A wide spectrum of clinical presentations occurs in patients with tetralogy of Fallot. Patients with this congenital anomaly may become symptomatic shortly after birth, while other patients with this lesion may be acyanotic asymptomatic adults. Other associated cardiovascular anomalies further modify the clinical picture and previous operative intervention may alter the function and anatomy in patients with tetralogy. Furthermore, other forms of cyanotic congenital heart disease may mimic tetralogy. Six patients are presented illustrating some unusual variants in tetralogy of Fallot and illustrating other forms of cyanotic congenital heart disease mimicking tetralogy. Recognition of unusual variants in Fallot's tetralogy and other anomalies resembling tetralogy is essential to a successful operative result.

Tetralogy of Fallot, the most common form of cyanotic congenital heart disease, is a spectrum of anomalies ranging from acyanotic asymptomatic adults to severely cyanotic gravely ill infants. Total corrective operations or palliative procedures are available for almost all patients with Fallot's tetralogy, but the operative result may be dependent on recognition of unusual anatomic features, delineation of associated cardiac malformations, and proper differentiation from other mimicking forms of congenital heart disease. This report describes variants of tetralogy of Fallot in four patients and clinical findings mimicking this anomaly in two patients who proved to have other cardiac anomalies. Attention is directed to problems in diagnosis since correct clinical assessment of these patients is essential to proper management.

Individual Variant Cases

Tetralogy of Fallot with Right Ventricular Systolic Pressure Exceeding Systemic Systolic Pressure

Patient 1, a ten-year-old boy, had a precordial murmur noted at birth and cyanosis at the age of one year. Thereafter, he had many upper respiratory infections and cyanotic spells. He was markedly cyanotic and had severe clubbing of the fingers, marked elevated "a" waves of the jugular venous pulse, a prominent right ventricular lift, a single second sound, and a loud holosystolic murmur which extended through the second heart sound and which was audible along the left sternal border (Fig 1A and B). Chest roentgenogram demonstrated a right-sided aortic arch and the electrocardiogram showed severe right ventricular hypertrophy with T wave inversion across the entire precordium (Fig 2). At catheterization, the right ventricular systolic pressure exhibited mild pulsus alternans and exceeded the systemic arterial systolic pressure by 105 mm Hg (Fig 3). Indicator-dilution studies, however, revealed the presence of a right-to-left shunt originating from the right ventricle and the result of angiography was consistent with tetralogy of Fallot (Fig 4 and 5). At operation, the defect, high in the ventricular septum, was obstructed by the septal tricuspid leaflet; this accounted for the disparity between systolic pressures in the two ventricles.

Comment: Several features suggested that the ventricular septum in this patient with severe cyanosis was intact: 1) the "a" wave in the jugular venous pulse was markedly elevated; 2) the murmur along the left sternal border was long, loud, harsh, and extended beyond the second heart sound.
TETRALOGY OF FALLOT

A.

PCG

PA

3 LICS

JVP

ECG

B.

PCG

PA

JVP

ECG

sound; 3) the electrocardiogram showed severe right ventricular hypertrophy with marked T wave inversion; 4) the systolic pressure in the right ventricle greatly exceeded that in the systemic artery; and 5) the right ventricular pressure tracing was triangular in shape and had a notch on the upstroke, a finding favoring pulmonic stenosis with an intact septum.\(^1\) The presence of a right aortic arch, however, favored tetralogy of Fallot since this anomaly is observed in approximately one fourth of patients with tetralogy.\(^2\)

In most patients with Fallot's tetralogy, the right ventricular systolic pressure equals the left ventricular systolic pressure, since the ventricular septal defect is large. A number of patients with tetralogy have been reported, however, in whom the right ventricular systolic pressure exceeded that in the left ventricle.\(^3,4\) It is probable that a tricuspid valve leaflet occluded the ventricular septal defect in these patients. The importance of preoperative recognition of this complication rests in the potential danger of leaving a residual ventricular septal defect after relief of right ventricular outflow obstruction; this results in a large left-to-right shunt which floods the lung and increases the flow burden on the left ventricle.

**Tetralogy of Fallot with Absent Pulmonic Valve**

Patient 2, a 23-year-old man, had dyspnea and fatigue all his life. A prominent right ventricular heave and systolic thrill were palpable and a to-and-fro murmur was present along the left sternal border. Chest roentgenogram disclosed a right aortic arch and huge pulmonary arteries. The electrocardiogram demonstrated right axis deviation and right bundle branch block. At catheterization, the brachial arterial saturation was 96 percent; the right ventricular pressure was 110/9 mm Hg, and the pulmonary arterial pressure, 20/10 mm Hg with the gradient occurring at the infundibulum. There was a net left-to-right shunt through the ventricular septal defect of 1.4 to 1. An angiogram showed huge pulmonary arteries, ventricular septal defect, and a right-sided aortic arch (Fig 6). Operation disclosed an absent pulmonic valve in addition to right ventricular infundibular stenosis and ventricular septal defect. The defect was closed and

**Figure 1.** Panel A—Phono-cardiogram, carotid pulse tracing, and electrocardiogram in patient 1. A long systolic murmur is present, suggesting an intact ventricular septum. Panel B—Jugular venous tracing demonstrating large "a" waves, an unusual finding in tetralogy of Fallot. PCG = phonocardiogram; CP = carotid pulse; ECG = electrocardiogram; JVP = jugular venous pulse; PA = pulmonary area; LICS = left intercostal space; SM = systolic murmur.
Figure 2. Electrocardiogram of patient 1. Severe right ventricular hypertrophy is evident.

the right ventricular outflow tract widened. Both postoperative physical examination and cardiac catheterization revealed residual pulmonic regurgitation but there was no pressure gradient between the right ventricle and pulmonary artery and no residual shunting between the ventricles. Symptomatically, the patient was much improved.

Comment: Absence of the pulmonic valve is a recognized but unusual accompaniment of tetralogy of Fallot.5-7 Patients with this anomaly generally have systolic and diastolic murmurs, and aneurysmally dilated pulmonary arteries. The right-sided aortic arch was a clue to the diagnosis of tetralogy of Fallot in this acyanotic patient.

Development of Pulmonary Hypertension after Systemic-Pulmonary Anastomosis in Tetralogy of Fallot

Patient 3, an 18-year-old girl, had a precordial murmur at birth and cyanosis from one month of age. At age three years, a left subclavian-to-pulmonary arterial anastomosis was performed. She was improved for two years,

Figure 3. Simultaneous right ventricular and brachial arterial pressure tracings of patient 1. During systole the right ventricular pressure is markedly higher than brachial arterial pressure, suggesting an intact ventricular septum. RV = right ventricle; BA = brachial artery.
but cyanosis, syncope, and dyspnea recurred. At age five, an end-to-side anastomosis between the right pulmonary artery and descending aorta was performed. She was improved for six years, but dyspnea, fatigue, and increasing cyanosis gradually returned. At age 17, she had severe clubbing and cyanosis, a prominent right ventricular heave, and a grade 1/6 short systolic ejection murmur along the left sternal border. Chest roentgenogram disclosed a right aortic arch. The vascular markings in the left lung were diminished. The central pulmonary markings in the right lung were accentuated and the right main pulmonary artery dilated. Electrocardiogram showed severe right ventricular hypertrophy and right atrial enlargement. At catheterization, the arterial saturation was 67 percent. The systolic pressures in both cardiac ventricles were equal. The right pulmonary artery was entered retrograde from the aorta through the Pott's anastomosis. The right brachial arterial pressure was 88/5 (mean = 68) while simultaneous right pulmonary arterial pressure was 81/54 mm Hg (mean = 66) (Fig 7). The pulmonary-to-systemic flow ratio was 0.4 to 1. Results of angiography revealed a severely stenotic right ventricular infundibulum. Direct injection into the Pott's anastomosis showed considerable constriction between the main and branch pulmonary arteries, a change consistent with severe pulmonary hypertension. Injection into the aortic root disclosed that the left subclavian artery ended blindly in the upper lobe of the left lung (Fig 8). Because of development of pulmonary hypertension in the right lung and evidence of partial thrombosis of the left lung, operation for either partial or total correction was considered too hazardous. She did well for one year, but died suddenly with massive pulmonary hemorrhage. Autopsy revealed changes of

**FIGURE 4.** Right ventricular angiogram of patient 1 in the anterior-posterior projection. The aortic arch is right-sided. There is marked stenosis of the right ventricular infundibulum (arrow).

**FIGURE 5.** Panel A—Left ventricular angiogram of patient 1 in the lateral projection. A small amount of dye traverses the ventricular septal defect from left ventricle to right ventricle. LV = left ventricle; RV = right ventricle; Ao = aorta. Panel B—Right ventricular angiogram in the lateral projection. The right-to-left shunting through the ventricular septal defect is apparent. PA = pulmonary artery.
severe hypertensive pulmonary vascular disease in the right lung (Fig 9), thrombosis of the anastomosed left subclavian artery, and occlusion of the pulmonary arteries to the left upper lobe.

COMMENT: The development of pulmonary hypertension as a consequence of systemic-pulmonary anastomosis in patients with tetralogy of Fallot was reported by McCaff and associates. The following criteria should be satisfied in order to postulate that patients develop increased pulmonary vascular resistance as a consequence of a previous palliative operation: 1) that pulmonary blood flow was reduced initially; 2) that pulmonary blood flow was increased by operation; 3) that an elevation of pulmonary vascular resistance did not antedate operation; and 4) that no other cause for pulmonary vascular disease existed.

These criteria were fulfilled in the present patient. The diagnosis of tetralogy of Fallot was established by catheterization before the first operation, and after each palliative operation, a marked, albeit transient, improvement in the symptoms occurred. The clinical improvement and decrease in cyanosis after each operation suggested that the pulmonary vascular resistance was low enough at the time of operation to permit significant left-to-right
TETRALOGY OF FALLOT

FIGURE 8. Aortic root angiogram of patient 3. The pulmonary artery anastomosis is visualized leading to the right lung. The Blalock-Taussig anastomosis to the left lung ends blindly. Ao = aorta; PA = pulmonary artery; B-T = Blalock-Taussig anastomosis.

shunting through the anastomosis. Lastly, in this patient, other causes for pulmonary vascular disease were absent. Thus, within a six-year-period after the Pott's anastomosis, the pulmonary arterial vascular resistance markedly increased ("Eisenmenger reaction").

Tetralogy of Fallot with Systemic Hypertension

Patient 4, a 22-year-old man, who had a precordial murmur and cyanosis since birth, squatted frequently in childhood, and at age 18 years, catheterization confirmed the diagnosis of tetralogy of Fallot. Increasing dyspnea and fatigue prompted further evaluation at age 22. The blood pressure was 188/144 mm Hg in both arms, the fingers and toes were severely clubbed and cyanotic, the jugular venous pulse had markedly elevated "a" waves (Fig 10), the second heart sound was single, and a grade 3/6 systolic murmur was audible along the left sternal border. Chest roentgenogram revealed a prominent right ventricular lift and thrill along the left sternal border, and a grade 5/6 systolic murmur at the base. Electrocardiogram showed left axis deviation and no right ventricular hypertrophy (Fig 11). At catheterization, the right and left ventricular systolic pressures were equal and a ventricular septal defect

renal glomeruli were large. The cause of death was intracerebral hemorrhage.

COMMENT: Although systemic hypertension is uncommon in patients with tetralogy of Fallot, it is possible that hypertension may have salutary effects in them. The marked elevated aortic pressure may be an added stimulus to the development of bronchial arterial collaterals which become a source of blood to the lungs. Ironically, in the present patient, the systemic hypertension which may have augmented pulmonary blood flow during life, probably accounted for the terminal fatal intracerebral hemorrhage.

INDIVIDUAL SIMULATOR CASES

Hypoplastic Right Ventricle Simulating Tetralogy of Fallot

Patient 5, a five-year-old girl who was noted to have a precordial murmur at birth, grew and developed slowly. At age three years, a patent ductus arteriosus was operatively closed. A coarse thrill was felt in the pulmonary artery after ligation of the ductus. Growth and development did not accelerate postoperatively, and she was referred to the National Heart Institute. Examination disclosed a prominent right ventricular lift and thrill along the left sternal border, and a grade 5/6 systolic murmur at the base. Chest roentgenogram revealed a small pulmonary trunk. Electrocardiogram disclosed left axis deviation and no right ventricular hypertrophy (Fig 11). At catheterization, the right and left ventricular systolic pressures were equal and a ventricular septal defect

FIGURE 9. Section of muscular pulmonary artery and plexiform lesion arising from it in the right upper lobe of lung. The plexiform lesion is indicative of severe pulmonary hypertension. The adjacent alveolar spaces are filled with blood. Elastic von Gieson stain, × 73.
was found. A 70 mm Hg peak systolic pressure gradient was present across the pulmonic valve. A right ventricular angiogram revealed immediate filling of the aorta, and a tiny (hypoplastic) right ventricular cavity.

**Comment:** Although the patient had a ventricular septal defect, equal systolic pressures in both ventricles, pulmonic stenosis, and an overriding aorta, all compatible with Fallot's tetralogy, the electrocardiogram showed little evidence of right ventricular forces, indicating hypoplasia of the right ventricle. Considering the hypoplastic right ventricle, an attempt at total correction with closure of the ventricular septal defect would carry a sizable risk. A palliative operation will be performed if symptoms progress.

**Single Ventricle Simulating Tetralogy of Fallot**

Patient 6, a 22-year-old woman, had a precordial murmur from birth and cyanosis was noted during exercise at age two years. Bacterial endocarditis occurred at ages 9 and 16 years. Examination revealed slight cyanosis,
TETRALOGY OF FALLOT

I

II

AVR

AVL

AVF

AV

V1

V2

V3R

V3

V4

V5

V6

FIGURE 12. Electrocardiogram of patient 6. The RS complexes in leads V1-V4 are suggestive of biventricular hypertrophy.

a long systolic thrill, and a grade 5/6 harsh systolic murmur along the left sternal border. Chest roentgenogram was normal. The electrocardiogram had a normal axis with transitional RS complexes in V1-V4, suggestive of biventricular hypertrophy (Fig 12). Catheterization revealed an arterial saturation of 81 percent and a systolic gradient of 85 mm Hg between the "right" ventricular body and pulmonary trunk. Results of ventricular angiography on two occasions were interpreted as showing a ventricular septum. Corrective operation, therefore, was undertaken. The aorta and pulmonary trunk were of normal size. A vertical incision was made into the outflow tract of the "right ventricle" and into a huge mass of hypertrophied muscle. It was necessary to begin resection of this mass of muscle before the interior of the ventricle could be visualized and accordingly the septal bands of the crista were removed. At this point, the ventricular cavity was visualized and no ventricular septum was present. The pulmonary artery was banded in an attempt to protect the lungs from what would now be systemic pressures. The patient was hypotensive when bypass was terminated, an effective blood pressure could not be maintained, and she died.

COMMENT: Differentiation of single ventricle with pulmonic stenosis from tetralogy of Fallot is sometimes difficult despite extensive preoperative studies. Most patients with single ventricle have transposed great arteries, but the arterial trunks in our patient were normally situated. The electrocardiogram had tall RS complexes in leads V1 through V4, a finding in one patient reported by Elliott and co-workers. In retrospect, the electrocardiogram was very atypical for tetralogy and should have been a strong clue that a different or additional malformation was present.

DISCUSSION

In tetralogy of Fallot, the size of the ventricular septal defect varies little from patient to patient, whereas the degree of right ventricular outflow obstruction varies considerably. Thus, the wide spectrum of clinical features presented by patients with Fallot's tetralogy is related more to differing degrees of right ventricular outflow obstruction and not to differing sizes of the ventricular septal defect. If the infundibular stenosis is mild, the patient may be acyanotic, and have only left-to-right shunting. With severe pulmonic stenosis, the patient is cyanotic, has oligemic lungs, polycythemia, and right-to-left shunting through the ventricular septal defect. Although there is overriding of the aorta in all these patients, this abnormality does not appear to play a significant role in explaining differences in clinical presentations.

The clinical features of tetralogy may be further modified by associated cardiovascular anomalies, the common ones being right aortic arch, persistent left superior vena cava, obstructed ventricular septal defect by a tricuspid valvular leaflet, atrial septal defect, absent pulmonic valve, stenosis of a pulmonary arterial branch, absent pulmonary artery, hypoplasia of the left side of the heart, anomalies of the coronary arteries, and patent duc tus arteriosus. Recognition of these associated lesions often determines the appropriate operative approach for either palliative or corrective procedures.

Knowledge of the location of the aortic arch often determines the approach to a subclavian-pulmonary arterial anastomosis. A persistent left superior vena cava emptying into the coronary sinus may produce no hemodynamic abnormalities, but its recognition is important when total correction is contemplated. During a corrective operation, all

CHEST, VOL. 57, NO. 3, MARCH 1970
venous return to the right atrium must be temporarily occluded to have a bloodless operative field. A left superior vena cava emptying into the coronary sinus will flood the operative field if the coronary sinus is not cannulated or the left superior vena cava not ligated or clamped. If an obstructed ventricular septal defect is not recognized preoperatively, and the sole lesion is considered to be pulmonic stenosis, the ventricular septal defect may allow massive shunting from the systemic to pulmonary circulation once the pulmonic stenosis is relieved. Residual left-to-right shunting through an atrial septal defect may persist if an associated atrial septal defect is not recognized preoperatively. Alternatively, in the immediate postoperative period, if an increase in the filling pressure of the right ventricle is desired, it may not be achieved if a persistent right-to-left shunt at the atrial level exists. The consequences of not recognizing peripheral branch stenosis may be catastrophic when palliative operations are performed as an obstruction proximal to a systemic to pulmonary anastomosis limits the shunt available to the opposite lung. After complete correction of tetralogy, hypertension of the main pulmonary artery may result if there are severely narrowed right and left pulmonary arteries. An anomalous or abnormally large coronary artery coursing over the right ventricle often determines the site of ventriculotomy. Inadvertent bisection of this vessel may severely compromise a right ventricle already compromised by ventriculotomy.

Of other cyanotic congenital cardiac malformations which may mimic tetralogy of Fallot, transposition of the great arteries, single ventricle with pulmonic stenosis, particularly the variety with normally related great arteries, and hypoplasia of the right ventricle have been the most difficult in our experience to distinguish from tetralogy.

References

Reprints requests: Lawrence S. Cohen, M.D., Associate Professor of Medicine, The University of Texas Southwestern Medical School, 5323 Harry Hines Boulevard, Dallas, Texas 75235.