Early Results and Late Developments of the Waterston Anastomosis

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SUMMARY

The early results and late developments are presented of a consecutive series of 36 patients who underwent anastomosis of the ascending aorta to right pulmonary artery during a six-year period for a variety of congenital malformations associated with cyanosis and severe pulmonary stenosis or atresia. Twenty-six were infants under one year of age, and 16 of these were under one month of age at the time of operation. The early operative mortality of 22% was related to the severity of the anomaly and the young age of the patient. There were no early deaths in those aged three months or more. If the anastomosis was patent, symptomatic relief was good. However, the long-term mortality was 53%. Except for one baby who died of an associated congenital anomaly, the deaths were related to some consequence of the Waterston anastomosis that was unforeseen at the time of its employment. These included obliteration of the anastomosis, kinking of the anastomosis with partial or complete interruption of continuity between right and left pulmonary arteries, obliteration of the right pulmonary artery, progressive severe obstruction to right ventricular outflow and decreased flow to the left lung, as well as the complications of an excessive shunt with cardiac failure and pulmonary vascular obstructive disease. One or more subsequent palliative operations were required in nine symptomatic patients. Of the ten children with tetralogy of Fallot who underwent later open-heart repair, four died because of the difficulty in takedown of the Waterston and relief of the acquired stenosis or atresia of the right pulmonary artery and of the right ventricular outflow tract and hypoplasia of the left pulmonary artery. This mortality rate of 40% in these tetralogies contrasts with a concurrent mortality rate of less than 5% in a consecutive series of 50 patients with a tetralogy who had not had a previous Waterston procedure. We believe that this form of palliation should be reserved for those symptomatic, cyanotic newborns who are candidates for palliative rather than reparative surgery and who are not suitable for a Blalock-Taussig or Potts anastomosis.

Additional Indexing Words:

Anastomosis of ascending aorta to right pulmonary artery
Cyanotic congenital heart disease
Cyanotic newborn
Interruption of continuity of pulmonary artery
Kinking of anastomosis
Pulmonary atresia
Pulmonary vascular obstructive disease
Surgery, open-heart
Surgery, palliative
Pulmonary stenosis

In view of the available alternatives in surgical procedures for increasing pulmonary blood flow in patients with severe pulmonary stenosis or atresia, it is imperative for pediatric cardiologists and cardiovascular surgeons to evaluate periodically the short- and long-term results of the various anastomotic procedures for palliation. Since the late 1960s, the anastomosis of the ascending aorta to the right pulmonary artery, originally described by Waterston in 1962 and introduced into the English literature independently by Edwards and Cooley, has become the most widely used shunt procedure in infants. It is the purpose of this paper to report on the early and late results in 36 consecutive cases of the Waterston anastomosis and to evaluate them in comparison with the results of other anastomotic procedures.

Material

Between February 1967 and March 1973, 36 patients underwent an intrapericardial anastomosis between the ascending aorta and right pulmonary artery. Sixteen were newborns under one month of age and ten of these were less than one week old. Another ten were infants between one month and one year, and the remaining ten were over one year of age at the time of operation (table 1). All had complete cardiac catheterization with contrast visualization prior to the creation of the shunt. Eighteen had tetralogy of Fallot, seven of whom had pulmonary atresia; eight had tricuspid atresia, and ten had miscellaneous complex malformations in which there was pulmonary atresia or severe stenosis (table 2).

In general, newborn patients who came to surgery had more complex and more severe cardiac malformations than...
the older infants. For example, of ten newborns in the first week of life only one had a tetralogy of Fallot, whereas the other nine had more complex malformations, including seven with pulmonary atresia. Of six babies aged one to four weeks, three had tetralogy with pulmonary atresia, while of the ten babies who were between one and 12 months at the time of surgery, seven had tetralogy, two of them with pulmonary atresia.

Waterston operations on the ten children over one year of age were performed during the period when this procedure was first described and seemed to merit employment and at a time when it was not customary to undertake open-heart surgery for tetralogy of Fallot prior to the age of six years. The Waterston anastomosis was the initial palliative procedure in five children over the age of one year. The other five children had a Waterston anastomosis performed after they had outgrown the benefits of their initial shunt procedure (two Blalock-Taussig anastomoses in one boy, a Potts procedure in one, and a single subclavian-to-pulmonary artery anastomosis in three more). Of these five children, three had conditions not yet amenable to open-heart repair: single ventricle with severe pulmonary stenosis in two and tricuspid atresia in one.

Mortality

Of the original 36 patients, 19 died during the seven-year period. The early mortality rate was 22% and the total mortality rate was 53% (table 1). Eight deaths occurred in the first two weeks after operation.

Six of these patients were severely cyanotic newborns who were considered moribund when surgery was undertaken. Two deaths were caused by heart failure produced by too large an opening. The other deaths were due to intraoperative events in the severely ill infants and/or to inability to create a shunt of adequate size to permit blood flow.

Among the 28 immediate survivors, 11 late deaths occurred two months or more after the shunt procedure. Three of these were among the nine patients who had no subsequent cardiac surgery. Their deaths were due to an inadequate shunt in one, an excessive shunt in another, and to noncardiac cause in the third who had multiple congenital anomalies. Eight late deaths followed a second operation, four after another palliative operation, and four after open-heart surgery.

Operative mortality was clearly related to young age and to severity of malformation (tables 1–3). There were no early deaths among 17 patients over the age of three months, but four of ten babies undergoing surgery in the first week of life died early, as did two of six infants aged one week to one month. These early deaths and the subsequent late deaths resulted in long-term survival for only three of the ten babies operated on in the first week and only six of 16 operated on in the first month of life.

Morbidity

The postpericardiotomy syndrome with prolonged fever, accompanied by pericardial, often pleural, and sometimes pulmonary parenchymal involvement, occurred in seven patients. This is in agreement with the generally observed incidence of 30% of this syndrome following intrapericardial surgery.4, 6 The disease was mild in four, moderate in two, and severe in one 13-year-old boy who needed two pericardiocenteses for pericardial tamponade and then improved when treated with steroids.

Infective endocarditis and cerebrovascular com-

### Table 1

<table>
<thead>
<tr>
<th>Age at Anastomosis and Outcome</th>
<th>Deaths</th>
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</thead>
<tbody>
<tr>
<td>Age</td>
<td>Ops.</td>
<td>Early</td>
</tr>
<tr>
<td>&lt; 1 wk</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>1 wk – 1 mo</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>1 mo – 1 yr</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>1 yr – 5 yrs</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 5 yrs</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Grand total</td>
<td>36</td>
<td>8</td>
</tr>
<tr>
<td>Mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTS = long-term survival.</td>
<td></td>
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</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Age at op.</th>
<th>Total group</th>
<th>Tetrology</th>
<th>Tricuspid Ateisia</th>
<th>Single Ventricle</th>
<th>CTGA VSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>LTS</td>
<td>No.</td>
<td>LTS</td>
<td>No.</td>
<td>No.</td>
</tr>
<tr>
<td>&lt; 1 wk</td>
<td>10</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>1 wk – 1 mo</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1 mo – 1 yr</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>1 yr – 5 yrs</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 5 yrs</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>17</td>
<td>18</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

Abbreviations: CTGA = complete transposition of the great arteries; LTS = long-term survival; VSD = ventricular septal defect.
Table 3

<table>
<thead>
<tr>
<th>Age at anastomosis</th>
<th>No.</th>
<th>Died</th>
<th>Mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 wk</td>
<td>10</td>
<td>4</td>
<td>40%</td>
</tr>
<tr>
<td>1 wk – 3 mo</td>
<td>9</td>
<td>4</td>
<td>44%</td>
</tr>
<tr>
<td>&gt; 3 mo</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total group</td>
<td>36</td>
<td>8</td>
<td>22%</td>
</tr>
</tbody>
</table>

Complications did not occur in these survivors during this period of follow-up.

Subsequent Operations

Among 28 patients who survived the first two postoperative weeks, only nine were considered not to need another operation following the Waterston shunt. Ten palliative operations were done in nine subjects with three early deaths and one late. Open-heart surgery was performed in ten patients with four deaths (table 4).

Palliative operations were undertaken within two days to three years after the Waterston shunt because of symptoms in the patients. The shunt was inadequate in eight subjects, all of whom were under the age of four months at the time of the original operation. The ninth patient was an 11-year-old boy with single ventricle, who had outgrown a previously effective, but now small, left Blalock-Taussig anastomosis. The Waterston shunt resulted in cardiac failure and development of pulmonary hypertension documented at systemic levels seven months postoperatively (fig. 1). An operation to decrease the size of that anastomosis failed and the child died.

In the eight patients in whom the shunt was too small initially, or else became so, an attempt to enlarge a restricted anastomosis was successful in one toddler and was impossible in another whose entire right pulmonary arterial tree was found to be fibrosed. This patient underwent a third operation, a Potts anastomosis, and has improved.

A second shunt procedure was employed as palliation in six children under the age of three years. Three were Blalock-Taussig and three were Potts anastomoses. Two patients had tetralogy and the others had more complex anomalies. Both children with tetralogy died, one within a few hours after a Potts anastomosis proved to be too large. The other baby had a successful Blalock-Taussig anastomosis two days after a Waterston shunt that did not function. She died later of the effects of brain damage from a severe hypoxic spell two days after the Waterston shunt was performed.

Open-heart surgery was carried out in ten patients. Eight operations were elective, in that the child was doing satisfactorily from the parents’ point of view, with a seemingly well-functioning Waterston shunt. Two children had symptoms to indicate that the shunt was not functioning satisfactorily. The four deaths were due to difficulties directly related to the effects of

Table 4

<table>
<thead>
<tr>
<th>Age at anastomosis</th>
<th>Revision Waterston</th>
<th>Palliative</th>
<th>Other shunt</th>
<th>Open repair</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>No.</td>
<td>Died</td>
<td>No.</td>
<td>Died</td>
</tr>
<tr>
<td>&lt; 1 wk</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1 wk – 1 mo</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1 mo – 1 yr</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1 yr – 5 yrs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 5 yrs</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>3</td>
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</table>

Oversized anastomosis in eleven-year-old boy, S.T., with pulmonary pressure at systemic level when measured seven months following establishment of an aortico-right pulmonary arterial anastomosis that soon proved to be too large.

Selective injection into the ascending aorta shows opacification of both right and left branches without interruption of continuity but with evidence of far greater flow into the much-enlarged right branch and only average flow into the left branch. This discrepancy was due to some kinking or angulation that interfered with flow to the left lung.
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the aortico-right pulmonary artery anastomosis. Six children with tetralogy are improved after open-heart surgery that was unusually difficult because of complications of the Waterston anastomosis, that were unforeseen at the time the anastomosis was created. These complications will be discussed later.

Survival

Of the 17 long-term survivors, four are doing satisfactorily with an adequate shunt and no medication. In addition to severe pulmonary stenosis or atresia, three of these have tricuspid atresia and the fourth, a single ventricle. No further surgery is contemplated.

Three others gradually developed cardiac failure because of the shunt’s becoming excessive, but failure is well controlled on digitalis and medical management, and no further surgery is planned in two of these who have tricuspid atresia. The third, who has tetralogy of Fallot, is a likely candidate for open-heart surgery in the future. The six patients with tetralogy who survived reparative surgery are clinically well and asymptomatic although none has normal cardiovascular anatomy or physiology.

Effects, Functional and Anatomic

The results of the Waterston anastomosis should be judged not only by the adequacy of pulmonary flow, which determines its success as a palliative measure, but also by the anatomical effects on the right pulmonary artery and pulmonary arterial tree and on the right ventricular outflow tract. These considerations critically influence the outcome when intracardiac repair is attempted.

Functional Effects

The patient’s benefit from this artificial patent ductus depends upon the degree of increase in pulmonary blood flow that is achieved. The adequacy of pulmonary flow was best judged clinically by noting the improved appearance and performance of the patient, by presence of a continuous murmur of a functioning anastomosis over the right or both lung fields, by radiologic signs of only slight increase in heart size and of average pulmonary vascularity in the two lung fields, by electrocardiographic evidence of increase in left ventricular forces, and by polycythemia of minimal degree.

Initial relief of cyanosis, polycythemia, and exercise intolerance was good to excellent in 22, fair in four, and poor in two of the 28 early survivors. From the outset, two anastomoses were oversized, two were open but too small, and two others never functioned at all. Thus, 22 of 28 anastomoses were initially of the desired size. Six weeks to eighteen months later, four others had become inadequate, two had ceased functioning, and nine that initially were adequate shunts had become excessive.

The adequacy of total pulmonary flow after surgery in the 28 immediate survivors correlated with the preoperative severity of obstruction to right ventricular outflow. Of the patients with pulmonary atresia, about half (6 of 13) achieved adequate flow. When some forward flow from the right ventricle to the main pulmonary artery was present (pulmonary stenosis), the chances of symptomatic improvement after surgery were distinctly better; 13 of 15 such patients had an increase in pulmonary flow.

In this series, the surgeons deliberately tried to prevent an oversized anastomosis and the complications of cardiomegaly, cardiac failure and pulmonary hypertension. In the newborns with markedly diminished pulmonary blood flow and small right pulmonary artery, the problem was not so much that of creating too large an anastomosis as of trying to prevent too small an opening which could become obstructed by a thrombus. In the older infants and children, the surgeons were careful to avoid making an orifice greater than 4–5 mm in diameter. Nevertheless, this complication of too large an anastomosis did occur in 11 patients, either immediately or after a few months. Two immediate deaths were due to cardiac failure from too large a shunt. Of 28 patients who survived longer than two weeks postoperatively, nine developed pulmonary overcirculation and cardiomegaly, documented by radiology, as well as left ventricular hypertrophy, documented by electrocardiographic results. Six required treatment for congestive heart failure and two died. One was an 11-year-old boy, previously mentioned (fig. 1), whose pulmonary arterial pressure was at systemic level seven months after the Waterston shunt. He had severe pulmonary hypertensive angiopathy at postmortem examination nine months following the surgery. Two who developed excessive pulmonary blood flow were newborns, aged two and three days respectively, at the time of surgery. Heart failure developed at the age of six weeks, a time lag coincident with the period of physiologic drop of pulmonary vascular resistance.

Anatomic Effects

At each operation the surgeon performed the anastomosis as posterior as possible on the aortic wall. Although over-all pulmonary flow was clinically adequate in 22 of 28 immediate survivors, unequal distribution of blood into the two lungs, with preferential flow to the right lung, was often noted (figs. 1–4). This disproportionate division of pulmonary blood flow was
found to be due to kinking at the anastomotic site so that blood flowed from the aorta into the distal right pulmonary artery but less well or not at all into the proximal portion of the right pulmonary artery and across into the left branch.

Kinking of Anastomosis

Kinking could be evaluated reliably in 22 patients, in 18 by selective injection of contrast medium at postoperative cardiac catheterization, in two at a later operation, and in two at autopsy (tables 5 and 6). All 22 had evidence of kinking. In twelve patients it was severe, with complete obstruction between the distal and proximal segments of the right pulmonary artery in eight, and with a nonfunctioning anastomosis in four. With maximal angulation there was complete occlusion and interruption of the continuity between the distal and proximal portions of the right pulmonary artery (figs. 2–4). The proximal right pulmonary artery was continuous with the main pulmonary artery and the left branch (fig. 2). The distal right pulmonary artery was in communication only with the aorta through the Waterston anastomosis (figs. 3, 4).

Severe kinking occurred more often in patients in whom the anastomosis was performed early in infancy than at an older age (table 6). Of the seven patients who were over one year of age when the shunt was performed, only one was demonstrated to have severe angulation of the right pulmonary artery, whereas 11 of 15 who were less than one year of age at operation had marked kinking. Six other survivors, not yet restudied, have clinical evidence of kinking, with decreased pulmonary vascularity in the left lung field and increased markings on the right. In no long-term survivor has there been evidence of increased blood flow to the left lung.

Development of Increasingly Severe Pulmonary Stenosis or Atresia

This occurred in eight of the ten patients with tetralogy of Fallot who demonstrated moderate pulmonary stenosis preoperatively, and in one patient with tricuspid atresia. In the eight cases of tetralogy there was evidence at recatheterization three to five years after the Waterston anastomosis of increasingly severe infundibular stenosis with little increase with time in size of the pulmonary valve ring, main or left pulmonary artery. In two of these there was complete obstruction to right ventricular outflow. In one of the latter, as well as in the child with tricuspid atresia, complete obliteration of the right pulmonary arterial tree occurred.

Worsening of outflow tract obstruction had the effect of decreasing pulmonary blood flow to the left lung, while at the same time kinking of the right pulmonary artery at its connection to the aorta prevented an adequate shunt to the left pulmonary artery. The net effect was that of persistent hypoplasia or even of progressive decrease in relative size of the left pulmonary artery.

| Table 5 |
|-----------------|------|-------|-------|-------|-------|
| Interval Between Anastomosis and Re-evaluation |
| Age at op. | No. pts. | <6 mo | 6–24 mo | 24–36 mo | >36 mo |
| <1 yr | 15 | 4 | 4 | 4 | 3 |
| >1 yr | 7 | 1 | 2 | 3 | 1 |
| Total | 22 | 5 | 6 | 7 | 4 |
RESULTS OF WATERSTON ANASTOMOSIS

Figure 4

Severe kinking with interruption of continuity of right pulmonary artery in five-year-old girl, C.G., whose right ventricular injection at this study showed complete obliteration of the right ventricular outflow tract that had been stenosed but patent at the age of five days when the Waterston shunt was created. Selective injections into left ventricle (left panel) and at the aortic stoma of the Waterston shunt (right panel). Note that from the left ventricle, only the aorta and large right pulmonary artery are opacified. Selective catheterisation of the stoma of the Waterston also shows large flow only to right pulmonary artery. In comparison with figure 3, there is greater shunt of blood into this right lung, but the flow is not so excessive as in figure 1.

These anatomic changes made subsequent open-heart surgery difficult and at high risk in the ten patients with tetralogy in whom it was carried out. In only one was a small Waterston shunt obliterated from inside the aorta. Death occurred from bleeding about the aorta. The method of takedown of the anastomosis in the others has been described by Ebert and Gay.26, 27 Of the nine remaining patients, two with complete obstruction of the right pulmonary artery died because it was impossible to control bleeding and reconstruct continuity between the proximal and distal portions of the right pulmonary artery. In one child the distal right pulmonary artery was found to be only a fibrous cord beyond the anastomotic area. Complete obstruction to the right ventricular outflow tract was also confirmed, but it could be removed and a pericardial patch inserted to establish an adequate outlet from the right ventricle to the main and left pulmonary arteries.

Four children had pericardial patches placed to enlarge the constricted right pulmonary artery and all survived intracardiac repair with clinical improvement. Postoperative cardiac catheterization in three demonstrated narrowing in the patched pulmonary artery.

In six patients the right ventricular outflow tract was enlarged by a pericardial patch. In two the patch extended across the pulmonary ring.

The tenth child to undergo open-heart surgery had pulmonary atresia and died after a Rastelli procedure to place a graft from the outflow tract of the right ventricle to the main pulmonary artery and a smaller graft to the hypoplastic left pulmonary artery. Because of the uneven distribution of pulmonary blood flow, with less going to the left lung than to the right, the left pulmonary artery had not enlarged as we had hoped when the Waterston shunt was employed.

The high death rate (40%) in these ten children with tetralogy of Fallot contrasted with the mortality rate of less than 5% in a consecutive, concurrent series of 50 patients undergoing open-heart repair during this same period of 1971–73.

The heightened risk of subsequent surgery was related to one or more of these aforementioned effects of the Waterston shunt that were not anticipated when the operative technique was introduced: (1) angulation of the right pulmonary artery so that blood flow was increased more to the right lung than the left, with effects on the right pulmonary artery of this intravascular obstruction that ranged from hyperten-

Table 6

Kinking of Anastomosis at Restudy

<table>
<thead>
<tr>
<th>Age at op.</th>
<th>No. of pts.</th>
<th>Kinking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>&lt;1 yr</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>&gt;1 yr</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
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</table>

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sive pulmonary angiopathy to complete obliteration of the right pulmonary arterial tree, and (2) concomitant worsening of intraventricular obstruction so that right ventricular outflow to the main and left pulmonary artery became less effective.

Discussion

Although covering a much shorter period, the results of this follow-up on survival of children who had a Waterston anastomosis may be compared to the long-term results of anastomosis of the subclavian-to-pulmonary artery (Blalock-Taussig) and the descending aorta-to-left pulmonary artery (Potts-Smith).

Now there is more emphasis on salvage of the sick, cyanotic newborn by early palliative surgery than in the 1950s and 1960s when the Blalock-Taussig and Potts anastomoses were the principal procedures available and when these sick babies often did not come to corrective surgery. White et al., in their report on 500 patients with the Blalock-Taussig anastomosis in a comparable number of years of postoperative follow-up, but at a time when open-heart repair was not yet available, concluded that patients who obtained good results from the shunt had a 67% chance for the maintenance of that improvement five to eight years after operation. Pulmonary hypertension was found in only a small number, approximately 1%.7,8

A well-recognized limitation of the Blalock-Taussig shunt was nonfunction in young infants needing operation. This was due to the small size of the subclavian artery and also of the pulmonary artery.8,9 Anastomosis of the aorta by means of Potts or Waterston anastomosis overcame the limitation of the small size of the systemic artery in infants, but carried with it the possibility of creating too large an anastomosis. In the 1950s and the early 1960s the Potts anastomosis was widely used for palliation of these small babies.9 Long-term follow-up findings on the Potts anastomosis were disappointing because of three developments unforeseen at the time the operation: 1) the development of pulmonary vascular obstructive disease following too large an anastomosis, 2) the difficulty of takedown of the shunt during later open-heart surgery, and 3) progressive severity of obstruction to right ventricular outflow. In their review of 112 patients who underwent cardiac catheterization at various intervals up to 20 years after the Potts anastomosis, Cole et al. found 16 cases with elevated pulmonary vascular resistance, an incidence of 14.3%.10 Bernuth et al. reported on 13 cases of pulmonary vascular obstructive disease out of 26 patients with tetralogy of Fallot and a Potts shunt who were catheterized for evaluation for open-heart repair.11

It is reasonable to expect that the incidence of pulmonary vascular obstructive disease following a Waterston anastomosis will be similar to that after a Potts anastomosis since it is the size rather than the site of the aortico-pulmonary anastomosis that determines this complication. In the early years of the Potts operation an anastomosis of 8–9.5 mm was originally recommended.9 Those patients were generally older than most patients undergoing the Waterston operation today. In Potts’ original series, 25 of the 45 were over two years of age, and none was under four months,12 so the performance of that large a connection was technically possible.

Those anastomoses were performed at a time when little was known about damage to the pulmonary arterioles secondary to too large a left-to-right shunt through a surgically created systemic-to-pulmonary artery anastomosis. In the 1960s, when the complication of pulmonary vascular obstructive disease was well recognized,13–16 it was recommended that Potts anastomoses not exceed 4–5 mm. In 1971, Cole et al. demonstrated that of their 12 patients who had had a recently-performed Potts anastomosis, and were catheterized up to five years after surgery, none had developed elevated pulmonary vascular resistance.10 They correctly anticipated that the complication of pulmonary vascular obstructive disease would not be unique to the Potts operation.

The three types of anastomosis may be compared according to ease of takedown of the shunt at subsequent reparative surgery. Interruption of a Blalock-Taussig anastomosis at the time of open-heart surgery has not contributed significantly to mortality.17 However, early in the experience with intracardiac repair for tetralogy of Fallot in patients who had a previous Potts anastomosis, the surgical mortality was nearly three times the mortality rate in patients who did not have a previous shunt procedure or who had only one Blalock-Taussig anastomosis: 75% after Potts vs 30% after Blalock-Taussig anastomosis,18,19 22.2% vs 8.6%,20 and 33% vs 12%.21 Kirklin et al. in 1965 reported a 20% mortality in 35 patients with a previous Potts anastomosis.22 Results were improved after a different method of takedown of the anastomosis of descending aorta-to-left pulmonary artery was devised. Their approach for closure of the shunt between descending aorta and left pulmonary artery was through an incision into the left pulmonary artery while the patient was under hypothermia of 26° to 28° C and 10–15 min of circulatory arrest.23,24 In their last series, Kirklin et al. reported no deaths in the group of 13 patients with normal or only mildly elevated pulmonary vascular resistance. Gross et al. successfully used this surgical approach with a mortality rate of 15% in 43 consecutive patients.26
RESULTS OF WATERSTON ANASTOMOSIS

It has been our experience, as well as that of others, that takedown of the Waterston shunt also complicates subsequent open-heart repair considerably. Because of the relatively small numbers of patients with a Waterston shunt who have later needed intracardiac repair, only further experience will tell whether morbidity and mortality will indeed be lower in most surgeons' hands than following obliteration of a Potts anastomosis.

It was originally envisioned that transaortic closure of the stoma would be the standard approach for takedown of the Waterston anastomosis during intracardiac repair. Because of the kinking, however, and of the need to create or preserve patency of the right pulmonary artery, this approach could be utilized in only one of the ten patients herein reported.

In planning for open-heart repair in a patient with tetralogy and a Waterston anastomosis we believe it is essential to perform complete cardiac catheterization with selective contrast visualization not only to evaluate the septal defect, overriding aorta, and the precise anatomy of the right ventricular outflow tract and pulmonary arterial tree, but also to identify the presence and degree of kinking of the anastomosis.

Angiographic recognition of interruption between the right and left pulmonary artery following a Waterston anastomosis can best be achieved by selective injection of contrast material into two sites: 1) the ascending aorta close to the stoma of the shunt (figs. 3 and 4), and 2) the main pulmonary artery (if there is no pulmonary atresia). In the tetralogy of Fallot, injection into the right ventricle alone may be followed by simultaneous opacification of the ascending aorta and the main pulmonary artery. When there is discontinuity between the two main branches of the pulmonary artery, the distal right pulmonary artery can fill from the ascending aorta while the proximal right and left branch can fill from the main pulmonary artery. Thus, both branches can be opacified and the diagnosis of discontinuity between the two may be missed. At the time of opacification of the main pulmonary artery one should look for the stump where the proximal right pulmonary artery narrows or terminates (fig. 2).

The progression from pulmonary stenosis to a more marked degree of obstruction and even to pulmonary atresia following a successful palliative shunt to increase flow to the lungs was not an unexpected occurrence after a Waterston procedure. It has been observed after a Potts anastomosis and even in the patient who has not been treated by surgery. When blood bypasses a narrowed right ventricular outflow tract, there is little mechanical stimulus for that passage to grow or to remain patent. The progressive nature of obstruction to right ventricular outflow has recently been stressed as a major reason for early open-heart correction in selected cases of tetralogy of Fallot. The combined effects on the left pulmonary artery of the kinking at the anastomosis and of increasingly severe outflow tract obstruction deprive the left pulmonary artery of adequate blood flow.

The Decision for Early Palliative or Reparative Surgery

Choice of a palliative procedure to increase pulmonary blood flow is based on the early and long-term effects just considered. In addition, when such palliation is to be undertaken, the choice of anastomosis is determined by several other factors such as the position of the great arteries, the direction of the aortic arch, and the size of the right or left pulmonary artery. For example, with anterolateral position of the aorta in corrected transposition of the great arteries and a functional tetralogy, a Waterston anastomosis is quite difficult to construct and is unlikely to function, while in a tetralogy with right aortic arch, a Potts anastomosis cannot be accomplished. The choice of anastomosis is also influenced by the present anticipation that a palliative anastomosis for a basically uncorrectable lesion may not need subsequent takedown at all.

Among the various palliative procedures, the complication of kinking is unique to the anastomosis of ascending aorta to the right pulmonary artery. This development seems to be related to growth of the baby and to realignment of the anastomosed arteries rather than to the manner of performing the anastomosis. The operations in this report were performed by several surgeons, all of whom attempted to make the anastomosis as far posteriorly on the right side of the ascending aorta as possible.

When the anastomosis is between the left descending aorta and left pulmonary artery (Potts anastomosis), blood flows into the right as well as the left branch. Furthermore, there is no risk of postpericardiotomy syndrome after an extrapericardial anastomosis.

We believe that in saving most severely cyanotic infants with decreased pulmonary blood flow who are under the age of three months, the Waterston shunt is more effective than the Blalock-Taussig anastomosis, and unlike the Potts anastomosis, it can be carried out in those with a right aortic arch as well as in the larger number with a left arch. The Waterston procedure, however, is associated with or followed by certain complications. Early, the anastomosis may fail to function, and there is the risk of morbidity and even death from the postpericardiotomy syndrome. The occurrence of too large an anastomosis with resultant complications.

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immediate cardiac failure or early pulmonary vascular disease can be avoided if the size of the opening is carefully made. However, the possibility of the stoma’s growing excessively relative to the growth of the child still exists. Kinking of the right pulmonary artery and interruption of its continuity with the left pulmonary artery seems to be inherent in this type of anastomosis as the child grows. This complication adds considerably to the difficulty and risk of open-heart surgery in that patient.

Our present policy is to perform this operation only for the severely cyanotic newborn with pulmonary stenosis or atresia whose anatomy and condition are unsuitable for a Potts or Blalock-Taussig anastomosis, but not to employ it for older infants or children if some other palliative procedure is possible or if early open-heart repair is feasible. Since the untoward long-term consequences of the anastomosis appear to be related to growth and seem to be progressive, we believe re-evaluation by cardiac catheterization and angiocardiography should be performed within two years of establishment of the shunt.

Choice of early open-heart repair versus a palliative procedure in the symptomatic, cyanotic newborn depends on accurate preoperative diagnosis and on the developing skills in pediatric and cardiac surgical management. If early reparative surgery for the baby with tetralogy of Fallot can be accomplished at less risk than from combined operations of early palliation and later repair, and if the long-term results following early open-heart repair are shown to be as good as those following open-heart surgery in childhood, then the use of palliative procedures will be reserved for the more complex malformations with cyanosis and decreased flow in which there is now no established repair procedure.

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Circulation. 1974;50:220-229
doi: 10.1161/01.CIR.50.2.220

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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