# Early and Late Results After Intracardiac Repair of Tetralogy of Fallot *

## 5-Year Review of 337 Patients

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### Material and Methods

THE TETRALOGY of Fallot was defined as previously described.[7] On the basis of severity of cyanosis and symptoms prior to any surgical treatment, cases were classified as having acyanotic, mild, moderate or severe forms of the condition. As in the previously reported cases,[11] there was a positive correlation between the severity of the clinical state and the hematocrit value and arterial oxygen saturation. Patients with agenesis of the left pulmonary artery, continuous murmur (other than those with a surgically created aortic-pulmonary communication) or end-to-end Blalock anastomosis are considered separately because of the importance of these associated conditions.

During the period under study (1960 through 1964), open intracardiac repair was advised for all patients over about 5 years of age. No case was deemed inoperable. A preliminary anastomotic operation was advised only for children less than about 5 years of age who were in urgent need of surgical help; intracardiac repair was then done when they reached the age of 5 to 6 years. Cardiac catheterization and angiocardiography were done only in selected cases.

Operation was performed via a median sternotomy incision. Cardiopulmonary bypass was employed with a Mayo-Gibbon pump oxygenator, hypothermia to 26 to 30° C. and perfusion flow rates of 2.0 to 2.4 L./min./$m^2$. In the last several years, exposure was facilitated by a single long period (30 to 60 min.) of aortic cross clamping after profound cooling of the heart by the perfusate and by external cardiac cooling, or by intermittent cross clamping for 10 to 20 minutes with the perfusate temperature at 30° C. In the last few years, the right ventricle was usually opened by a transverse incision. When a patch was used to repair the ventricular septal defect, knitted Teflon was usually employed although pericardium or Teflon felt were occasionally chosen. When possible, the pulmonary stenosis was relieved by valvotomy, by correction of infundibular stenosis, or both. When this did not give adequate relief, an inlay patch (usually of pericardium but sometimes of tightly woven Teflon) was used to widen the outflow tract of the right ventricle, pulmonary valve ring and first portion of the pulmonary artery.[10] In a few cases the patch was placed only in the outflow tract of the ventricle. Intracardiac pressures were measured with a strain-gauge manometer after repair but before the chest was closed. Functioning Blalock anastomoses were closed prior to the intracardiac repair, as

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described previously.[9] Potts' anastomosis was exposed via an incision in the left pulmonary artery and closed during total circulatory arrest.[6]

Autopsy findings were available in cases in which the patient died in the hospital. Late symptomatic results were judged by personal examination in most cases and by correspondence with patients and their local physicians in others. Data on cardiothoracic ratios were obtained by measurement of the appropriate thoracic roentgenograms. A significant shunt at ventricular level was considered to be present postoperatively if autopsy revealed the defect, if hemodynamic studies revealed a left-to-right shunt of more than 10% or if the roentgenogram suggested pulmonary hyperemia.

## Early Results

**Hospital Mortality.** Hospital mortality for all patients was 15, 11, 11, 10 and 7 per cent, respectively, for each of the years from 1960 through 1964. These results compare favorably with the annual hospital mortality previously reported by us [7, 11] for 1955 through 1959: 50, 28, 24, 19 and 16 per cent, respectively. The gradual decrease (Fig. 1) in overall mortality has occurred even though the majority of cases represented the severe form of the condition and there was no case selection. This decrease is probably related largely to improvements in operative technic, reduced use of outflow patches, better preservation of myocardial function during the intracardiac procedure, improved hemostasis, use of hemodilution and some improvements in postoperative care.

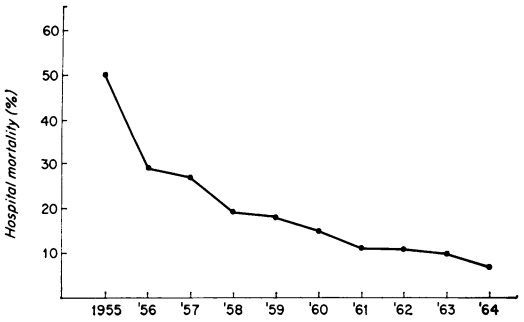


FIG. 1. Hospital mortality in 509 cases of tetralogy of Fallot treated surgically, 1955 through 1964.

Hospital mortality was related to the type of case (Table 1). There were no deaths in this 5-year period among acyanotic patients or among those with mild cyanosis and mild symptoms; mortality was 3 per cent among patients with moderate cyanosis and symptoms. Patients with severe cyanosis and symptoms represented a greater operative risk but, even in these, mortality was 15% in 1963 and 4% in 1964. Particularly difficult problems were presented by 10 patients with severe associated defects (agenesis of left pulmonary artery, continuous murmur or previous end-to-end Blalock anastomosis); four of these died in the hospital.

There seemed to be some relationship between age and hospital mortality (Table

TABLE 1. *Hospital Mortality After Intracardiac Repair in 337 Cases of Tetralogy of Fallot*

| Type of Case | 1960 | | 1961 | | 1962 | | 1963 | | 1964 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) |
| Acyanotic | 7 | 0 | 5 | 0 | 3 | 0 | 3 | 0 | 7 | 0 |
| Mild | 5 | 0 | 4 | 0 | 3 | 0 | 3 | 0 | 2 | 0 |
| Moderate | 25 | 0 | 14 | 7 | 18 | 6 | 12 | 0 | 7 | 0 |
| Severe | 48 | 27 | 39 | 15 | 34 | 15 | 39 | 15 | 49 | 4 |
| Severe with associated defect* | 1 | 0 | 1 | 0 | 3 | 33 | 1 | 0 | 4 | 75 |
| Total | 86 | 15 | 63 | 11 | 61 | 11 | 58 | 10 | 69 | 7 |

* Continuous murmur, agenesis of left pulmonary artery, end-to-end Blalock anastomosis.

TABLE 2. *Effect of Age on Hospital Mortality After Intracardiac Repair of Tetralogy of Fallot (Moderate and Severe Forms Only)*

| Age (years) | Total Cases | Hosp. Mort. (%) |
|---|---|---|
| <5 | 26 | 19 |
| 5–15 | 193 | 11 |
| >15 | 66 | 12 |
| Total | 285 | 12 |

2); mortality was somewhat higher in patients less than 5 years of age at the time of repair.* The overall mortality of 19% in patients less than 5 years old must be interpreted in light of the fact that, generally, open operation in this group of seriously ill, young patients was done after a palliative operation had already failed.

There was no clear difference in risk between primary repair and repair after a successful end-to-side Blalock anastomosis had been done. Both groups had low hospital mortality in 1963 and 1964 (Table 3). Mortality was greater (20% overall) in patients who had a functioning Potts' anastomosis. The relatively high mortality in patients with nonfunctioning shunts is probably related to the fact that they sometimes were less than 5 years of age and desperately ill and that they tended to have a particularly well-developed collateral arterial circulation and aortic-pulmonary collateral circulation.

Presumed primary causes of hospital death are summarized in Table 4. The lack of deaths from hemorrhage since 1961 is probably related to greater skill in establishing hemostasis surgically, to a policy of prompt re-exploration (within 6 to 10 hours postoperatively) in patients who bleed considerably through the drainage tubes, and, perhaps, to the use of hemodilution and maintenance of adequate heparin levels during long perfusions. Patients with a Potts' anastomosis pose particular problems because they may have developed severe pulmonary vascular disease secondary to a surgically created large left-to-right shunt and because entrapment of air in the aorta during circulatory arrest and closure of the anastomosis may give rise to fatal air embolization.

Hospital mortality was somewhat higher when an inlay patch was placed across the pulmonary valve ring (Table 5). This may be related to the possibly greater anatomic severity of these cases and to the longer operating time when a patch was used. However, a depression of right ventricular performance secondary to pulmonary valve incompetence probably develops and contributes significantly to operative risk.

Patches were used less frequently in

* In this and most subsequent analyses only patients with moderate and severe forms of tetralogy are included. Acyanotic patients and those with mild cyanosis and symptoms did well under all circumstances.

TABLE 3. *Effect of Previous Operation on Hospital Mortality After Intracardiac Repair in 285 Cases of Tetralogy of Fallot (Moderate and Severe Forms Only)*

| | 1960 | | 1961 | | 1962 | | 1963 | | 1964 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) |
| Repair as primary op.* | 40 | 13 | 26 | 12 | 30 | 10 | 25 | 8 | 22 | 5 |
| Repair after functioning Blalock anastomosis† | 18 | 33 | 14 | 7 | 15 | 7 | 20 | 5 | 23 | 0 |
| Repair after functioning Potts' anastomosis | 7 | 14 | 11 | 18 | 4 | 25 | 3 | 67 | 10 | 10 |
| Repair after nonfunctioning shunt | 8 | 13 | 2 | 50 | 3 | 33 | 3 | 33 | 1 | 0 |
| Total | 73 | 18 | 53 | 13 | 52 | 12 | 51 | 12 | 56 | 4 |

* A few patients had had a previous closed Brock operation.
† Some patients had had bilateral Blalock anastomosis.

TABLE 4. *Presumed Causes of Hospital Deaths After Intracardiac Repair of Tetralogy of Fallot (1960–1964)*

| | Presumed Cause of Hospital Death | | | |
|---|---|---|---|---|
| | Low Cardiac Output | Pulmonary Dysfunction | Hemorrhage* | Other |
| Repair as primary op. | 7 | 5 | 2 | 1 |
| Repair after functioning Blalock anastomosis | 2 | 1 | 4 | 2 |
| Repair after Potts' anastomosis | 1 | 0 | 1 | 5† |

* Last death from this cause was in 1961.

† Two deaths were from air embolization, one from severe pulmonary vascular disease, one from residual ventricular septal defect and one from staphylococcal pneumonia.

more recent operations. Thus in 1963 outflow patches across the pulmonary valve ring were used in 20 per cent of patients with moderate and severe forms of the malformation and in 1964 in 14 per cent. The proportion of severe cases treated surgically actually increased during this period (Fig. 2), so it is believed that the reduction in use of outflow patches was the result of greater skill in relieving infundibular and valvular pulmonic stenosis. The reduction has not been accompanied by a significant increase in average RV/LV peak pressure ratio after repair. It is interesting that this ratio is consistently a little higher in patients with an outflow patch than in those without it.

There was no apparent relationship between hospital death and RV/LV peak pressure ratio after repair, but very few patients were left with ratios more than 0.75. Results of the two methods of minimizing myocardial damage during aortic cross clamping were similar.

**Permanent Heart Block.** There were five instances of permanent heart block in the 337 cases (1.5%) treated surgically during this period. All five patients had had pacemaker wires inserted at operation but three died: one 24 hours postoperatively with low cardiac output, one 4 days postoperatively of pulmonary dysfunction and one (with a large Potts' anastomosis) 12 days postoperatively of the results of massive air embolization.

**Effects of a Previous Blalock Anastomosis.** It has alreay been noted that there was no demonstrable difference in hospital mortality between patients with a functioning Blalock anastomosis and those without it. However the operation can be technically much more difficult when it includes closure of a previously established subclavian-pulmonary artery anastomosis. The subclavian artery is often friable and densely adherent to surrounding structures. The immense collateral circulation developing after such a shunt further complicates

TABLE 5. *Effect of Inlay Patch Across Pulmonary Valve Ring on Hospital Mortality After Intracardiac Repair on Tetralogy of Fallot (Moderate and Severe Forms Only)*

| | 1960 | | 1961 | | 1962 | | 1963 | | 1964 | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) | Total No. | Hosp. Mort. (%) |
| Repair with patch across valve ring | 44 | 23 | 27 | 26 | 19 | 11 | 10 | 20 | 8 | 0 | 108 | 19 |
| Repair without patch* | 29 | 10 | 26 | 0 | 33 | 12 | 41 | 10 | 48 | 4 | 177 | 7 |
| Total | 73 | 18 | 53 | 13 | 52 | 12 | 51 | 12 | 56 | 4 | 285 | 12 |

* In the early years a few of these patients had a small patch in the outflow tract only.

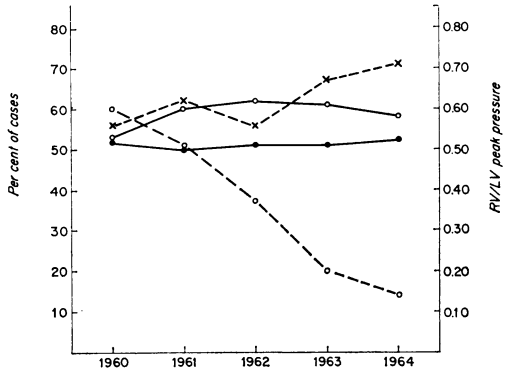


FIG. 2. Trends in use of patch across pulmonary valve ring in intracardiac repair of tetralogy of Fallot, 1960 through 1964. *Open circles and broken line,* percentage of cases in which patch was used; *x's and broken line,* percentage of cases classified as severe form; *open circles and solid line,* ratio of peak pressures, RV/LV, in cases with patch; *solid circles and solid line,* ratio of peak pressures, RV/LV, in cases without patch.

open-heart operation, particularly when it is delayed many years.

In 1963 and 1964 there was slightly less use of patches across the pulmonary valve ring in patients with a functioning Blalock anastomosis than in those without it, but the difference is probably not significant (Table 6). In this period when a patch was not used there was a somewhat lower average value for RV/LV peak pressure ratio after repair when a previous Blalock anastomosis was present than when it was not (Table 7).

## Late Results

**Clinical Status.** The clinical status was excellent in 93 per cent of the patients at the time of follow up (Table 8). Two patients are alive but are quite disabled and are to be restudied to determine the reason. Three patients have undergone successful reoperation for repair of a residual or recurrent ventricular septal defect and are now in excellent health. Four patients have died. One died suddenly 2 months after operation and one died suddenly 4 months after operation; sinus rhythm had been present in both and, in both, autopsy showed the repairs to be intact. Another died suddenly 4½ months postoperatively; autopsy revealed a moderate-sized ventricular septal defect where there had been partial separation of a closure which had been effected by direct suture. The follow-up data for patients operated on in 1960 are very similar to those for the group as a whole. Thus, within the period of this study there is no evidence of late deterioration of the patients.

**Heart Size.** In some of the cases data were available to allow a comparison between heart size preoperatively and late postoperatively (Table 9). The mean cardiothoracic ratio was essentially unchanged postoperatively when an outflow patch was not required but was a little greater postoperatively when a patch was employed. Results of previous studies [15] suggest that left ventricular size is not increased after repair and that right ventricular enlargement may be responsible for these apparent changes.

When a surgically created large aortic-pulmonary anastomosis has been made, the left ventricle does enlarge.[19] Intracardiac

TABLE 6. *Use of Right Ventricular Outflow Patch in Intracardiac Repair of Tetralogy of Fallot in 1963 and 1964 (Moderate and Severe Forms Only)*

| | Total No. | Patch Used | |
|---|---|---|---|
| | | No. | % |
| Repair as primary op. | 47 | 9 | 19 |
| Repair after previous Blalock anastomosis | 43 | 6 | 14 |

TABLE 7. *Effect of Use of Right Ventricular Outflow Patch in Intracardiac Repair of Tetralogy of Fallot on RV/LV Peak Pressure Ratio Immediately After Repair*

| | Mean Ratio, RV/LV Peak Pressure | |
|---|---|---|
| | No Patch | Patch |
| Repair as primary op. | 0.55 | 0.66 |
| Repair after previous Blalock anastomosis | 0.49 | 0.65 |

TABLE 8. *Late Results of Intracardiac Repair of Tetralogy of Fallot* (1960–1964)*

| Result | Entire Period | | 1960 only | |
|---|---|---|---|---|
| | No.† | % of Total Traced | No.‡ | % of Total Traced |
| Excellent | 217 | 93 | 62 | 93 |
| Good | 6 | 3 | 2 | 3 |
| Reoperation | 3 | 1 | 1 | 1 |
| Late death | 4 | 2 | 1 | 1 |
| Unsatisfactory | 2 | 1 | 1 | 2 |
| Total | 232 | | 67 | |

* This table includes only those patients who: 1) were operated on 6 months or more prior to January 1, 1965, 2) survived the early postoperative period (264 patients), and 3) could be traced. Thirty-two of the patients who survived operation could not be traced.

† Patients with severe associated defects are not included in this table.

‡ Three of the 70 patients who survived operation could not be traced. Mean follow-up period was 33 months (range, 11 to 61).

repair and closure of the anastomosis then may result in an overall decrease in cardiothoracic ratio because the resultant decrease in left ventricular size may be greater than any increase in right ventricular size.

**Status of Repair of Ventricular Septal Defect.** There was a low incidence of known significant residual or recurrent ventricular septal defects (Table 10). Although the method of assessment may underestimate this incidence somewhat, these data plus previous hemodynamic studies [1] indicate that most patients (at least 90%) have either no shunt or an insignificant one after intracardiac repair and that there is no tendency for late reopening of the defect. In those cases in which a significant shunt has been found postoperatively, evidence was noted within a few days after operation.

**Status of Outflow Patch.** Follow-up observations after use of tightly woven Teflon for enlargement of the outflow tract, pulmonary valve ring and base of the pulmonary artery have been presented previously; [16] in the present series, too, no late enlargements were noted. In one patient with Teflon only in the outflow tract, however, there appeared to be an aneurysm of moderate size.

When pericardium was used, no progressing enlargements (aneurysms) were noted (Table 11). The varying degrees of prominence appear to be related primarily

TABLE 9. *Cardiothoracic Ratios Before and After Intracardiac Repair of Tetralogy of Fallot* (1960–1964)*

| | Cases | Mean Cardiothoracic Ratios | | % of Cases with Postop. Increase of 0.05 or More |
|---|---|---|---|---|
| | | Preoperative | Postoperative | |
| No patch used: Repair as primary op. | 37 | 0.48 | 0.49 | 16 |
| Repair after previous Blalock anastomosis | 24 | 0.52 | 0.53 | 17 |
| Patch used: Repair as primary op. | 18 | 0.51 | 0.53 | 21 |
| Repair after previous Blalock anastomosis | 7 | 0.51 | 0.55 | 29 |

* Based on 86 cases (cyanotic patients only) in which data were available both preoperatively and more than 6 months postoperatively.

TABLE 10. *Residual Ventricular Septal Defects (VSD) After Intracardiac Repair of Tetralogy of Fallot* (1960–1964)

| Method of Repair of VSD | Traced Patients | Significant Residual VSD | |
|---|---|---|---|
| | | No. | % of Total Traced |
| Suture* | 72 | 4 | 6 |
| Patch† | 92 | 7 | 8 |

* Patients operated on primarily in 1960 and 1961.
† Patients operated on primarily in 1962, 1963 and 1964.

to the initial size of the patch because increasing prominence has not been noted in patients in whom serial roentgenograms were available.

### Severe Associated Defects

Certain associated defects occurred frequently; these included: atrial septal defect, anomalous right coronary artery giving rise to left anterior descending coronary artery, acquired pulmonary atresia in patients with surgically created Blalock or Potts' anastomosis,[17] and persistent left superior vena cava. These did not significantly complicate the operation and have not been considered separately. Primary cases of tetralogy with a continuous murmur, cases with atresia of the left pulmonary artery and cases with an end-to-end Blalock anastomosis pose particularly serious problems and therefore are considered separately in this section (Table 12).

One patient with continuous murmur had an associated patent ductus arteriosus; this patient did well. In our overall experience the most common cause of this murmur has been massive aortic-pulmonary collateral circulation, and aortography in such cases shows numerous large branches of the aorta going to the lungs. Special maneuvers are necessary at operation; despite these, the two patients in this category died postoperatively. In one patient the left pulmonary artery derived directly from the aorta. At intracardiac repair this was divided and the distal end was anastomosed to the main pulmonary artery; this patient has done well.

One patient with agenesis of the left pulmonary artery died 12 hours postoperatively. One patient is alive but still has moderate exercise intolerance 44 months postoperatively; cardiac catheterization 3 years postoperatively showed absence of shunt, pulmonary arterial pressures of 50/20 mm. Hg and brachial arterial pressures of 110/70 mm. Hg. The third patient is in intractable heart failure 20 months postoperatively; cardiac catheterization has shown absence of shunt, pulmonary artery pressure of 80/20 mm. Hg, right ventricular pressure of 80/20 mm. Hg (an outflow patch was placed across the pulmonary valve ring) and left ventricular pressure of 98/17 mm. Hg. It appears that the marked restriction of the pulmonary arterial tree in this group presents a serious obstacle to a successful result.

One patient whose end-to-end left Blalock anastomosis was ligated at the time of intracardiac repair has an excellent result 3 years postoperatively. Another similar patient had a very protracted convalescence due to apparent infarction and abscess formation in the left lung but has a good result 24 months postoperatively. In the third patient, flow to the left lung was restored at intracardiac repair by division of the left subclavian artery near its origin and implantation of it into the main pulmo-

TABLE 11. *Results After Placement of Pericardium Across Pulmonary Valve Ring in Intracardiac Repair of Tetralogy of Fallot* (1960–1964)

| Appearance of Outflow Tract in Thoracic Roentgenogram (6 to 55 Months Postop.) | No. Patients | % of Total Traced |
|---|---|---|
| Normal | 11 | 46 |
| Mildly prominent | 11 | 46 |
| Moderately prominent | 2 | 8 |
| Progressing enlargement | 0 | 0 |

nary artery. Unfortunately after doing well he died suddenly of aspiration of food and liquids on the ninth postoperative day. Autopsy showed a totally unsuspected congenital esophagotracheal fistula without esophageal atresia; he had undergone previous surgical treatment for imperforated anus. A successful similar reconstruction has been reported by Gerbode and coworkers.[5]

TABLE 12. *Results After Repair of Tetralogy of Fallot With Serious Associated Defects* (1960–1964)

| Associated Defect | No. | Hosp. Deaths | Late Result |
|---|---|---|---|
| Continuous murmur | 4 | 2 | Excellent, 2 |
| Agenesis of left pulmonary artery | 3 | 1 | Unsatisfactory, 1; fair, 1 |
| End-to-end Blalock anastomosis | 3 | 1 | Now good after protracted convalescence, 1; excellent, 1 |

## Discussion

Analysis of these data has not changed our concept that primary intracardiac repair of tetralogy of Fallot should be recommended for almost all patients over the age of about 5 years. Because of subtle inadequacies of cardiopulmonary bypass as now done and because of the technical problems of working inside the small heart of infants and small children with tetralogy, when symptoms are severe in these cases a palliative operation is recommended with open operation to be performed at about 5 years of age. It is unwise to defer open repair until symptoms return. Use of the Potts' anastomosis probably should be abandoned because of the greater risk associated with subsequent open operation when it is present compared to when a Blalock anastomosis is present. When a Blalock operation seems unlikely to be successful in small infants, ascending aorta-right pulmonary artery anastomosis could be considered.[3, 4, 14] An end-to-end Blalock anastomosis should never be done. The proper use of closed valvotomy and partial infundibulectomy (Brock operation) in palliative management of these small patients has not yet been assessed fully.

Although there is debate concerning the relative size of the left ventricle in tetralogy of Fallot,[12, 15] there is evidence that after repair it is capable of maintaining an adequate systemic blood flow at a reasonable filling pressure.[18] Significant increases of pulmonary vascular resistance have not been observed by us (in the absence of a Potts' anastomosis) except in patients with agenesis of the left pulmonary artery and in a few patients with extensive gross thrombosis of large branches of the pulmonary arteries. No evidence has been obtained that the lung is in any way unprepared to receive a full pulmonary blood flow.[18] Therefore, these are not considerations in possible selection of patients for operation. Although none was encountered in the present study, it is recognized that cases of tetralogy of Fallot do exist in which right and left pulmonary arteries are so small that they offer a severe obstruction to flow. Treatment of any kind is difficult in these instances which, fortunately, are rare.

Certain severe associated defects occur uncommonly and must be carefully evaluated prior to operation.

Operative mortality is now low, even in severe cases, and probably is related to accuracy of repair, adequate whole-body perfusion and proper postoperative care. Low cardiac output can still occur and lead to death, and better ways of preservation of myocardial function are being sought. Pulmonary dysfunction will continue to constitute an occasional problem until the technics of cardiopulmonary bypass are improved. Numerous considerations confirm the wisdom of relieving the pulmonary stenosis without a patch across the valve ring whenever possible. Our experience indicates that with proper technics this is possible in most cases. A proper technic of repair of the ventricular septal defect clearly results in few instances of

permanent heart block and a high incidence of complete repair.[8]

Late results are excellent, within the limits of the follow-up period, in about 90% of patients surviving operation, as also found by Wolf and associates,[20] Lillehei and associates[13] and Bristow and associates.[2] Slight increase in heart size is common but reassurance for the future is given by the absence of progressing cardiomegaly. Resistance across the outflow tract 2 weeks after operation[1] seems to be somewhat less than it is immediately after repair but there is no evidence as yet of a significant later decrease. An increase has not been seen.

## Summary

Details are given of a 5-year experience with intracardiac repair of tetralogy of Fallot in 337 patients. Hospital mortality varied according to severity of the condition, age of the patient, nature of previous surgical treatment and presence or absence of an outflow patch across the pulmonary valve ring. There has been a progressing decrease in overall hospital mortality to 10 and 7 per cent in 1963 and 1964, respectively. Permanent heart block has occurred in 1.5 per cent of cases. The clinical status was excellent in 93 per cent of the patients at long-term follow up. The cardiothoracic ratio was essentially unchanged after operation unless a patch across the outflow tract had been employed; in these cases it was somewhat greater in the late postoperative period. More than 90 per cent of patients gave evidence of essentially complete repair of the ventricular septal defect. Certain uncommon severe associated defects (continuous murmur, agenesis of left pulmonary artery, end-to-end Blalock anastomosis) significantly affect the choice of technic and the results of operation.

## References

1. Albertal, G., H. J. C. Swan and J. W. Kirklin: Hemodynamic Studies Two Weeks to Six Years After Repair of Tetralogy of Fallot. Circulation, **29**:583, 1964.
2. Bristow, J. D., Z. A. Adrouny, G. A. Porter, V. D. Menashe, A. Starr and H. E. Griswold: Hemodynamic Studies After Total Correction of Tetralogy of Fallot. Amer. J. Cardiol., **9**:924, 1962.
3. Cooley, D. A.: Personal communication.
4. Edwards, S.: Personal communication.
5. Gerbode, F., J. J. Osborne, W. J. Kerth and M. F. O'Brian: Complete Correction of Tetralogy of Fallot. West. J. Surg., **72**:1, 1964.
6. Kirklin, J. W. and R. A. Devloo: Hypothermic Perfusion and Circulatory Arrest for Surgical Correction of Tetralogy of Fallot With Previously Constructed Potts' Anastomosis. Dis. Chest, **39**:87, 1961.
7. Kirklin, J. W., F. H. Ellis, Jr., D. C. McGoon, J. W. DuShane and H. J. C. Swan: Surgical Treatment for the Tetralogy of Fallot by Open Intracardiac Repair. J. Thor. Surg., **37**:22, 1959.
8. Kirklin, J. W., D. C. McGoon and J. W. DuShane: Surgical Treatment of Ventricular Septal Defect. J. Thor. Surg., **40**:763, 1960.
9. Kirklin, J. W. and W. S. Payne: Surgical Treatment for Tetralogy of Fallot After Previous Anastomosis of Systemic to Pulmonary Artery. Surg. Gynec. & Obstet., **110**: 707, 1960.
10. Kirklin, J. W. and W. S. Payne: Tetralogy of Fallot. *in* Benson, C. D.: Pediatric Surgery. Chicago, Year Book Medical Publishers, Inc., 1962, vol. 1, pp. 462–471.
11. Kirklin, J. W., W. S. Payne, R. A. Theye and J. W. DuShane: Factors Affecting Survival After Open Operation for Tetralogy of Fallot. Ann. Surg., **152**:485, 1960.
12. Lev, M., H. J. A. Rimoldi and U. F. Rowlatt: The Quantitative Anatomy of Cyanotic Tetralogy of Fallot. Circulation, **30**:531, 1964.
13. Lillehei, C. W., M. J. Levy, P. Adams and R. C. Anderson: Corrective Surgery for Tetralogy of Fallot: Long-Term Follow-up by Postoperative Recatheterization in 69 Cases and Certain Surgical Considerations. J. Thor. Surg., **48**:556, 1964.
14. Michaud, P., H. Termet and R. Verney: Ascending Aorto-right Pulmonary Artery Prosthetic Bridging, a Repair Method in Certain Cases of Tetralogy of Fallot. Ann. Chir., **16**:859, 1962.
15. Miller, G. A. H., J. W. Kirklin, S. H. Rahimtoola and H. J. C. Swan: Volume of the Left Ventricle in Tetralogy of Fallot. Amer. J. Cardiol. In press.
16. Payne, W. S. and J. W. Kirklin: Late Complications After Plastic Reconstruction of Outflow Tract in Tetralogy of Fallot. Ann. Surg., **154**:53, 1961.
17. Sabiston, D. C., Jr., W. P. Cornell, J. M. Criley, Catherine A. Neill, R. S. Ross and H. T. Bahnson: The Diagnosis and Surgical

Correction of Total Obstruction of the Right Ventricle: An Aquired Developing Systemic Artery—Pulmonary Artery Anastomosis for Tetralogy of Fallot. J. Thor. Surg., **48**:577, 1964.

18. Theye, R. A. and J.W. Kirklin: Physiologic Studies Early After Repair of Tetralogy of Fallot. Circulation, **28**:42, 1963.
19. Walzem, D. E. and E. B. Singleton: Tetralogy of Fallot: Radiologic Evaluation Before and After Surgical Treatment. Radiology, **81**: 760, 1963.
20. Wolf, M. D., B. Landtman, C. A. Neill and H. B. Taussig: Total Correction of Tetralogy of Fallot. I. Follow-up Study of 104 Cases. Circulation, **31**:385, 1965.

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## Discussion

Dr. David C. Sabiston, Jr. (Durham, N. C.): Several important points in the correction of tetralogy of Fallot have been emphasized, and I would like to confine my remarks to one aspect of the problem, that is, the effect of a previous subclavian-pulmonary (Blalock) shunt on mortality at the time of open correction.

Dr. Paul Ebert and I recently completed a survey on a hundred patients with tetralogy of Fallot who were corrected by open operation during the past 2 years. These patients were divided into two groups: 1) those who had previous subclavian-pulmonary shunts and 2) those who had not had a previous shunt. It became apparent early in the study that patients with previous shunts who ultimately required another operation had higher hematocrits, more intense cyanosis, and less exercise tolerance than those patients being operated upon for the tetralogy as a primary operation. Furthermore, the angiocardiographic studies showed that the majority of patients who had had previous shunt procedures and who had outgrown them had more severe anatomic cardiac malformations.

The important feature of the study was the fact that despite the history of a previous operation and more severe cardiac changes, those patients with a previous subclavian-pulmonary shunt had a *lower* mortality than did the patients who had not had a previous shunt procedure. From these data one can say firmly that a previous shunt operation does not increase the risk at the time of open correction and may offer certain protection.

Dr. Conrad R. Lam (Detroit): In September, 1964, some of us saw a motion picture in Washington at the World Congress on Cardiology. This was the film by Dr. Walton Lillehei showing the repair of a tetralogy of Fallot, using his cross-circulation method with the human donor.

I remember the presiding officer kept calling time on Dr. Lillehei, wanting him to step down, but Dr. Lillehei persisted until at least the ventriculotomy had been closed.

We have come a long way since then, and Dr. Kirklin and his group at the Mayo Clinic, of course, have come the greatest distance.

The remarkable feat of operating on some 541 cases and bringing the mortality down to 7% is, of course, most enviable.

All of us would like to stand at the operating table and see how they do it. I should like to comment on the problem of surgically induced pulmonary insufficiency. Our group has believed that the deliberate production of pulmonary insufficiency is very damaging, and we had two especially bad results in which the young patients have had swollen livers and ascites, and a third operation has had to be attempted to relieve the pulmonic insufficiency. Very small Starr-Edwards valves were put in and these operations were not successful.

I had a question with regard to the age at which they would attempt the operation but this has been answered. Apparently this group prefers to wait until the child is at least 5 years old.

Dr. Frank Cole Spencer (Lexington, Ky.): I also had the privilege of reading the manuscript by Drs. Wallace and Kirklin, and am particularly impressed by the significant data that it contains. Two points are outstanding: the operative mortality has decreased to 7%, and outflow tract patches were used in only 14% of the patients.

The low mortality rate indicates that death from a low cardiac output syndrome or respiratory insufficiency has decreased to the vanishing point. It still occurs in a small percentage of cases.

Why has this occurred? The authors, with the limitation of time, have not had an opportunity to go into this, but I am certain one reason is the precise operative technic employed. The fact that no deaths have occurred from hemorrhage since 1961, despite operations upon cyanotic children with an increased bleeding tendency, is ample tribute to a precise technic.

The other factors which are probably significant are three in number: 1) adequate correction of the anatomic defect, 2) avoiding any injury to a coronary artery and 3) avoiding coronary air embolism. Coronary artery injury and coronary air embolism can both be easily overlooked at operation, and then subsequent death erroneously attributed to cardiac failure.

The other significant point is the use of outflow tract patches in only 14% of the patients. The dilemma of the cardiac surgeon operating for tetralogy is "to patch or not to patch." If a patch is not inserted and a serious obstruction remains, an immediate fatality often occurs. On the other hand, the insertion of a patch produces permanent pulmonary insufficiency whose long-term effects are uncertain. The data presented in the paper indicate that a comparison of the right and left