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Tetralogy of Fallot
Risk factors associated with complete repair

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Ninety-six consecutive total repairs of the tetralogy of Fallot are reviewed. There was an overall hospital mortality of 8·3 per cent and a total incidence of low output cardiac failure of 18·8 per cent, and this was the principal cause of death and the most important source of postoperative morbidity. In 49 cases there had been a previous palliative shunt procedure and there was a strikingly lower mortality and a highly significant lower morbidity in this group. Other factors which correlated in a positive fashion with increased mortality and morbidity were chronic hypoxia (as evidenced by polycythaemia), age below 5 years, severe postoperative right ventricular hypertension, and (to a lesser extent) extensive right ventricular outflow tract reconstruction.

Data are presented to support the hypothesis that a palliative shunt procedure should be considered in the severely polycythaemic child with a surgically 'unfavourable' right ventricular outflow. This policy carries a low early mortality in our hands (5·4%), and is associated with a low mortality (3·9%) at subsequent repair. This compares with a mortality of 12·8 per cent for primary repair, and the incidence of low output cardiac failure is five times as high in the primary repair as compared to the previously shunted group.

The congenital heart defect which is now almost universally known as the tetralogy of Fallot was first recognized as a pathological entity by Nils Stensen in 1671. In the succeeding centuries it was known to a number of medical writers but it was not until 1888, after a series of papers by Louis-Etienne Fallot, who in fact called the condition 'Cyanose Cardiaque', that the clinical and pathological features were clearly described and correlated. This author drew attention to four cardinal features of the condition in such a clear and concise fashion that the eponym, 'Fallot's tetralogy', seems to be a fitting memorial.

In 1945, Blalock and Taussig first described an operation to palliate the symptoms of the condition, and the first attempt at complete repair of the lesion was made in 1954 by H. W. Scott using whole body hypothermia and circulatory arrest.

The subsequent development of safe methods of cardiopulmonary bypass has allowed refinements of surgical techniques such that the operative mortality for complete repair is now about 5 to 10 per cent in most reported series (Malm *et al.*, 1966; Gottsman *et al.*, 1969; Kirklin and Karp, 1970).

In an effort to try to recognize factors which correlate with the continuing hospital mortality, we have reviewed the results achieved in a consecutive series of 96 operations conducted during a 4-year period.

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Subjects and methods

During the four-year period ending in 1974, all operations for total repair of the tetralogy of Fallot have been reviewed. The data recorded included age at operation, weight centile using hospital graphs derived from data by Tanner, Whitehouse, and Takaishi (1966), history of a previous shunt procedure, haemoglobin level in g/dl, method of outflow tract reconstruction, the ratio of right ventricular to left ventricular systolic pressure measured at the conclusion of the operation, total cardiopulmonary bypass time, blood loss in the first 6 postoperative hours expressed as ml/kg per hr, mean systolic blood pressure during the first 24 postoperative hours, urine flow during the first 24 postoperative hours expressed as ml/kg per hr,

and the subsequent postoperative course in hospital.

The two morbidity end-points which were considered were (1) death in hospital and (2) low output cardiac failure. This latter end-point was a clinical diagnosis which was arbitrarily defined by the following features: (1) cool, cyanosed extremities; (2) systolic blood pressure less than 90 mmHg (12 kPa) for the initial 24 hours after operation; (3) urine flow less than 0·7 ml/kg^{-1} hr^{-1} for the whole of the 24-hour period; and/or (4) the necessity for a catecholamine infusion to overcome the clinical signs listed as 1 to 3 above

Preoperative and intraoperative observations were correlated with the two morbidity end-points and, in part, with each other. The significance of observed correlations was tested by standard statistical methods (Snedecor and Cochran, 1967).

Operative techniques

The techniques used during the operation and perfusion were substantially the same for all cases during the period under review. Perfusions were conducted with haemodiluted primes, a bubble oxygenator, a roller pump, and the nasopharyngeal temperature was reduced to 25°C. Intracardiac manoeuvres were carried out with intermittent periods of aortic cross-clamping up to 20 minutes at any one time. The left ventricle or the left atrium was vented. The ventricular septal defect was patched with two-way stretch knitted 'dacron' material. Right ventricular outflow tract patches, when used, were generally of autogenous pericardium, and in a few cases a monocusp valve was fashioned to provide at least temporary pulmonary valve competence. Right atrial and central arterial pressures were monitored postoperatively in all patients, and left atrial pressure was monitored also on some occasions. Postoperative management was along conventional lines and catecholamine infusion was usually the first drug intervention used if a low cardiac output was diagnosed.

Results

Influence of prior shunt on results of complete repair

The overall results in relation to hospital mortality are shown in Table 1. This shows that the overall mortality for all 96 operations was 8·3 per cent. The mortality was considerably higher in the unshunted as compared with the previously shunted group though the difference on these figures was not statistically significant.

The causes of death in the 8 fatal cases are listed in Table 2. The mode of death in all 8 cases was low output cardiac failure as defined above, but in the two previously shunted patients there seemed to be a demonstrable cause for this in that unrecognized obstructive pulmonary vascular disease had supervened in one patient after a Waterston shunt and in the second case the right ventricular outflow tract obstruction had not been relieved. In the remaining 6 cases, all unshunted, there was no such discernible cause for the low output cardiac failure unless one postulates that low pulmonary flow from

TABLE 1 *Mortality in 96 consecutive cases of total repair of Fallot's tetralogy*

	Cases	*Mortality*
Primary repair	47	6 (12·8%)
Previous shunt	49	2 (3·9%)
Total	96	8 (8·3%)

(0·30>P>0·20)

TABLE 2 *Causes of death in 96 consecutive cases of total repair of Fallot's tetralogy*

Cause of death	*Cases*
Low output cardiac failure	6 (all unshunted)
Obstructive pulmonary vascular disease	1 (previous Waterston shunt)
Unrelieved right ventricular obstruction	1 (previous left Blalock)
Total	8

TABLE 3 *List of previous shunt operations and mortality at subsequent repair*

Shunt		*Cases*		*Mortality*	
Right pulmonary artery to aorta (Waterston)		18		1 (5·5%)	
Left pulmonary artery to aorta (Pott's)		9		0	
Left subclavian artery to left pulmonary artery	Blalock	8	22	1 (12·5%)	1 (4·5%)
Right subclavian artery to right pulmonary artery		14		0	

early life may result in a left ventricle which is not 'trained' to sustain a normal cardiac output.

In any event, for the purpose of this paper, the total mortality in this series in both shunted and unshunted cases was regarded as the result of low output cardiac failure, and statistical analyses were made on this assumption.

Table 3 lists the various types of pulmonary to systemic shunts which required to be taken down at the time of complete repair together with the operative mortality in each group. Though in our experience the technically easiest shunt to take down is a right Blalock, there is no evidence from these figures that one shunt rather than another introduces a significant risk of fatal complications at the time of complete repair.

The second analysis was to determine the total incidence of low output cardiac failure in the entire series of 96 operations. The total incidence was regarded as the fatal cases plus those non-fatal cases which met the arbitrary definition of low output failure as described above. This analysis is set out in Table 4 and shows clearly that there was 5 times the incidence of this event in the unshunted as opposed to the shunted subset; this difference was highly significant.

TABLE 4 *Incidence of low output cardiac failure*

	Cases	*Cardiac failure*
Primary repair	47	15 (31·9%)
Previous shunt	49	3 (6·1%)
Total	96	18 (18·8%)

(0·005>P>0·001)

Influence of patient age on results of complete repair

None of the patients in this series was under the age of 2 years. The distribution of patients according to age is illustrated in the bar-graph represented in Fig. 1 and the data are analysed in Table 5. The patients in the shunted group tended to be slightly older, with a median age of 8·3 years as opposed to the unshunted group with a median age of 6·1 years. The mortality and total incidence of low output cardiac failure was 2 to 3 times higher in the patients under the age of 5 years though on the figures available the significance of this difference is not certain. However, our experience suggests that patients over the age of 5 years, especially if they have a prior shunt, have a better postoperative course.

Influence of patient's weight (physical development) on results of complete repair

The great majority of the patients in this series were much below the appropriate weight in relation to their age. This is illustrated in the bar-graph

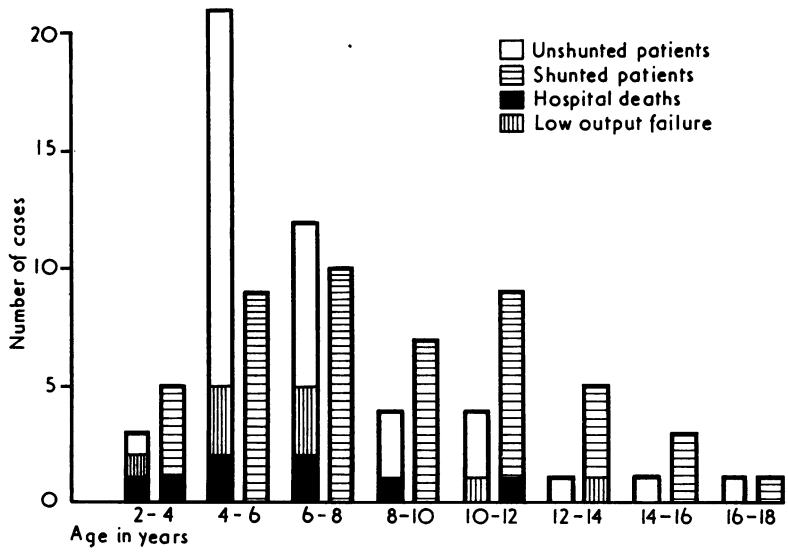

FIG. 1 *This bar graph depicts the distribution of the shunted and unshunted patients in the various age groups. The median age of the unshunted patients was 6·1 years compared with 8·3 years in the shunted patients, but this difference did not reach significant levels (0·10 > P > 0·05).*

TABLE 5 *Relation of age to mortality and power failure*

	Age (y)	*No.*	*Mortality*		*Power failure*	
Primary repair	<5	16	3 (18·7%)	P>0·20	7 (43·7%)	P>0·20
	>5	31	3 (10·7%)		8 (25·8%)	
Previous shunt	<5	9	1 (11·1%)	P>0·20	2 (22·2%)	P>0·20
	>5	40	1 (2·5%)		3 (7·5%)	
All cases	<5	25	4 (16%)	P<0·20	8 (32%)	P<0·05
	>5	71	4 (5·6%)		10 (14·1%)	

represented in Fig. 2. Half the patients in the unshunted group were below the 10th centile for weight, and a similar proportion in the shunted subset were below the 20th centile. This indicates that the entire group of 96 patients were much less well physically developed than the average population of their age and this difference was highly significant ($P < 0.001$). However, there was no statistically significant difference in the distribution of the two groups, shunted and unshunted, according to weight centiles, and the mortality and morbidity seemed randomly distributed over the range of centile subgroups as is evident from Table 6. It is concluded that body weight adjusted for age has no predictive value in anticipating hospital morbidity or mortality.

Influence of preoperative haemoglobin levels on results of complete repair

A raised haemoglobin level in these patients was taken as evidence of chronic hypoxia caused by a reduced or suboptimal pulmonary blood flow. As expected, there tended to be a higher proportion of shunted patients in the groups with normal or near normal haemoglobin levels as is illustrated in Fig. 3, though the difference in observed distribution did not reach significant levels. There was a significantly higher mortality and morbidity in the group with haemoglobin concentrations in excess of 19 g/dl. This is evident in the analysis set out in

TABLE 6 *Relation of body weight to mortality and low output cardiac failure*

Weight (centile)	*All cases*	*Mortality*	*Power failure*
<10th	44	6 (13·7%)	9 (20·5%)
10th–50th	34	1 (3·3%)	4 (13·2%)
>50th	18	1 (5·6%)	5 (20·2%)
		NS	NS

Shunted and unshunted cases appeared randomly distributed between 3 weight/centile subsets.
NS=not significant.

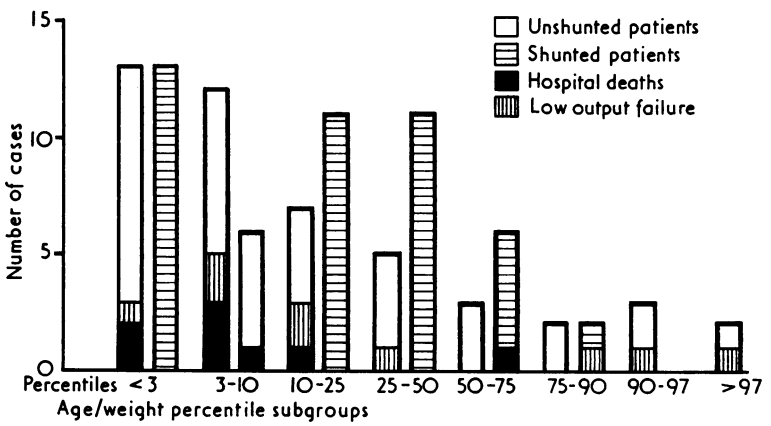

FIG. 2 *This bar graph depicts the distribution of shunted and unshunted patients according to weight centiles. There was no significant difference in the distribution of the two groups, but both distributions differed highly significantly from an expected normal population ($P < 0.001$).*

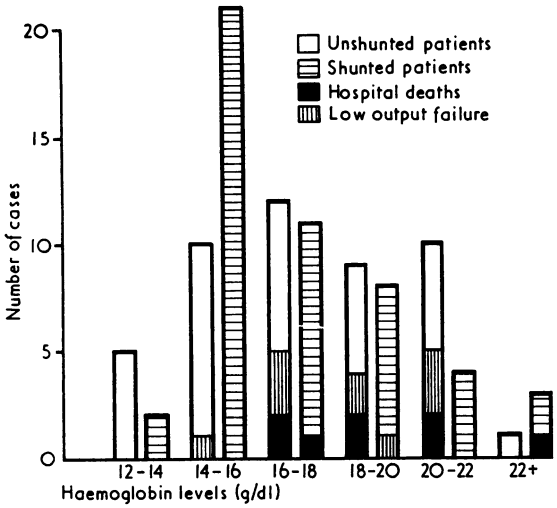

FIG. 3 *This bar graph depicts the distribution of shunted and unshunted patients according to haemoglobin levels. The median level in the unshunted group was 17·4 g/dl compared with 16·3 g/dl in the shunted group, but this difference did not reach significant levels (0·20 > P > 0·10).*

Table 7 and the figures certainly support the thesis that high haemoglobin levels are associated with increased operative risk.

Combined influence of major preoperative risk factors on results of complete repair

From the analysis thus far it seemed that earlier shunting was associated with a reduced morbidity, whereas a high haemoglobin level was associated with an increased risk. By combining these two factors (see Table 8) it was possible to define a low risk group with haemoglobin levels in the normal range, whether or not shunted, a moderate risk group who had raised haemoglobin levels but were previously shunted, and a high risk group who had both high haemoglobin levels and had not had a previous shunt. The observed difference in morbidity in these three clinical groups was highly significant.

If each of these three groups was further subdivided into subgroups below and above the age of 5 years (see Table 9), the numbers become too small to achieve statistical significance, but the mortality and morbidity in the younger age subgroups seem to be appreciably higher.

TABLE 7 *Relation of haemoglobin levels to mortality and low output cardiac failure*

	No.	*Haemoglobin conc.*	*Mortality*	*Cardiac failure*
Primary repair	16	< 16 g/dl	0	1 (6·3%)
	17	16–19 g/dl	2 (11·8%)	7 (41·7%)
	14	> 19 g/dl	4 (28·6%)	7 (50·0%)
			P > 0·2	P < 0·05
Previous shunt	23		0	0
	17		1 (5·9%)	1 (5·9%)
	9		1 (11·1%)	2 (22·2%)
			NS	NS
All cases	39	< 16 g/dl	0	1 (2·6%)
	34	16–19 g/dl	3 (8·8%)	8 (23·5%)
	23	> 19 g/dl	5 (21·7%)	9 (39·1%)
			P < 0·025	P < 0·001

TABLE 8 *Mortality and morbidity in relation to polycythaemia plus a prior shunt*

Category	*Cases*	*Mortality*	*Low output cardiac failure*
Hb < 16g/dl Shunted and unshunted	38	0	1 (2·6%)
Hb > 16 g/dl and shunted	26	2 (7·7%)	3 (11·5%)
Hb > 16 g/dl and unshunted	32	6 (18·6%)	14 (43·8%)
		P < 0·0005	P < 0·0005

Intraoperative correlates of postoperative mortality and morbidity

As indicated above, all the operations were conducted along substantially the same lines, and two

TABLE 9 *Mortality and morbidity in relation to polycythaemia, age, and prior shunting*

Category	*Cases*	*Mortality*	*Low output cardiac failure*
Hb < 16 g/dl Age > 5 yr	30	0	0
Hb < 16 g/dl Age < 5 yr	8	0	1 (12·5%)
Hb > 16 g/dl Shunted Age > 5 yr	21	1 (5%)	2 (10%)
Hb > 16 g/dl Shunted Age < 5 yr	5	1 (20%)	1 (20%)
Hb > 16 g/dl Unshunted Age > 5 yr	20	3 (15%)	7 (35%)
Hb > 16 g/dl Unshunted Age < 5 yr	12	3 (25%)	7 (58%)

intraoperative factors were tested for correlation with the postoperative results. These were: (1) the relation of the right ventricular to the left ventricular systolic pressure at the completion of the operation, and (2) the method of right ventricular outflow tract reconstruction.

Relation of ratio of right to left ventricular post repair systolic pressures to results of complete repair At the conclusion of each operation, after cardiopulmonary bypass had been discontinued and when a reasonably stable circulation had been re-established, pressures were recorded in both the right and the left ventricular cavities by needle puncture. A ratio of right to left ventricular systolic pressures below one-third was regarded as indicating a good right ventricular outflow tract reconstruction. If the ratio was between one-third and two-thirds this was generally considered as acceptable but not optimal. If the ratio was in excess of two-thirds this was regarded as unsatisfactory, and on several occasions a further bypass run was conducted in an attempt to allow a more complete relief of the right ventricular outflow tract obstruction. The justification for these attitudes is apparent from perusal of Table 10 which shows quite clearly that there was a statistically significant increase in mortality and morbidity in those cases in which the right ventricular pressure remained high at the end of the repair operation. Shunted and unshunted cases were randomly distributed between the first two groups but as it happened a majority of cases in the third group had previously been shunted. The reason for this was, in part, that this group of patients had been regarded at the time of the original investigation to have a right ventricular outflow tract which was unfavourable for early repair, and hence some of these were shunted as a preliminary procedure hoping that as the child grew older right ventricular outflow tract reconstruction might be technically easier. Despite the fact that in general a previous shunt was associated with a low mortality and morbidity it does not seem to protect the patient from the serious prognostic import of a high residual right ventricular pressure.

TABLE 10 *Relation of RVp/LVp after repair to mortality and low output cardiac failure*

RVp/LVp	*Cases*	*Mortality*	*Cardiac failure*
0·40	34	1 (2·9%)	4 (12·6%)
0·40–0·70	51	3 (6·0%)	9 (17·7%)
0·70	11	4 (36·4%)	5 (45·5%)
		0·005>P>0·001	0·01>P>0·05

Shunted and unshunted cases were randomly distributed between first 2 groups but 75 per cent of cases in third group were unshunted.
RVp/LVp=ratio of right to left ventricular systolic pressures.

Method of right ventricular outflow tract reconstruction and results of total repair While it is generally recognized that the major obstacle to successful total correction is difficulty with the reconstruction of the right ventricular outflow tract, it has none the less been suggested that a long outflow tract patch across the pulmonary valve ring resulting in pulmonary valve regurgitation is associated with higher mortality and morbidity and, therefore, should be avoided if at all possible (Kirklin and Karp, 1970). Our experience in this regard is set out in Table 11. Our patients were about equally divided into a first group with an intact, unobstructed pulmonary valve, a second group which required pulmonary valvotomy with the inevitable production of some pulmonary valve regurgitation, and a third group which required extensive patch reconstruction of the outflow tract with the patch extending across the pulmonary valve ring and therefore associated with free pulmonary valve regurgitation (except for three isolated cases in which a monocusp valve was constructed from pericardium). As can be seen, there was an increased mortality and morbidity in those patients requiring extensive right ventricular outflow tract reconstruction, but on the basis of these figures the observed difference was not significant. Our experience suggests that it is far more important to achieve more or less complete relief of right ventricular outflow tract obstruction by whatever means is necessary even if this leaves a regurgitant pulmon-

TABLE 11 *Relation of right ventricular outflow tract reconstruction to mortality and low output cardiac failure*

Reconstruction	*Cases*	*Mortality*	*Cardiac failure*
Infundibulectomy alone	30	1 (3·3%)	3 (10%)
Infundibular patch	5	0	0
Pulmonary valvotomy with PR	32	2 (6·25%)	7 (21·9%)
Patch reconstruction across pulmonary valve ring	29	5 (17·4%)	8 (27·6%)
		0·30>P>0·20	

Shunted and unshunted cases appeared randomly distributed between 4 reconstruction groups.
PR=Pulmonary valve regurgitation.

ary valve. This last feature seems of little importance, in the short term at least, so long as the right ventricular pressure is low.

Bypass time

Not surprisingly the total cardiopulmonary bypass time in the previously shunted group of patients was slightly longer than in the unshunted patients. The median bypass time for the shunted patients was 101 minutes compared with a median figure of 93 minutes for the unshunted patients, but this difference was not statistically significant from our figures.

Postoperative drainage

Again, not surprisingly, the postoperative chest drainage during the first 6 hours in the previously shunted group was slightly larger, amounting to a median figure of 2·7 ml/kg^{-1} hr^{-1} compared with a median figure of 1·9 ml/kg^{-1} hr^{-1} for the unshunted group, but once again this difference was not statistically significant.

Discussion

Although in the experience of some surgeons a previous systemic to pulmonary artery anastomosis is associated with a higher surgical mortality at the second stage repair (Ehrenhaft, Fisher, and Lawrence, 1963), the general consensus is that a previous shunt does not militate against a good result at the time of complete repair. There have been only a few published reports (Leachman, Hallman, and Cooley, 1965; Ebert and Sabiston, 1967) in which data are supplied to support the thesis that there is a lower incidence of complications in the previously shunted group. Two reasons have been advanced for this lower morbidity. In the first place a previous shunt results in a reduced haemoglobin level, and in the second place it may increase left ventricular size and work potential when this is initially small. Our data could be interpreted to support either or both of these hypotheses.

Early complete repair has been advocated (Barratt-Boyes and Neutze, 1973; Rees and Starr, 1973) because of the alleged high mortality from shunting in infancy. However, this has not been our experience. During the period in which we undertook the 96 total repairs which have been reviewed, we also operated on a further 37 infants, under the age of 2, with the tetralogy of Fallot and electively performed shunt operations, with only 2 hospital deaths (5·4%) and no late deaths. Only a few of this group of infants came forward for complete repair during the period under review. The number who died from natural causes without surgical referral is not known.

Clearly, the final answer to the question of the best surgical policy to follow in respect of these patients will come when it is possible to follow a whole cohort of infants with this diagnosis from infancy to adult life in centres with varying surgical policies. Only then will we be able truly to appreciate the total attrition from natural causes, from early shunting or early repair, and from early shunting (if indicated) and subsequent repair.

In the meantime, we believe our experience justifies a continuing policy (in our unit, at least) of performing a shunt procedure in infants with the tetralogy of Fallot who have significant hypoxic symptoms, especially if the right ventricular outflow tract, as depicted by cineangiography, seems to require an extensive reconstruction. Delayed, elective, total repair can then be undertaken with the expectation of a low operative mortality and morbidity.

Finally, our experience also lends strong support to the idea that persistent right ventricular hypertension after repair carries a bad immediate prognosis.

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