Total Correction of Tetralogy of Fallot

I. Follow-up Study of 104 Cases

By Muriel D. Wolf, M.D., Bernard Landman, M.D., Catherine A. Neill, M.D., and Helen B. Taussig, M.D.

During the past two decades great strides have been made in the surgical treatment of tetralogy of Fallot. Prior to 1944, only conservative medical treatment could be offered to these patients. Since the development of the systemic-pulmonary artery shunt operation that year, this procedure has been extensively employed all over the world. The symptomatic relief offered by this operation is well known. This operation and its modifications, later supplemented by pulmonary infundibulectomy or valvulotomy (Brock procedure), were for 10 years the only operative procedures available.

In 1955 the first patient with tetralogy of Fallot had the defect corrected by open intracardiac surgery. Since then rapid progress has been made in operative technics and in the methods of extracorporeal perfusion. A sufficiently large number of patients with a tetralogy of Fallot have now undergone open-heart surgery to permit a preliminary evaluation of the results.

This paper presents an analysis of the follow-up in the first 146 consecutive patients with tetralogy of Fallot who underwent open-heart surgery at the Johns Hopkins Hospital from September 1956 to January 1962 and who have been followed until May 1962. The surgical and perfusion technics employed in these cases have been described by Bahnson and associates, who also discussed many of the factors concerned in the immediate mortality and morbidity. The present study is concerned chiefly with the follow-up of the 104 patients discharged from the hospital alive.

Material and Methods

Each of the 146 patients included in this study had a tetralogy of Fallot except for one patient who, after careful pathologic examination, was found to have both great vessels arising from the right ventricle. One case of corrected transposition included in Bahnson's paper has been omitted from this report.

Of the 146 patients, 129, or 89 per cent, were cyanotic. The remaining 17 patients who were acyanotic had a right ventricular pressure approximately equal to the systemic pressure but had a predominant left-to-right shunt. Ninety-one of the cyanotic group had had a previous systemic-pulmonary arterial shunt operation and five had had a pulmonary valvulotomy (Brock procedure). No previous surgery had been performed in the 17 acyanotic patients and in 33 of the cyanotic patients.

The group as a whole was severely incapacitated and included a high proportion of deeply cyanotic patients. Disability was graded as severe in 32 patients who had frequent episodes of squatting or cyanotic spells; moderate in 83 patients, mild in 30, and absent in one. The hematocrit level was measured in 145 patients: it was 49 per cent or less in 36 patients, between 50 and 69 per cent in 85, and 70 per cent or higher in 24.

Eighty-four patients were male and 62 were female. One interesting sex difference was observed: of the 42 patients with infundibular stenosis and a normal or nearly normal pulmonary valve, 32, or 76 per cent, were male, whereas in the group of patients with combined infundibular and valvular stenosis, the sex ratio was equal (table 1).

The age at operation varied between 15 months and 40 years. One hundred and fifteen patients (79 per cent) were between 5 and 20 years of age (table 1).

At operation the pulmonary stenosis was relieved by infundibular resection or valvulotomy.
or both. A patch was used to widen the right ventricular outflow tract in 57 patients (39 per cent). An Ivalon patch was used in the early cases and Teflon has been in use since September 1959. The ventricular septal defect was closed with a patch in all but seven patients in whom the defects were small and were closed by direct suture.

Factors Influencing Immediate Mortality

Forty-two of the 146 patients died during their stay in the hospital. These early post-operative deaths have been analyzed previously. Three patients died after discharge from the hospital and are discussed later under late deaths. The over-all mortality was 31 per cent.

As in any study based on a consecutive series of cases including the earliest patients operated upon, it is difficult to separate mortality caused by technical surgical difficulties (block, hemorrhage, sepsis, incomplete relief of stenosis, etc.) from difficulties related to the severity of the cardiac condition pre-operatively. Nevertheless, an attempt has been made to analyze briefly a few of the factors that appear to increase the risk of surgery.

The three most important factors appeared to be the severity of the pulmonary stenosis, the age of the patient, and the presence of additional complicating lesions.

The severity of the pulmonary stenosis, as evidenced by the degree of cyanosis, the disability of the patient, the age at first cardiac operation, and the need for an outflow patch, was of paramount importance in affecting the immediate operative mortality. One hundred and twenty-nine of the patients were cyanotic and, of these, 43 died, a mortality rate of 33 per cent: whereas of the 17 acyanotic patients only two died, a mortality rate of 12 per cent. The increased risk in the cyanotic group was apparently related more to the severity of the pulmonary stenosis than to any single postoperative complication, such as hemorrhage, even though severe postoperative bleeding was more frequent in patients with high hematocrit levels.

The preoperative degree of disability also appeared to be related to the operative risk: the mortality rate was 35 per cent in the 115 patients with moderate or severe disability as compared to 16 per cent in those with only mild disability. Disability, too, is related to inadequacy of the pulmonary blood flow with exercise.

Previous cardiac surgery had been performed in 96 of the 129 cyanotic patients. No significant difference in mortality was found between those with no previous operation or with one previous end-to-side subclavian pulmonary anastomosis. Previous end-to-end shunts, Pott’s anastomosis or bilateral anastomoses were associated with an extremely
high mortality of approximately 70 per cent.\textsuperscript{3} Frequently these latter shunts were done in patients with more severe pulmonary stenosis and small pulmonary arteries. This would suggest that the increased mortality in these patients is not only associated with operative problems with these shunts, but also with the degree of pulmonary stenosis.

Six of seven patients who underwent the first shunt operation prior to 18 months of age died at subsequent total correction, again suggesting that the severity of the pulmonary stenosis affects the operative outcome.

A right ventricular outflow patch was used in a total of 57 patients of whom 24 (42 per cent) died. By contrast, among 89 patients with no outflow patch the mortality rate was 24 per cent. The mortality rate was higher when the outflow patch extended into the pulmonary artery (49 per cent of 39 patients) than when it was limited to the right ventricle (29 per cent of 17 patients).

The age of the patient also affected the risk of operation. In the group of five patients under 5 years of age, the three cyanotic patients died, whereas the two acyanotic patients lived, giving an over-all mortality of 60 per cent under 5 years. Although the number of patients is small, the mortality rate in this and other series in the very young patients leads us to think that total correction is contraindicated at the present time in this age group.

The over-all mortality in patients between 5 and 10 years of age was 27 per cent. In patients under 10 years of age, however, 10 of 15 patients with an outflow patch died as compared with three of 27 without a patch, a six-fold increase in mortality rate. Thus young patients with a severe degree of pulmonary stenosis necessitating an outflow patch had an extremely high operative risk. In patients over 11 years of age there was no significant difference in mortality whether or not a patch was used (fig. 1).

The lowest mortality was found in the comparatively small group of patients between 21 and 40 years. This was in all probability related to the relatively mild degree of pulmonic stenosis present in these patients, only one of whom had needed a shunt procedure prior to 8 years of age.

Cardiac failure and severe associated defects had a significant effect on the immediate mortality rate. A total of nine patients had such complicating lesions including aortic aneurysm, severe thoracic scoliosis, pulmonary hypertension of systemic levels, and chronic congestive failure. Only one of the nine patients survived surgery.

Less severe associated defects were present in 18 patients including atrial septal defects in four, persistent left superior vena cava in four, patent ductus arteriosus in two, absent or defective pulmonary valve in two, and mild thoracic scoliosis in six. These lesions had no significant effect on mortality.

Follow-up Results in 104 Patients

Of the 104 patients discharged from the hospital alive, 25 have been followed for less than 6 months, 16 for 6 months to 1 year, 52 for between 1 and 3 years, and 11 between 3 and 5 years. There were three late deaths;

\begin{figure}[h]
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\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{Outflow patch related to age at operation and mortality.}
\end{figure}

\textit{Circulation, Volume XXXI, March 1965}
one occurred at 3 months and the other two
at 20 months and 28 months, respectively,
after surgery. Thus 101 patients were living
at the completion of the study.

Complete follow-up data including clinical
findings, electrocardiogram, x-ray, hemoglo-in, and hematocrit values were available on
98 patients. No follow-up studies were avail-
able for three patients, one of whom, how-
ever, was reported to be doing well. No x-rays
were available for three additional patients.
The postoperative electrocardiograms are
analyzed in a separate communication.4

Symptomatic improvement has been good
in all cases and cyanosis has disappeared.
With only one exception the hematocrit levels
have returned to normal. The over-all post-
operative results were divided into four main
groups (table 2).

Group I consisted of 37 patients with a
normal heart size, (i.e., with a cardiothoracic
ratio of 49 per cent or less) and no significant
residual intracardiac defects; mild pulmo-

Table 2

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<tr>
<th></th>
<th>No outflow patch, 65</th>
<th>Outflow patch, 33</th>
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<tbody>
<tr>
<td></td>
<td>No. pts.</td>
<td>Pulmonary insufficiency</td>
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<td></td>
<td></td>
<td>Absent</td>
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<tr>
<td>Group I</td>
<td>37</td>
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<tr>
<td>Normal heart size</td>
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<td>(CTR 49 per cent or less); no residual defect</td>
<td>20</td>
<td>8</td>
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<td>Group II</td>
<td>36</td>
<td>7</td>
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<td>CTR 50 per cent or more; no residual defect</td>
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<tr>
<td>Group III</td>
<td>22</td>
<td>8</td>
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<td>CTR 50 per cent or more; residual defect present</td>
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<td>Group IV</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Late deaths</td>
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<td>Total</td>
<td>98*</td>
<td>36</td>
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* Follow-up data or x-rays were unavailable on six of the 104 patients discharged from the hospital alive.

all of these patients however had a cardio-
thoracic ratio of 50 per cent or more, and
29 of the 36, or 80 per cent, had pulmonary valvular insufficiency.

Group III was composed of 22 patients all
of whom showed persistent cardiomegaly with
a cardiothoracic ratio of 50 per cent or more
and residual defects of varying severity.

Group IV—late deaths have occurred in
three patients, all of whom had residual de-
fects.

Heart size was evaluated prior to and fol-
lowing surgery in the 98 patients with com-
plete follow-up data. Sixty-five patients
showed insignificant changes of 5 per cent or
less in the cardiothoracic ratio; 12 showed a
decrease and 21 an increase in heart size. A
cardiothoracic ratio between 55 and 75 per
cent was present in 29 patients, although in
only eight was it greater than 60 per cent.
Eighteen of these 29 patients had some com-
plcating lesion or residual defect.

Although gross persistent cardiomegaly was
most frequently associated with complications
or residual defects, lesser degrees of cardiac
enlargement were observed in the 36 patients
in group II in whom total correction had
apparently been completely successful. When the heart size was correlated with the presence or absence of an outflow patch and the presence or absence of pulmonary valvular insufficiency (table 2), it was found that the incidence of a normal heart size was higher in patients without pulmonary insufficiency. Thus 23 (59 per cent) of 39 patients with a competent pulmonary valve had a normal heart size compared with 14 (23 per cent) of 59 patients with pulmonary insufficiency. Of 65 patients without a right ventricular outflow patch 28 (43 per cent) had hearts of normal size as compared with nine (27 per cent) of the 33 patients with an outflow patch. Thus in the present series the presence of pulmonary insufficiency and of an outflow patch increased the liability to persistent cardiac enlargement.

Cardiac murmurs were analyzed preoperatively and postoperatively (table 3).

A systolic murmur was audible along the left sternal border in all patients prior to surgery and in most cases was associated with a thrill. Postoperatively the systolic murmur usually decreased in intensity and became less harsh in character, but in only eight patients did it completely disappear. A thrill persisted postoperatively in 16 patients, including all those with residual ventricular septal defects and a few with significant degrees of residual pulmonary stenosis.

Aortic insufficiency was present preoperatively in three patients, two of whom survived surgery. One required reoperation because of persistent patency of the ventricular septal defect, but even following the second operation he continued to have cardiomegaly and moderately severe aortic insufficiency. The other patient, a 40-year-old man, was in chronic cardiac failure preoperatively and at surgery was found to have a calcified aortic valve ring and considerable calcification of the tricuspid valve and myocardium. Although he had considerable symptomatic relief, he has remained in chronic cardiac failure for 2½ years following surgery.*

Three additional patients developed aortic insufficiency postoperatively; in two it was mild and the blood pressure has remained within normal limits. The third patient had incomplete closure of the ventricular septal defect and after a second operation, again with unsuccessful closure of the ventricular defect, he developed moderately severe aortic insufficiency. Aortic insufficiency as a serious complication has also been noted by other observers.5, 6

Pulmonary valvular insufficiency was present postoperatively in a total of 59 patients. It was present prior to and following surgery in two patients with an absent or rudimentary pulmonary valve. Pulmonary insufficiency appeared postoperatively in another 57 patients. Thirty of the 33 patients with right ventricular outflow patches (88 per cent) developed pulmonary insufficiency, compared with only 27 (42 per cent) of the 65 patients in whom no

*This patient died after this study was closed.

### Table 3

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<th>Cardiac Murmurs</th>
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<td><strong>No murmur</strong></td>
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<td><strong>Systolic murmur</strong></td>
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<td>146 Preoperative</td>
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<td>104 discharged</td>
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<td>from hospital</td>
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<tr>
<td>104 Postoperative</td>
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<td>98 Long-term</td>
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<tr>
<td>follow-up</td>
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<td>3 Late deaths</td>
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<td>3 No follow-up</td>
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*This patient died after this study was closed.*
outflow patch was needed. The correlation between pulmonary insufficiency and persistent postoperative cardiomegaly has already been discussed (table 2).

A continuous murmur due to a functioning systemic-pulmonary anastomosis was present preoperatively in 78 patients and persisted following surgery in one patient in whom no attempt was made to tie off a small end-to-end anastomosis.

Residual defects were present in a total of 25 patients including the 22 in group III and the three patients who died after discharge from the hospital. Residual defects in the ventricular septum were present in 14 of the 146 patients (10 per cent). This incidence is comparable to the experience of other centers.7-10 Two patients with incomplete closure of the ventricular defect died in the early postoperative period. Another patient died at a second operation. Among the 11 remaining patients discharged from the hospital with clinical evidence of a persistent ventricular septal defect, the diagnosis has been confirmed by cardiac catheterization in eight. Two of the 11 have had a second operation. One developed aortic insufficiency postoperatively, and, as previously mentioned, still has a residual ventricular defect; in the other patient the aortic insufficiency present preoperatively showed further progression. Six of the other nine patients are under observation, but a second operation has not been advised, as all are asymptomatic although they show some cardiac enlargement. One of these patients also has aneurysmal dilatation of the pulmonary artery associated with a rudimentary pulmonary valve.

Three patients with residual ventricular defects died suddenly some months after surgery. The first, a girl of 28 years, had clinical evidence of a persistent ventricular septal defect and increased pulmonary blood flow, but she responded fairly well to digitalis and was discharged from the hospital. She died suddenly at home 3 months following surgery: no autopsy was obtained. The second patient died suddenly 28 months after surgery while leading a normal life. He had clinical evidence of a ventricular septal defect and at catheterization 10 months postoperatively showed a 1.2 volume per cent increase in oxygen saturation in the right ventricle and moderate pulmonary hypertension of 64/17 mm. Hg. He had also shown electrocardiographic evidence of a progressive conduction disturbance with a change from incomplete to complete right bundle-branch block. At autopsy the presence of a small ventricular septal defect was confirmed, and, in addition, an area of round-cell infiltration was found in the ventricular septum. Earle's group8 reported a somewhat similar carditis as a late fatal complication of open-heart surgery in a patient with tetralogy of Fallot.

The third patient had a small residual ventricular septal defect at catheterization 14 months postoperatively with an increase in oxygen content of 1 volume per cent at the right ventricular level, a right ventricular pressure of 47/11 mm. Hg and a pulmonary artery pressure of 25/10 mm. Hg. She died suddenly nearly 2 years postoperatively; autopsy showed a very small ventricular septal defect and a narrow pulmonary valve orifice of approximately 5 mm. in diameter.

Residual pulmonary stenosis was suspected clinically in five patients because of a loud harsh systolic murmur of the stenotic type over the pulmonary area. Postoperative catheterization confirmed this clinical impression in one patient who was the third late death discussed above.

Pulmonary hypertension of mild or moderate degree was present postoperatively in six patients. One of these had a previous end-to-end anastomosis, which was not ligated at open-heart surgery, and at catheterization 8 months postoperatively the pressure in the main pulmonary artery was 46/14 mm. Hg, with a mean of 27. The second patient had had a patent ductus ligated 9 years prior to open-heart surgery; at catheterization 15 months after total correction she was found to have a systolic pressure in the pulmonary artery of 50 mm. Hg. She was also of interest in that she developed diabetes some months postoperatively at the age of about 12 years.
Four other patients had mild pulmonary hypertension associated with a small residual ventricular septal defect: three of these are clinically doing well, and the fourth was the second patient discussed under the late deaths.

Aneurysmal dilatation of the main pulmonary artery developed in one patient in whom Ivalon had been used for the outflow-tract patch (fig. 2). This patient also had a small residual ventricular septal defect. The aneurysm developed within 9 months of surgery but has not increased in size during the subsequent 3 years. No such complication has been observed to date in any of the patients with a Teflon patch. A similar aneurysm following the use of Ivalon has been reported by Payne and Kirklin.1

Complete heart block has persisted in only two patients although it occurred in the early postoperative period in a total of 10 patients who survived surgery. Both patients are asymptomatic but have cardiac enlargement and their physical activity has been restricted by their physicians.

Other residual defects include aortic insufficiency in three patients, an electrocardiographic pattern of myocardial infarction in two, and atrial fibrillation in one. The electrocardiographic follow-up data are analyzed in a separate communication.4

Discussion

In this group of 146 patients, the high mortality rate was in large part due to technical factors, since the series included the earliest operated cases. The highest mortality rate was encountered in young patients under 10 years of age with either a small pulmonary valve ring or hypoplastic pulmonary artery, which necessitated the use of an outflow patch. A shunt operation rather than corrective surgery in such young patients would thus seem to be the procedure of choice.

The severity of the pulmonary stenosis had a significant effect on the operative results; there was a higher mortality among the more cyanotic patients, among the more disabled, and among those who were 18 months of age or younger at the time of their first cardiac operation. The lowest mortality was among older patients, 21 to 40 years of age, a group with a less severe degree of pulmonary stenosis, only one of whom had required a first cardiac operation prior to 8 years of age.

In the follow-up of 104 patients it was found, as might be expected, that pulmonary valvular insufficiency occurred more frequently in those patients with a right ventricular outflow patch. Furthermore, pulmonary insufficiency and right ventricular outflow patches were associated with an increased incidence of cardiac enlargement: patients without an outflow patch but with pulmonary insufficiency showed lesser degrees of cardiomegaly.

The indications for patching are not clearly defined, as the use has varied considerably from year to year and is known to vary widely from center to center. In this series no correlation could be found between the need for an outflow patch and the hematocrit level or the amount of disability. Neither was there a correlation between the need for an outflow patch and the presence of a previous shunt.

The role of the ventriculotomy in persistent cardiac enlargement is difficult to assess. In
some patients, however, the extent and type of ventriculotomy may be of major importance, as no other complicating lesions were present.

The more serious long-term complications have included heart block, aortic insufficiency, and small residual ventricular septal defects. These residual defects are naturally of concern, since all three of the late deaths occurred in patients with small and anatomically apparently insignificant defects. None of the three had any known disturbance of cardiac rhythm; nevertheless, inasmuch as sudden death occurred in each instance during normal mild activity, the possibility of the abrupt development of an arrhythmia must be considered.

Of the 101 patients on whom adequate clinical follow-up data were obtained, 91 were leading normal lives with normal exercise tolerance. Ten of them were limited in their activities by their physicians because of persistent cardiac enlargement but were clinically asymptomatic. Although numerous complications have been discussed, it should be stressed that 37 patients have hearts of normal size with no gross residual defect although 14 of this group have mild pulmonary insufficiency. Another 36 patients have some degree of cardiac enlargement but are otherwise well, asymptomatic, and without residual defects. Even among the 22 patients in group III, in whom residual cardiac defects are known to be present, the large majority are asymptomatic and are leading normal lives.

Summary and Conclusions

One hundred and forty-six consecutive patients underwent open-heart surgery for correction of tetralogy of Fallot at The Johns Hopkins Hospital from September 1956 to January 1962. Forty-two died in the early postoperative period and 104 were discharged from the hospital alive. Three late deaths have occurred after discharge from the hospital; all of these deaths occurred in patients with small residual ventricular septal defects.

The major factors that influenced the immediate mortality included cyanosis and degree of disability, both of which correlated with the severity of the pulmonic stenosis. More than one previous shunt procedure, a Pott's anastomosis, the presence of severe associated defects, or an outflow patch in young patients under 10 years of age, were all associated with an unfavorable prognosis.

Of the 104 patients in the follow-up group, 41 have been followed for less than 1 year, 52 from between 1 and 3 years, and 11 between 3 and 5 years. Complete follow-up data including x-rays were available in 98. Systolic murmurs persisted in all but eight patients. Pulmonary valvular insufficiency was present in 59 patients and was twice as frequent in those with right ventricular outflow patches.

Of the 101 patients living at completion of the study, 37 have normal cardiothoracic ratios and no residual defects. Thirty-six patients are clinically well with slight cardiac enlargement. Twenty-two patients are clinically asymptomatic but have residual cardiac defects including small residual ventricular defects in eight, aortic insufficiency in five, and complete heart block in two.

Despite the residual cardiac defects, all of the patients have had symptomatic improvement, and, in man this improvement has been dramatic.

Acknowledgment

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TOTAL CORRECTION OF TETRALOGY OF FALLOT


English Medicine Before 1500 A.D.

Up to the time of the Tudors the practice of medicine was the province of the physician, who was a man of learning, generally in Holy orders, and usually a graduate of Oxford or Cambridge, where he first took a degree in Arts and then proceeded to study medicine. The whole course of study might take up to fourteen years. Alternatively the physician might be licensed by the Dean of St. Paul’s or the Bishop of London or of the diocese in which he lived. Up to the time of Henry VIII physicians diagnosed disease according to methods handed down from antiquity, and gained their knowledge by study of volumes written in the Latin or Greek tongue, never in English. They prescribed medicines, but it was considered beneath their dignity to dispense them. The dispensing was done by the apothecaries, whose shops were inspected by the physicians to see that all was in order. No physician was allowed to perform any cutting operation, but he could direct the surgeon to do it for him.

The surgeon and barber-surgeon were on a lower educational plane than the physician; they belonged to their respective Company or Guild and were trained on the apprentice system. The physician often told the surgeon what he wished to be done and sometimes supervised the operation. The general function of the surgeon was to treat injuries and external ailments, but he was also allowed to treat some general diseases such as syphilis and the plague, although he was not supposed to prescribe for internal ailments. Midwifery was usually in the hands of women who had gained their knowledge by practical experience.—ZACHARY COPE, KT. Some Famous General Practitioners and other Medical Historical Essays. London, Pitman Medical Publishing Co., Ltd., 1961, p. 29.
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