in patients with the tetralogy that has been accumulated over the past 15 years now indicates that the original concept of the lesion as a single, fairly narrowly limited entity is no longer valid. The tetralogy of Fallot can now be demonstrated to occupy a broad spectrum in the field of congenital cardiac anomalies, presenting in widely varying forms. While the entity has been termed a tetralogy, it is becoming apparent that only 2 features, namely, the pulmonary stenosis and the ventricular septal defect, are essential in the determination of the clinical and physiologic patterns of this defect.

Thus, certainly the right ventricular hypertrophy, one of the classic components of the tetralogy, is a purely secondary phenomenon and can be dismissed as a significant factor in the determination of the clinical picture. The role of dextroposition of the aortic root is more difficult to assess and possibly not so easily dismissed. However, clinical and physiologic evidence together with the findings at operation in these patients suggests that the dextroposition of the aorta is of functional origin and not anatomic.

This idea was first noted by Eisenmenger in his discussion of ventricular septal defect in 1898,\(^\text{28}\) when he pointed out that in the presence of large ventricular septal defects, the anatomic relationship of the aorta to the membranous portion of the septum is such that overriding may occur, even though the aorta arises in an entirely normal position from the left ventricle. Thus, in the tetralogy of Fallot, if the ventricular septal defect is closed, there usually is no technical difficulty relative to the position of the aorta.

It is the size of the ventricular defect and the degree of the pulmonary stenosis and the varying combinations of severity of these 2 defects that are responsible for the clinical and physiologic findings. The classical tetralogy has a moderately sized ventricular septal defect and a moderate to severe pulmonary stenosis, resulting in relatively equal pressures in the 2 ventricles, a decreased pulmonary blood flow, and a predominantly right-to-left shunt. However, the patient with the tetralogy of Fallot may be acyanotic, relatively asymptomatic, and masquerade as a patient with an isolated pulmonary stenosis. The pulmonary stenosis is marked and the ventricular septal defect small, resulting in a pressure within the right ventricle greatly exceeding that within the left ventricle. There will be a minimal right-to-left shunt and no left-to-right shunt.

The other end of the spectrum also reveals an acyanotic patient with almost full activity. This patient has a large ventricular septal defect and a very mild infundibular stenosis with a resulting large left-to-right shunt and no right-to-left shunt. The pressure in the right ventricle may be equal to or less than that within the left ventricle. Pulmonary hypertension may exist and the systolic pressure gradient between the pulmonary artery and right ventricle may be minimal. This patient is usually thought to have a large ventricular septal defect, and the diagnosis of tetralogy of Fallot is not considered.

Should we continue the use of the term tetralogy of Fallot? Probably for a better understanding of the clinical and hemodynamic features of this anomaly, this term should be discarded. However, it is certain that it will disappear from our terminology only slowly and with great reluctance.

**SUMMARIO IN INTERLINGUA**

Le tetralogia de Fallot es le plus commun congenite defecto cardiac cyamotic ancora compatibile con le mantenentia del vita in ultra del prime infantia. Illo esseva le prime congenite lesion cyamotic in quae il esseva possibile meliorar le probabilitate del supervivientia per intervenciones chirurgico. Le interesse de iste lesion esseva etiam le principal stimulus in le disveloppamento de nostre currente fundo de cognoscenciale relative a congenite defectos cardiac.

Tamen, a causa de iste experientias initial in casos del classic tetralogia de Fallot e a causa del si-appellate operation pro "babies blau," nos tende a opinar in general que le paciente con tetralogia de Fallot debe esser cyamotic e marcatamente incapacitate. In casos que non corresponde a iste conception, le diagnose de
tetralogia de Fallot non es seriemente prendite in consideration.

In le curso del passate 12 annos un massa considerabile de datos clinic e physiologic in re patientes con tetralogia de Fallot ha esite accumulato, e le resultato es que nos debe concluder que le conception original de iste lesion como un sol e sati strictemente circumscripte entitate ha perdite su validitate. Il es nunc possibile demonstrar que le tetralogia de l’alot occupa un large spectro in le campo del congenite anomalias cardiac e que illo se presenta sub le guisa de multiple variationes. Ben que le entitate ha esite designate como tetralogia, il deveni de plus in plus apparente que solamente 2 tractos—i.e. stenosis pulmonar e defecto ventriculo-septal—es essential in le determination del configuration clinic e physiologic de iste defecto.

Assi, hypertrophia dextero-ventricular—un del componentes classis del tetralogia—es certo un phenomeno purmente secundari e pote esser rejicite como factor significative in le determination del tableau clinic. Le rolo del dextro-position del radice aortic es plus difficile a evalutar e possibilemente non pote esser rejicite con le mesme grado de assecurantia. Tamen, observationes clinic e physiologic insimul con constatationes al operation de iste patientes pare indicar que le dextro-position del aorta es de origine functional e non anatomic.

Iste notion esseva primo signalate per Eisenmenger in su discussion del defecto ventriculo-septal in 1898,2 quando ille observava que in le presentia de grande defectos ventriculo-septal le relation anatomic inter le aorta e le portion membranose del septo es de natura a render possibile le occurrentia de un cavalamento, ben que le sito del origine del aorta ab le ventriculo sinistre es totalmente normal. Per consequente, si in caso de tetralogia de Fallot le defecto ventriculo-septal es claudite, il ha usualmente nulle difficultate technic quanto al position del aorta.

Il es le magnitude del defecto ventricular e le grado del stenosis pulmonar e le multiple combinationes del varie grados de severitate de iste 2 defectos que es responsabile pro le constatationes clinic e physiologic. Le forma classic de tetralogia de Fallot ha un defecto ventriculo-septal de magnitude moderate e un stenosis pulmonar de grado moderate o sever con le resultato de relativamente equal pressiones in le 2 ventriculos, un reduce fluxo de sanguine pulmonar, e un derivation predominamente dextero-sinistre. Tamen, patientes con tetralogia de Fallot pote esser acyanotic e relativamente asymptomatic, e lor comportamento pote similar le comportamento de patientes con isolate stenosis pulmonar. In tal cases le stenosis pulmonar es mareate e le defecto ventriculo-septal parve, con le resultato que le pression intra le ventriculo dextere excede grandemente le pression intra le ventriculo sinistre. Le derivation dextero-sinistre es minimal, e nulle derivation sinistro-dextere es presente.

Etiam le altere extremo del spectro mostra un patiente acyanotic con quasi non-restringite activitate. Iste patiente ha un grande defecto ventriculo-septal e un levissime stenosis infundibular con le resultato de un pronunciate derivation sinistro-dextere e nulle derivation dextero-sinistre. Le pression in le ventriculo dextere pote esser equal o inferior al pression in le ventriculo sinistre. Hypertension pulmonar pote existere, e le gradient de pression systolic inter le arteria pulmonar e le ventriculo dextere pote esser minimal. In cases de iste typo, on conclude usualmente que le patiente ha un grande defecto ventriculo-septal, e le diagnose de tetralogia de Fallot non es prendite in consideration.

Il es probabile che abandonar le termino tetralogia de Fallot promovera le appreciation del caracteristicas clinic e hemodynamic de iste anomalia, sed il es a expectar que su disparition ab nostre terminologia va esser lente e ardue.

REFERENCES
4 BLALOCK, A., AND TAUSSIG, H. B.: The surgical treatment of malformations of the heart in
which there is pulmonary stenosis or pulmonary atresia. J.A.M.A. 128: 189, 1945.

Medical Eponyms

By Robert W. Buck, M.D.


"The amount of oxygen taken from the air by an animal during a given time is measured as well as the amount of carbon dioxide given off. During the experimental period, a sample of arterial and one of venous blood is also taken. The oxygen content and carbon dioxide content is measured in both. The difference between the two oxygen measurements reveals how much oxygen each cubic centimeter of blood has taken up in its passage through the lungs, and thus we know the total amount of oxygen taken up during a definite period of time. Consequently the number of cubic centimeters of blood which passed through the lungs during this time may be reckoned, or if we divide by the number of heart beats during this period of time, we may determine how many cubic centimeters of blood were put out with each cardiac systole."
Tetralogy of Fallot: Clinical and Hemodynamic Spectrum of Combined Pulmonary Stenosis and Ventricular Septal Defect
MALCOM C. MCCORD, JACK VAN ELK and S. GILBERT BLOUNT, JR.

Circulation. 1957;16:736-749
doi: 10.1161/01.CIR.16.5.736
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1957 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/16/5/736

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org/subscriptions/