Aorta to Right Pulmonary Artery Anastomosis (Waterston's Operation) for Cyanotic Heart Disease


SUMMARY
Thirty patients with cyanotic heart disease, including Fallot's tetralogy, transposition of the great arteries, and tricuspid atresia had Waterston's anastomosis for gross effort intolerance or cyanotic attacks. The results were good in 28. Spontaneous closure of the anastomosis occurred in one patient. There was a tendency for preferential perfusion of the right lung, and unilateral pulmonary edema occurred in nine patients. Congestive heart failure appeared when the stoma was too large. Surgical technic to avoid kinking of the right pulmonary artery has been modified, and the importance of limiting the size of the anastomosis has been emphasized. Transaortic closure of the anastomosis through the aorta at the time of definitive correction was simple in three patients.

Additional Indexing Words:
Complications Congenital heart disease Cardiac failure
Arterial oxygen saturation Pulmonary edema Timing of complete correction
Transaortic closure of anastomosis

PALLIATIVE OPERATIONS for tetralogy of Fallot and allied cyanotic heart diseases have been widely practiced since Blalock's operation. Other types of systemic-pulmonary anastomotic procedures have also successfully relieved symptoms. At the present time, the efficiency of a palliative operation is judged not only by the initial result, but also by the long-term follow-up and the ease with which it can be closed at the time of definitive correction.

Waterston in 1962 used an anastomosis between the right pulmonary artery and ascending aorta which has been found useful in infants with small vessels. At the National Heart Hospital, this operation has been used in preference to other procedures in cyanotic patients with diminished pulmonary blood flow who require palliation. The results of Waterston's operation in 30 patients with cyanotic heart disease have been studied in detail.

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Methods

Clinical Material
Waterston's operation was performed on 30 patients with cyanotic heart disease between April 1966 and July 1968 (table 1). Their ages ranged from 8 months to 35 years. Each had one large ventricular septal defect associated with severe pulmonary stenosis or pulmonary atresia. Fallot's tetralogy was present in 21, tricuspid atresia or a variant in three, transposition of the great arteries in three, pulmonary atresia in two, and double outlet right ventricle in one patient. The operation was performed for recurrent cyanotic attacks in 16 patients and for severe effort intolerance in 14. This palliative procedure was chosen as a first stage operation in those whose basic lesions were suitable for total correction when they were younger than 5 years or when the hemoglobin exceeded 130% (18 g) irrespective of age. Preoperative cardiac catheterization and angiocardiography were performed in all patients.

Following operation, the patients were examined for signs of heart failure, pulmonary edema, and pleural effusion, as well as for evidence of a functioning shunt. A good result was judged by cessation of cyanotic attacks, improvement in exercise tolerance, and diminution of cyanosis at rest or with effort as well as a maintained reduction of the hemoglobin level.
Table 1

Data on 30 Patients with Waterston's Anastomosis

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* General anesthetic.

Abbreviations: LPA and RPA = left and right pulmonary arteries; R arch = right aortic arch; ASD = atrial septal defect; D.O.R.V. = double outlet right ventricle; PS = pulmonary stenosis; RV = right ventricle; CT = corrected transposition; TGA = transposition of the great arteries; PDA = persistent ductus arteriosus; Anom. RPV = anomalous right pulmonary veins; syst. art. sat O₂ = systemic arterial oxygen saturation; CF = congestive heart failure; plethora R > L = plethora of right lung more than of left.
The patients were followed up for periods of 4 months to 2 years. Postoperative investigations including aortography were carried out in seven patients. Three patients have since had total correction of Fallot's tetralogy with closure of the Waterston anastomosis.

**Surgical Technic**

The operation was performed through a right anterolateral thoracotomy through the fourth intercostal space. The superior vena cava was mobilized by division of the azygos vein and held forward by a tape passed around it. The right pulmonary artery was then dissected out, and its distal branches were controlled by untied ligatures. A curved Waterston clamp was applied to include the anterior surface of the right pulmonary artery and part of the overlying ascending aorta (fig. 1). A side-to-side anastomosis was then made between the two vessels as far posteriorly as possible behind the aorta to prevent forward kinking of the right pulmonary artery, and care was taken not to cause upward kinking by pulling up the distal right pulmonary artery (fig. 2). In two patients, early in the series, the anastomosis was made anterior to the superior vena cava, but making it behind the superior vena cava, as was done in the others, was considered better. The procedure involved opening the pericardium, but the extent of the opening was kept to a minimum.

In two patients with an aorta placed anteriorly and to the left (fig. 3), the left pulmonary artery was posterior to the ascending aorta. In one, a left anterior thoracotomy gave excellent access to these great arteries and the anastomosis was made between the left pulmonary artery and the medial side of the ascending aorta. In the other patient the pericardium was opened widely, and the anastomosis was made medial to the superior vena cava and close to the bifurcation of the pulmonary artery.

The anastomosis was closed during total correction in three patients. This was done immediately after instituting cardiopulmonary bypass. The ascending aorta was clamped above the region of the anastomosis, and the stoma was sutured from inside the ascending aorta. A few fine vascular pericardial adhesions, maximal over the right atrium, had to be divided.

**Results**

**General Clinical**

There was no operative or late mortality related to the procedure. In 28 patients the preoperative symptoms were completely relieved with improvement of effort tolerance and diminution of central cyanosis throughout the period of postoperative observation. In one patient with transposition of the great arteries multiple ventricular septal defects and pulmonary stenosis (case 20), sudden deterioration occurred after 7 months of well-being and improved symptoms. The patient had developed ventricular fibrillation during induction of anesthesia and the anastomosis was made quickly during cardiac arrest. Improvement was dramatic, but the continuous murmur, documented after the operation, disappeared 7 months later, and aortography...
anastomosis had been made anterior to the superior vena cava. Chest radiography showed good perfusion of the right lung (fig. 4A) in comparison with the left.

**Physical Signs**

The physical signs with a patent Waterston anastomosis resembled the signs of other forms of systemic-pulmonary shunt. Clubbing of the fingers regressed incompletely in 29 patients. Central cyanosis lessened in all but was still apparent at rest in 10 patients. This was in part related to the basic underlying lesions as transposition was present in three, tricuspid atresia in two and pulmonary atresia in three. Only two of the group who remained cyanosed at rest had tetralogy of Fallot (cases 3 and 8); both had small shunts, and one had perfusion of one lung only. Seven with large shunts were acyanotic after mild effort of running up 30 stairs, but the rest had some cyanosis after this exertion.

The pulse volume increased in all, and in all those with visible carotid pulsation immediately after operation, congestive failure always occurred in the first week. The continuous murmur, recorded in 20 patients, was maximal at the right sternal edge, increased on inspiration, and had a shorter softer diastolic element than in a patent Blalock anastomosis. In 10 patients the murmur appeared to be confined to systole running up to the second heart sound. Apical delayed (mid) diastolic
murmurs appeared in four patients with large left to right shunts (cases 2, 14, 15, and 23). A third sound was noted in 14 patients with other signs of congestive heart failure and disappeared when the heart failure improved. The jugular venous pressure rose with heart failure and in patients who developed pericarditis. Hepatomegaly was also present but disappeared quickly with therapy.

Complications
Congestive cardiac failure lasting for 1 to 18 weeks occurred in 15 patients. This was controlled by digoxin and diuretics which were continued for 2 months after the disappearance of elevated jugular venous pressure and pulmonary venous congestion. Cardiac failure lasted longer than 2 months in six and was worse in one patient (case 14) with an underdeveloped right ventricle and large atrial septal defect, in whom the shunt was too large (6 mm) for such a small child. One of the six with severe failure had tricuspid atresia and in the rest the size of the anastomosis was large, exceeding 4 mm in all.

Edema of the right lung was noted in nine patients (fig. 5). This was cleared after 3 to 5 weeks. In four patients it was associated with a pleural effusion which required paracentesis. Patients with edema in the lung were cyanosed during the first postoperative week and were helped by the administration of oxygen. Pulmonary edema cleared dramatically after removal of obstruction from the left pulmonary artery (fig. 5). Localized opacification in the middle of the right lung commonly occurred in the first 3 days and was attributed to localized edema. Five patients whose postoperative chest roentgenogram showed marked plethora of the right lung developed recurrent respiratory infections on that side during the period of follow-up. None of these had been prone to respiratory infection before.

Pericardial friction was heard during the first postoperative 2 weeks in seven patients, and symptoms of pericarditis with chest, neck, and shoulder pain with pyrexia occurred in five but was not recurrent.

Thoracic Radiology
The vascularity of the lungs increased in all patients (fig. 6). Vascularity diminished quickly in the one patient with spontaneous closure of the anastomosis. In 15 patients vascularity was greater in the right than the left lung, and in one (case 16) with transposition of the great arteries, the vascularity was greater in the left lung. In one patient the right upper lobe appeared to be selectively overperfused (fig. 4), and this

Figure 5
Case 1. Severe edema of the right lung and right pleural effusion after the Waterston anastomosis which subsequently cleared after an obstruction was removed from the origin of the left pulmonary artery. (A) Before operation. (B) Three weeks after the Waterston anastomosis. (C) Five months after the Waterston anastomosis and 6 weeks after removal of a membrane from the left pulmonary artery.
observation was confirmed by angiocardiography which showed that the right pulmonary artery had been kinked upwards (fig. 4B and C). In 14 patients the increase in vascularity appeared to be the same in both lungs. The heart size increased in all (fig. 6) except in the patient with transposition of the great arteries who had previously been in severe heart failure.

Electrocardiogram

Transient T-wave changes suggestive of pericarditis occurred in six patients. Patients with tetralogy and pulmonary atresia with successful shunts, followed for more than 9 months, showed an increase in the RV6 sometimes associated with a shift of the electrical axis toward normality.

Postoperative Investigations

Seven patients were reinvestigated 9 to 14 months after operation. Six of these were catheterized because of a postoperative problem such as heart failure (cases 1 and 2), the radiological appearance of the right lung and recurrent infection (cases 6 and 9), and cyanosis (cases 8 and 20). Only one patient with an ideal clinical result (case 24) was investigated after operation. In all there appeared to be preferential perfusion of the right lung even when the thoracic roentgenogram suggested that the pulmonary blood flow was increased on both sides.

The arterial oxygen saturation rose to 80% or more in all except case 8 in which the shunt was only perfusing the right lung. Case 20,

Figure 6

Case 3. Some increase in heart size and increase in pulmonary blood flow after the Waterston anastomosis. Patient had no complications. (A) Before operation. (B) 1 year after surgery.

Figure 7

Right ventricular angiocardiogram after total correction and closure of the Waterston anastomosis showing residual deformity of the right pulmonary artery at the site of operation (arrow).
with an arterial saturation of 49%, was reinvestigated after the shunt had spontaneously closed. Selective perfusion of the right lung occurred partly because of kinking of the right pulmonary artery but was also encouraged by the presence of stenosis proximal to the anastomosis. The right pulmonary artery pressure was measured at catheterization in only three patients as it was difficult to enter. In case 2 it was 45/10 mm Hg, in case 6 it was 41/12 mm Hg, and in case 24 it was 30/15 mm Hg. It was found to be easier to cross the anastomosis by passing the catheter retrogradely from the right brachial artery into the aorta, than by using the venous route. Distal right pulmonary artery pressures measured at operation prior to closure of the shunt were found to be 45/20 mm Hg in case 1 and 40/10 in case 9. Investigation of case 1 after complete repair and closure of the anastomosis showed a normal pulmonary artery pressure of 25/10 mm Hg and angiography showed only slight deformity of the pulmonary artery at the site of the closed anastomosis (fig. 7).

One patient (case 9) died from staphylococcal endocarditis 7 weeks after total correction. The pulmonary arteries of the right lung looked larger and more dilated than those of the left lung. Professor Reginald Hudson reported that the arteries from both lungs showed focal fibrous thickening which was more marked on the right where the vessels were seen to be more dilated.

Discussion

Patients with severe cyanotic heart disease due to insufficient blood flow through the lungs can be improved by a systemic-pulmonary artery anastomosis which may be indicated for patients who are too ill, too small, or have too complex a condition for total correction. The use of the subclavian artery is limited by the size of that artery and the possibility of kinking. The long-term results of the Blalock anastomosis have been fairly satisfactory, but there is a significant incidence of spontaneous closure and inadequate size of shunt. Tension and kinking of the subclavian artery in a Blalock anastomosis can be avoided by Waterston's method of detaching the artery at its origin and reanastomosing it to the descending aorta, but we have found this difficult to close from a median sternotomy at the time of definitive correction. Potts' anastomosis between the left pulmonary artery and the descending aorta gives good results in infants, but in patients with a rightsided aortic arch this operation is not satisfactory because the adjacent right upper lobe bronchus can put the anastomosis under tension. The major disadvantages of Pott's anastomosis are the difficulties in closing it at the time of total correction and the danger that pulmonary vascular disease may develop if the shunt is large.

Anastomosis of the right pulmonary artery to the ascending aorta is a simple procedure with a high success rate and low mortality. Some mortality in infants, in whom Waterston has found the procedure to be particularly helpful, is inevitable, but the present series does not include children under 6 months because small infants were not referred to the National Heart Hospital during this period. Edwards and his colleagues found it useful in infants and also particularly easy in the presence of a right aortic arch but suggested that it should not be done in patients with tricuspid or pulmonary atresia. In the present series this anastomosis has been found to be satisfactory in these conditions, but initial problems with unilateral pulmonary edema and effusion are to be expected with pulmonary atresia.

The disadvantages of Waterston's operation are that it may be difficult to control the size of the stoma and that it is easy to kink the right pulmonary artery and selectively perfuse part of, or only the right, lung. Kinking of the right pulmonary artery may be avoided by making the anastomosis as far posterior as possible, working from behind the mobilized superior vena cava.

The stoma size should be planned according to the size of the patient. It should not exceed 5 mm in diameter in patients of 9 to 14 years, although adults can tolerate a larger shunt. In infants an anastomosis of 2 to 3 mm is
sufficient, and between the ages of 2 and 9 years, 3 to 4-mm shunts are adequate. In patients with lesions like tricuspid atresia the anastomosis should be smaller than in patients with tetralogy of Fallot of the same age, and one must accept some residual cyanosis even at rest. A 5-mm anastomosis in a case of tricuspid atresia (case 17) was associated with left ventricular failure for 11 weeks. Although the cyanosis was diminished and the effort tolerance improved, the left ventricle increased considerably in size and the electrocardiographic findings worsened. This size shunt would have been well tolerated by a patient with Fallot's tetralogy. We have also found that with modifications the anastomosis can be beneficial in some forms of transposition of the great arteries with pulmonary stenosis. The anastomosis does not have length and it is unlikely to close spontaneously. In the one patient who had this complication, the operation was done quickly under exceptionally difficult circumstances, and there was probably some fault in technic.

Preferential perfusion of the right lung suggested by the thoracic roentgenograms, was common after the operation, but in the majority of patients there appeared to be an increase in the vascularity of both sides. No calculation was made of pulmonary blood flow in each lung, but aortography in the few cases investigated after surgery showed preferential perfusion of the right lung. Edema of the right lung and pleural effusion was seen when the shunt was large, and there was kinking of the right pulmonary artery. Selective perfusion of one lung was encouraged by the presence of proximal obstruction in either or both pulmonary arteries. Pulmonary edema and effusion cleared rapidly in case 1 after a membrane was removed from the origin of the left pulmonary artery and thoracic radiography suggested good blood flow in both lungs. Pulmonary edema and effusion occurred in both patients with pulmonary atresia, which may in part be related to some narrowing in the proximal pulmonary arteries but is more probably related to the sudden change to vigorous pulsatile flow in the pulmonary vessels. There is a tendency for all types of anastomotic operations to perfuse the ipsilateral lung better than the other side, and pulmonary edema has been reported with the Blalock operation.

Since it was easy to make the anastomosis too large, as shown by the frequency of heart failure, there must be potential risk of irreversible pulmonary vascular disease as with Pott's anastomosis. Although the distal right pulmonary artery pressures have not been found to be seriously elevated, the studies are inadequate. In all those on whom measurement was possible the pressures have been above normal. It is considered that in spite of the well-being of the patients as with any large patent anastomosis, complete correction should not be delayed indefinitely particularly if pulmonary edema or heart failure has been present. Although histologic study of the arteries in the lungs in case 9 did not suggest serious pulmonary vascular disease, the large shunt had been working for only 1 year, and one cannot predict the effect on the pulmonary arterioles if this had been left for several years. Infants or toddlers with Fallot's tetralogy in whom a successful Waterston operation has been done should have total correction as soon as they reach an ideal size which in our hands is between 5 and 7 years. However, when there is concern about the lungs as in case 6, definitive correction will be done before that age. Our aim in older patients who have had an anastomotic procedure to reduce the hemoglobin and improve the oxygen saturation is to proceed to complete correction in 1 to 2 years.

Closure of the anastomosis through the aorta was a simple procedure in three patients and added no morbidity to the correction. It was found to be simpler to close the Waterston anastomosis than other varieties of anastomoses, and the resulting deformity to the right pulmonary artery was minimal in the one patient studied.

Conclusions

A study has been made of 30 patients with cyanotic congenital heart disease who have
had Waterston's operation for relief of cyanotic attacks and severe effort intolerance. The results were excellent in 28 patients and there was no mortality. Preferential perfusion of the right lung was common and in some cases unilateral edema and effusion occurred. It was found to be important to control the size of the stoma by making it appropriate to the size of the patient and to avoid kinking of the right pulmonary artery. Transaortic closure of the anastomosis at the time of definitive correction was a simple procedure.

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Addendum

Since this paper was submitted a further 11 patients have had Waterston's anastomosis. Two patients, aged 13 months and 6 years, with pulmonary atresia developed pericardial effusion with tamponade between the second and third postoperative weeks. The first patient died 4 days after discharge from hospital, and necropsy showed a tense pericardium containing 300 ml of straw-colored fluid. Retrospectively this had probably been accumulating over the previous week. In the other patient, pericardial friction and fever developed on the tenth day and pericardial fluid quickly accumulated over the next 5 days with increase in heart size and signs of tamponade. Two hundred milliliters of slightly blood-stained fluid was removed with benefits, and a further 300 ml was removed on the following day. She was given steroids and improved.

The exact pathogenesis of this is uncertain. It is possible that a small amount of blood collected in the pericardium which was opened to make the anastomosis. The small opening in the pericardium was closed, the pericardium was not drained, and then a large reactive pericardial effusion collected.

References

Aorta to Right Pulmonary Artery Anastomosis (Waterston's Operation) for Cyanotic Heart Disease

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