BLALOCK-TAUSSIG ANASTOMOSIS FOR TETRALOGY OF FALLOT A TEN-TO-FIFTEEN YEAR FOLLOW-UP

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The mortality rate for total correction of Fallot's tetralogy on cardiac bypass with or without a Blalock-Taussig anastomosis is still relatively high (Kirklin *et al.*, 1959; Lillehei *et al.*, 1957; Taussig *et al.*, 1962). Favourable reports concerning the results of the Blalock-Taussig procedure in patients followed for five to ten years have been published (Taussig and Bauersfeld, 1953; Campbell and Deuchar, 1953; White *et al.*, 1956; Rumel, 1958; Brock, 1959; Shumacker and Mandelbaum, 1960). While total correction is the ideal, the mortality rate must be weighed against the long-term beneficial effects of the safer Blalock-Taussig operation.

In the present investigation we have studied the results of the Blalock-Taussig operation performed ten or more years ago in the United Birmingham Hospitals and have compared them with the outcome in a group of untreated patients with Fallot's tetralogy over the same period. We were also interested in the effects of a left-to-right shunt, created after birth, on the underperfused pulmonary circulation, since the occasional development of pulmonary hypertension has been reported in some of these patients (Leeds, 1958; Ross, Taussig, and Evans, 1958; Epstein and Naji, 1960; Ferencz, 1960; Paul, Miller, and Potts, 1961; McGaff, Ross, and Braunwald, 1962).

PATIENTS AND METHOD

Between the years 1948 and 1952 the diagnosis of Fallot's tetralogy was made in 42 patients. The diagnosis was based upon clinical signs and confirmed by cardiac catheterization and/or angiocardiography both before operation and again during the present investigation. In 30 of the patients, the disability was so great or was increasing so fast that operation was performed in or before the year 1952. The remaining 12 patients were less disabled and operation was not therefore recommended. The subsequent course of these two groups, henceforth referred to as the treated and untreated groups respectively, has been followed.

The treated group consisted of 30 patients, and 20 (67%) have survived for a mean period of 11.9 years (range 10-15). Their ages at the time of operation ranged between 4 and 37 years (mean 10.3). The remaining 10 are known to have died. Of the surviving patients, 19 have been studied and one refused investigation, although we have full details of his present clinical condition. There were 13 male and 7 female patients whose ages ranged from 14 to 37 years (mean 22.2) at the time of study. The untreated group comprised 12 patients (6 male and 6 female) whose ages ranged between 3 and 27 years (mean 11.7) when first seen. Excluded from this study were patients diagnosed in or before 1952, not operated on then, but operated upon since 1952.

At the time of the follow-up investigation in the treated group each patient was examined and exercise tolerance was graded according to the New York Heart Association (1953). Special investigations included hæmoglobin concentration and hæmatocrit measurement, electrocardiogram, phonocardiogram, and chest radiograph. Seventeen patients had cardiac catheterization which was performed by the usual method. Intravascular pressures were measured by capacitance manometers, the zero reference level for pressures being 10 cm. above the plane of the table. All pressures were averaged over at least three respiratory cycles. Expired gas was collected for three minutes in a Tissot spirometer and analysed in a Scholander

apparatus. Three samples each of arterial and right pulmonary arterial blood were taken for determination of oxygen saturation (Wade *et al.*, 1953). Blood samples for estimation of oxygen saturations were taken at various sites commencing distally in the right and left pulmonary arteries, which were entered in 15 patients, and ending in the superior vena cava.

The patients then exercised on a bicycle ergometer for five minutes at a constant load in the supine position. Oxygen uptake, right pulmonary and brachial arterial blood samples for oxygen saturation were measured between the fourth and fifth minutes of exercise, and intravascular pressures were recorded immediately before and after the measurement of oxygen uptake.

RESULTS

Treated Group. Analysis of the age distribution and results of the Blalock-Taussig operation in the 30 patients are shown in Tables I and II: 20 (67%) have survived for a mean period of 11.9 years (range 10–15), and the remaining 10 are known to have died. Only one patient died at the time of operation, and another patient died during a second operation one year later, following thrombosis of the first anastomosis. Four patients died in congestive cardiac failure within six months of operation. One died in his eighth post-operative year and three in their tenth post-operative year, in congestive cardiac failure. These last four patients were improved by operation and were relatively well until a few months before death. Necropsy was performed in only one of these patients (Patient No. 30, Table II), and this revealed histological features compatible with severe pulmonary arterial hypertension (Fig. 1). Direct intravascular pressures were not obtained, although a chest radiograph taken three months before death revealed a large heart and a pulmonary vascular pattern highly suggestive of pulmonary arterial hypertension (Fig. 2).

Effort Tolerance. After operation effort tolerance improved in all the patients, including four who have since died. In most the clinical improvement was immediate, but some continued to improve further over the ensuing years, and all have maintained their improved state.

At the time of the present investigation all the survivors had improved from class 3 or 4 to class 1 or 2. In addition, the tendency to squatting and cyanotic attacks has considerably diminished or disappeared. They were able to lead relatively normal lives in that they were either doing a full day's work or attending school. Some of the younger patients participated in games at school and some of the adults were able to dance.

Physical Examination. On examination all the patients were centrally cyanosed at rest and all except Patient 2 had clubbing of the fingers and toes. In three the clubbing was less marked on the side of the subclavian artery ligation. Of the patients who had had the operation before the age of 11 years 13 had a slightly shorter left arm with reduction in muscle mass as compared with the right. An example is shown in Fig. 3. There was clinical evidence of right ventricular hypertrophy and a systolic thrill in the pulmonary area with a typical systolic ejection murmur along the left parasternal border. Evidence of patency of the anastomosis as judged by the presence of a continuous murmur in the second interspace was present in all the patients.

General Investigation. The hæmoglobin concentration ranged between 15.0 and 21.7 g./100 ml. (mean 18.8) and hæmatocrit between 50 and 76 per cent.

The electrocardiogram showed right ventricular hypertrophy. All the patients were in sinus rhythm; 4 had right bundle-branch block, and 13 had "P" waves indicative of right atrial enlargement; 5 had evidence of left ventricular hypertrophy with "R" waves greater than 25 mm. in the left præcordial leads.

Phonocardiography confirmed the clinical auscultatory findings.

In none of the patients was there radiological evidence of cardiac enlargement. The cardio-thoracic ratio was less than 50 per cent in all, and the left pulmonary artery and its branches were more prominent and better filled than the right in most.

Intravascular Pressures. The results of measurements of pulmonary arterial and right ventricular systolic pressures, together with the percentage oxygen saturations of pulmonary arterial blood at rest are shown in Fig. 4. All had evidence of pulmonary stenosis with a marked difference in systolic

TABLE I
AGE DISTRIBUTION AND FUNCTIONAL CARDIAC STATUS OF SURVIVING PATIENTS BEFORE AND AFTER
BLALOCK-TAUSSIG OPERATION

Patient No. and sex	Age at operation (yr.)	Present age (yr.)	Functional classification			
			Class before operation		Class after operation	
			3	4	1	2
1 M	7	18	+		+	
2 M	17	31	+		+	
3 M	5	15	+		+	
4 M	5	19	+			+
5 F	19	34	+		+	
6 M	17	27	+		+	
7 M	7	18	+			+
8 M	14	24	+		+	
9 M	4	18	+		+	
10 M	16	28	+			+
11 M	5	18	+		+	
12 M	6	18	+		+	
13 F	4	14		+		+
14 F	6	16	+		+	
15 F	27	37		+		+
16 M	9	19	+			+
17 M	5	17	+			+
18 F	4	18	+			+
19 F	11	24		+		+
20 F	18	31	+			+
Mean	10.3	22.2				

TABLE II
AGE BEFORE AND AFTER OPERATION AND CAUSE OF DEATH IN THE PATIENTS WHO DIED

Patient No. and sex	Age at operation (yr.)	Age at death (yr.)	Cause of death
1 F	3	3	Died at operation
2 M	12	12	Died in congestive cardiac failure 6 months after operation
3 M	4	4	Died in congestive cardiac failure 6 months after operation
4 F	3	4	Died in congestive cardiac failure 6 months after operation
5 F	13	13	Died in congestive cardiac failure 6 months after operation
6 M	5	5	Died in congestive cardiac failure 6 months after operation
7 M	6	14	Died in congestive cardiac failure 8 years after operation
8 F	14	25	Cyanotic attack 10 years after operation
9 F	4	14	Died in congestive cardiac failure 10 years after operation
10 M	37	46	Died in congestive cardiac failure 10 years after operation
Mean	10.1	14	

pressure across the pulmonary valve. The right ventricular systolic pressure ranged between 80 and 170 mm. Hg (mean 111 mm. Hg). The patient who had a right ventricular systolic pressure of 170 mm. Hg had associated systemic arterial hypertension. In all but one patient the pulmonary systolic pressure ranged between 10 and 25 mm. Hg, and the average pulmonary mean pressure was 12 mm. Hg. The remaining patient (No. 2) had a moderately raised pulmonary arterial pressure (mean 26 mm. Hg). The pulmonary wedge pressure was within the normal range in all. During exercise the average pulmonary arterial mean pressure increased by 8 mm. Hg, and the pulmonary

FIG. 1.—Transverse section of a muscular pulmonary artery from Patient No. 30, showing medial hypertrophy and occlusion of the lumen by intimal fibro-elastosis, Grade 3 (Heath *et al.*, 1959). (Verhoeff-van Gieson $\times 250$).

FIG. 2.—Chest radiograph of Patient No. 30 taken three months before death. The main pulmonary arteries are prominent with dilatation of the right and left branches and of the first divisions. There is generalized enlargement of the heart.

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FIG. 3.—Hands of Patient No. 17: the left hand (side of anastomosis) is smaller than the right.

wedge pressure remained unchanged. In the patient with mild pulmonary hypertension the pulmonary arterial mean pressure increased by 10 mm. Hg.

Clinically and radiologically there was no evidence to suggest that the 3 patients who were not catheterized had severe pulmonary hypertension.

Blood Oxygen Saturation. Evidence of patency of the anastomosis was obtained since the left pulmonary arterial oxygen saturation was higher than the right in all the patients catheterized (Fig. 4). The brachial arterial oxygen saturation ranged between 90 and 76 per cent at rest. During exercise the arterial oxygen saturation always fell.

Oxygen Uptake. The oxygen uptake at rest ranged between 103 and 214 ml./min./m.² (mean 173; S.D. 29.2). In 10 normal subjects studied in this laboratory (Donald *et al.*, 1953) the mean oxygen uptake at rest was 140 ml./min./m.² (S.D. 22.7), which is significantly less ($p < 0.01$) than

FIG. 4.—Values for pulmonary arterial and right ventricular systolic pressures and pulmonary arterial oxygen saturations at rest in 15 patients. R.P.A. = right pulmonary artery; L.P.A. = left pulmonary artery.

FIG. 5.—Brachial arterial oxygen saturation plotted against oxygen uptake at rest and during exercise in 14 patients.

the oxygen uptake in the patients. The mean ventilation at rest ranged from 3.49 to 8.49 l./min. (mean 5.1; S.D. 1.37 l./min.) and the mean R.Q. was 0.78 (S.D. 0.037) and ranged from 0.73 to 0.81.

During exercise the oxygen uptake ranged between 420 and 640 ml./min./m.² (mean 518; S.D. 63.1) and was achieved without distress.

The brachial arterial oxygen saturation plotted against the oxygen uptake at rest and during exercise is shown in Fig. 5. In general the fall in arterial saturation was related to the severity of the exercise as judged by the oxygen uptake.

Untreated Patients. Of the 12 untreated patients, 9 (75%) have died and 3 are still alive. The ages at death ranged between 5 and 30 years (mean 13.1). Most appeared to have died in congestive cardiac failure but autopsy was not obtained in any, and there was no clinical evidence of severe pulmonary arterial hypertension. The 3 surviving patients are in functional class 2, and their present ages are 18, 23, and 39 years.

DISCUSSION

The natural life expectancy of patients with Fallot's tetralogy is variable. Most patients who have this malformation die during childhood but survivals as long as 69 years have been reported (Bain, 1954). Analysis of 115 patients with Fallot's tetralogy in Abbott's series (1936) revealed a mean survival of 12 years, but few survive 20 years (Keith, Rowe, and Vlad, 1958). In the untreated group of the present series, 75 per cent have died and their mean age at death was 13.1 years. In the treated patients the survival rate was 67 per cent, and the mean age of the survivors is 22.2 years. The difference between the survival rates for the treated and untreated groups was significant at the 5 per cent level. Furthermore the survivors of the treated group are all greatly improved, leading relatively normal lives and are able to perform without difficulty a moderate degree of exercise both as judged by history and the oxygen uptake. These patients were all severely disabled at the time of operation and judging by the mean survival of untreated patients (Keith *et al.*, 1958) they might not be expected to have survived so long. Taussig *et al.* (1962) have reported that although continued improvement occurred in all survivors five years after operation, 46 per cent of their patients followed for 10 to 13 years after operation had failed to maintain clinical improvement. To date there is no evidence of deterioration in the survivors of this series. Paul *et al.* (1961), have reported that clinical improvement has been maintained 11 to 13 years after aortic-pulmonary anastomosis.

The mortality for total correction of Fallot's tetralogy on cardiac bypass has ranged between 10 and 75 per cent (Lillehei *et al.*, 1957; Kirklin *et al.*, 1959; Brock, 1959). The mortality rate for the Blalock-Taussig operation is of the order of 2 per cent (Taussig *et al.*, 1962). Furthermore it is apparent that incomplete correction is neither uncommon nor without serious sequelæ (M. Gotsman, 1963, personal communication). It is clear from this series that the Blalock-Taussig procedure improves the survival and clinical conditions of patients with Fallot's tetralogy who are severely disabled. Unless the mortality rate for total correction considerably improves in the near future, the Blalock-Taussig operation should be preferred, at least in childhood. Furthermore, since clinical improvement has been adequately maintained in all the surviving patients and the heart size radiologically has remained within normal limits, there is no indication for complete correction at present. The indication for further surgical intervention should be based upon rapid deterioration in the clinical state (increased cyanosis and decreased effort tolerance) and an increase of the heart size.

Pulmonary hypertension occurred in one of the treated survivors, who died in his tenth post-operative year, and might have been present in the seven others who died, although there was no clinical evidence, at least, of severe pulmonary hypertension just before death. Since it was clinically not possible to detect minor degrees of pulmonary arterial hypertension, the incidence of this complication in this series cannot be assessed. Nor is it possible to determine the overall incidence from

other reported series, since these have usually been concerned with selected patients with pulmonary hypertension (Leeds, 1958; Ross *et al.*, 1958; Epstein and Naji, 1960; McGaff *et al.*, 1962).

Apart from the catheter findings there were no special clinical features that distinguished the single patient with mild pulmonary hypertension from the rest. The mechanism of pulmonary hypertension following a Blalock-Taussig anastomosis is not clear. It is not likely to be due to a large pulmonary blood flow that might be the cause in septal defects, since the shunt produced by operation would at most increase pulmonary flow to within normal or slightly higher limits. It has been suggested that even a small increase in blood flow through a previously underperfused and possibly abnormal pulmonary vascular tree might lead to pulmonary hypertension, since the vessels are relatively incapable of further distension (Heath *et al.*, 1959; Wagenvoort, DuShane, and Edwards, 1960). In some patients the presence of pulmonary arteriolar thrombi, presumably due to the low pulmonary intravascular pressures and flow (Rich, 1948), might also be an important factor in the pathogenesis of pulmonary hypertension when the pulmonary flow is increased at operation.

In three patients, clubbing of the fingers was less on the side of the sub-clavian artery ligation. This has been observed by Campbell and Deuchar (1953) and has been attributed to a reduction in limb blood flow (Lovell, 1950; Wilson, 1952). The reduction in arm size on the side of the anastomoses has not been previously commented upon, although this is not unexpected when the operation is carried out at an early age.

The resting oxygen uptake in the treated group was greater than the expected normal range. Conflicting reports have been published concerning the oxygen uptake in Fallot's tetralogy and other cyanotic heart conditions. Bing *et al.* (1948) found the oxygen uptake to be low while others have found it normal (Ernsting and Shephard, 1951; Davison, Armitage, and Arnott, 1953). Some of these patients were studied again after the Blalock-Taussig operation, and a rise in the oxygen uptake was observed (Bing *et al.*, 1948; Davison *et al.*, 1953). The mechanism of the increase in oxygen uptake remains obscure.

Unfortunately since autopsies were not obtained in the 9 untreated and 9 treated patients who died, we were unable to determine the precise cause of death. Undoubtedly, the most common cause of death in infancy and early childhood is "syncope." Bacterial endocarditis and cerebral abscesses account for 20 per cent and intercurrent infection is responsible for most of the remainder (Wood, 1956). In a series of 117 autopsies performed on patients with Fallot's tetralogy who had a Blalock-Taussig operation the commonest cause of death immediately after operation was congestive cardiac failure. The incidence of congestive cardiac failure as a cause of death remained high in those who died one or more years after operation. The anastomosis remained patent in 108 of the 117 patients investigated. The incidence of severe pulmonary arteriolar thrombotic lesions, characteristic of the unoperated patients, was low. In patients who had a good anastomosis initially, but who lost their clinical improvement with growth, there was a tendency towards the recurrence of the thrombotic lesions. Only three patients had evidence of severe pulmonary hypertension (Ferencz, 1960).

SUMMARY

Thirty patients with Fallot's tetralogy who have had a Blalock-Taussig operation performed ten or more years ago have been studied: 67 per cent have survived, are clinically improved, and leading relatively normal lives. In a group of untreated patients followed for the same period of time, 25 per cent have survived.

The Blalock-Taussig operation has a low mortality and the results are good. Since the mortality for total correction of Fallot's tetralogy is still high, the former operation is to be preferred, at least in childhood.

Two patients who developed pulmonary hypertension are described.

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