Balloon Septostomy for Transposition of the Great Arteries

S. P. SINGH, R. ASTLEY, AND F. G. O. BURROWS

From the Departments of Cardiology and Radiology, The Children's Hospital, Birmingham, United Birmingham Hospitals and University of Birmingham

Transposition of the great arteries is not a rare anomaly in infancy. Campbell and Suzman (1951) found an incidence of over 6 per cent among 400 cases of cyanotic heart disease. Among 138 cases of congenital heart disease under the age of 6 months, Coleman (1965) found that 27 had transposition of the great arteries. The anomaly is characterized by a short life and, with a few exceptions, death occurs in the first 6 months (Keith, Rowe, and Vlad, 1967). In children who live to more than 2 years of age, the correction of the condition by Mustard's technique has been successful (Mustard, 1964). Therefore, early palliative treatment is desirable to keep the child alive long enough for this operation to become possible. In 1950 Blalock and Hanlon introduced the palliative surgical technique of creating an interatrial septal defect for improved mixing of blood. This operation, however, carries a high mortality rate in small, deeply anoxic infants. The risks of thoracotomy, anaesthesia, and post-operative complications are obvious. The closed technique of rupturing the foramen ovale by repeatedly withdrawing a balloon-tipped Rashkind catheter (Rashkind and Miller, 1966; Watson and Rashkind, 1967), or Fogarty embolectomy catheter (Singh, Astley, and Parsons, 1968), from the left atrium to the right atrium achieves the same purpose as the Blalock Hanlon operation.

SUBJECTS AND METHODS

From November 1966 to November 1968, 38 infants with transposition of the great arteries were treated by balloon septostomy. One patient with transposition who had a large atrial septal defect and did not require palliative treatment, and four who had additional serious anomalies, such as severe coarctation of the aorta and tricuspid atresia, are not considered in this report. At the time of balloon septostomy the ages of these infants

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varied from a few hours to 3 months. All infants had a moderate to severe degree of cyanosis and with a few exceptions were in severe congestive cardiac failure. The diagnosis was confirmed by cine-angiocardiology from the right cephalic vein. Astrup values invariably showed metabolic acidosis, and this was corrected by giving intravenous sodium bicarbonate before starting the procedure. The right femoral vein was exposed and ligated just below the junction of the saphenous vein. A size 6 Fogarty's embolectomy catheter or a double lumen Rashkind catheter (Fig. 1) was introduced into the femoral vein and passed into the right atrium. The tip was manipulated through the foremen ovale into the left atrium (Fig. 2), with confirmation of its position by screening in the left anterior oblique position and often by entry into a pulmonary vein. As far as possible,

FIG. 1.—The tips (from above downwards) of Rashkind, No. 6 thrombectomy, and Nos. 6 and 5 embolectomy catheters.

FIG. 2.—Inflated balloon in the left atrium.

pressure of the catheter tip against the right atrial wall was kept to a minimum during this manipulation. In the left atrium the balloon was inflated with 1.5–2 ml. contrast solution and pulled quickly back into the right atrium, deflating the balloon immediately after the withdrawal. This procedure was repeated several times, increasing to 2.5–3 ml. contrast medium in the balloon. Right atrial saturations were estimated before and after the procedure by drawing blood through an ordinary cardiac catheter or the second lumen of the Rashkind catheter when the latter was being used.

RESULTS

Of the 38 infants, 34 survived balloon septostomy and 4 died on the same day (Table). One of these developed complete heart block and the other severe bradycardia and hypotension; one was found to have a subarachnoid haemorrhage. Another moribund infant who had previously been

resuscitated died after the septostomy. Two babies died 3 weeks and 6 weeks, respectively, after septostomy, due to severe bronchopneumonia. In 6 cases the relief of cyanosis and heart failure after balloon septostomy was of short duration. After initial improvement lasting a week to four and a half months they gradually became more cyanosed. Repeat balloon septostomy was done in all of these. Five cases required the Blalock Hanlon operation, which proved fatal in four. In one of these the death occurred four and a half months after the balloon septostomy. In one infant of 11 days, the improvement after septostomy lasted a week. An angiocardigram showed only a small shunt at atrial level. A second septostomy was performed, but again the result was disappointing and a Blalock Hanlon operation was performed. He was discharged from hospital but died of an undetermined cause at the age of 4 months. There were 3 more late deaths, 3, 5, and 6 months after balloon septostomy, in children who were progressing well (Table). Two had massive cerebral thrombosis with involvement of the internal carotid arteries.

Of the 24 children who are alive, 8 had been followed for a period of 18 months to 2 years. Seven have had balloon septostomy performed more than 12 months and less than 18 months ago. The results in this group seem to be satisfactory. There is no evidence of cardiac failure and the cyanosis is mild. The remaining 9 cases have been followed for less than 12 months.

DISCUSSION

Blalock and Hanlon's operation of creating an interatrial communication has been effective in reducing the hypoxia and congestive heart failure that are common features of transposition of the great arteries. The improvement in the left heart failure is probably due to the relief of the left atrial

TABLE
TIME AND CAUSE OF DEATH

Time of death	No. of patients	Cause of death
<i>Early deaths</i> 0–24 hours	4	(i) Atrioventricular block during septostomy resulting in hypotension (ii) Ventricular fibrillation during septostomy (had cardiac arrest previously); previous pulmonary artery banding (iii) Developed bradycardia and hypotension after procedure; was found to have subarachnoid haemorrhage (iv) Bradycardia during procedure
24 hours–6 weeks	5	(i) Severe bronchopneumonia and cardiac failure (large VSD) (ii) Severe bronchopneumonia (large VSD) (iii) Failure of balloon septostomy } operative mortality as a (iv) " " " " } result of Blalock Hanlon (v) " " " " } operation
<i>Late deaths</i> 3 months–6 months	5	(i) After Blalock Hanlon operation (ii) Cerebral thrombosis (iii) Cerebral thrombosis (iv) Cause of death not determined (v) Cause of death not determined

hypertension which is responsible for pulmonary venous congestion and respiratory distress. Improved atrial communication also provides better mixing of blood and produces higher systemic arterial oxygen saturation. However, the mortality of this operation is high, and it has been reported to be as much as 53 per cent in one large series (Cornell *et al.*, 1965).

The results of balloon septostomy in this hospital, as in other medical centres (Rashkind and Miller, 1968; Tynan, 1968), indicate that this closed method is a safer one than the open creation of an artificial atrial septal defect. Only 4 of 38 infants deteriorated and died soon after the procedure.

One of these had previously been resuscitated after multiple cardiac and respiratory arrests and was on a positive pressure ventilator when the procedure was attempted; another had a subarachnoid haemorrhage in addition to his heart defect. In most babies the cyanosis and signs of congestive heart failure improved after the balloon septostomy. The right atrial saturation was measured in 21 cases and it ranged from 15 to 47 per cent before and 57 to 79 per cent after the balloon septostomy. The average rise in the oxygen saturation immediately after the procedure was 26 per cent. We have not measured oxygen saturation at a later stage, but this early rise is comparable to the figure of an approximate 18 per cent rise in the arterial oxygen saturations a few months after the Blalock Hanlon operation that was found by Shafer and Kidd (1966).

Some patients were so improved after the balloon septostomy that they had to stay in hospital for only a few days. In 5 children with a moderate-to-large ventricular septal defect and a large pulmonary blood flow the results were not so dramatic. One had required pulmonary artery banding before the balloon septostomy was attempted and later died. One developed severe bronchopneumonia and died 3 weeks later. Another infant with a large ventricular septal defect died 6 weeks later. Pulmonary artery banding was contemplated but he developed severe staphylococcal pneumonia. The two babies who survived required a long stay in hospital and vigorous anticongestive measures.

In most infants with transposition of the great arteries and a sizeable ventricular septal defect there is an excessive pulmonary blood flow because the pulmonary vascular resistance is lower than the systemic resistance. The volume overload of the left ventricle increases the filling pressure in the left atrium, leading to left heart failure. Lack of success of medical treatment and confirmation of a large pulmonary blood flow (as shown most readily by the degree of pulmonary plethora on chest radiography) should indicate the need for pulmonary artery band-

ing for such cases. As well as decreasing the pulmonary blood flow and relieving left heart failure, pulmonary banding should prevent development of serious pulmonary vascular changes which have been reported to occur in transposition at a very early age (Mustard, Keon, and Trusler, 1968).

Smaller ventricular septal defects and persistent ductus arteriosus, which are common in transposition, do not appear to be so significant haemodynamically, and do not interfere with the clinical improvement given by septostomy. Of our 24 living patients, 11 had a small ventricular septal defect, 3 with an additional persistent ductus arteriosus; 3 had an isolated persistent ductus arteriosus.

Improvement after septostomy that is only temporary may be due to stretching of the foramen ovale without adequate tearing. In 6 infants after an initial improvement which lasted 1 week to 4 months there was progressive increase in cyanosis and dyspnoea. Repeat arterial oxygen saturation measurement and, in two cases, venous angiocardio-graphy, confirmed the inadequate flow through the interatrial communication. A second septostomy was attempted in these 6 but was satisfactory in only 1; the other 5 required a Blalock Hanlon operation.

In 1965 in experimental balloon septostomy on cadavers we failed to obtain satisfactory tears. This was initially attributed to the age of the subjects, who were some months old (Singh *et al.*, 1968). However, our recent experience suggests that a tough, untearable septum may cause failure in some infants who are only a few days old, while on the other hand, it is quite easy to tear the septum in some older children. Indeed, we have performed balloon septostomy with success in a 10-year-old boy (not included in this series). Thus it is not possible to suggest an upper age limit for the procedure.

Twenty-nine infants (76%) left the hospital after balloon septostomy (one of these had in addition a Blalock Hanlon operation). Of these, 24 children (63%) are now attending the follow-up clinic and have been followed from 2 months to 2 years. They show no evidence of cardiac failure and have a mild to moderate degree of cyanosis. One child, age 1 year, has more cyanosis than the others and this is attributable to associated pulmonary stenosis. There were 5 late deaths, and 1 child died four and a half months after balloon septostomy when an additional Blalock Hanlon operation was performed. The cause of sudden death at home in two asymptomatic mildly cyanosed infants was not determined; one of these had a Blalock Hanlon operation. Two of the late deaths occurred in apparently well infants due to thrombosis of the internal

carotid artery and its branches. Two more infants aged 18 months and 1 year had two episodes of cerebral thrombosis. All these babies were not very cyanosed and did not show evidence of dehydration or secondary polycythaemia. The bursting of the balloon is not uncommon during septostomy. We do not have records of its frequency or whether it actually occurred in these cases but there does exist the possibility that a minute fragment of rubber has led to clot formation and subsequent late embolization.

For minimum disturbance of the patient during septostomy, there is advantage in making the procedure as short as possible. Preliminary investigation can be very brief. A venous or right atrial contrast injection, with viewing on the television monitor of the x-ray image intensifier (preferably augmented by video tape recording), is usually sufficient to establish the diagnosis without waiting for processing of the cine-angiogram. Balloon septostomy can follow immediately, without recourse to full catheterization.

The No. 5 and 6 Fogarty embolectomy catheters have acorn tips which are sometimes easier to introduce than the Rashkind No. 6½ catheters. They are also cheaper but do have the slight disadvantage that they need filling with contrast medium to make them radio-opaque and they do not have a second lumen. The Fogarty thrombectomy catheter has a slightly less satisfactory tip, but it is radio-opaque and its balloon appears stronger. Recently we have used it with up to 5 ml. fluid.

Bleeding at the insertion site has occasionally been a problem. Preliminary tying of the femoral vein below the point of incision reduces the hazard should the vein tear. Occasionally we have had trouble with abnormal, tortuous, thin-walled vessels, sometimes bilaterally. Preliminary establishment of a continuous drip and cross-matching of blood is a wise precaution. If blood loss is more than approximately 5 per cent of the blood volume it should be replaced.

During manipulation of the catheter, pressure of its tip against the right atrial wall when attempting to enter the left atrium is apt to slow the heart and perhaps begin a chain of more severe rhythm disturbances. Such pressure is best kept to a minimum; if the catheter persists in an inferior-superior course it can usually be induced to turn backwards into the left atrium by inserting a wire stilette (such as that supplied with a Fogarty catheter), with a slight bend near its tip.

Transient arrhythmias during the pull-back of the balloon from the left atrium to the right atrium are not uncommon, especially if the pull is a slow one. The common arrhythmias seen were first

degree heart block, bradycardia, wandering pacemaker, and nodal rhythm. One infant developed atrial fibrillation which responded to intravenous epanutin. Of the 4 early deaths already discussed, 2 had developed complete heart block and one had severe bradycardia. Another moribund child, who previously had several episodes of ventricular fibrillation, had a further attack and died. One child developed a complete heart block which disappeared at the end of the procedure. Similarly, right bundle-branch block in one case was also of short duration. Babies have been known to develop permanent arrhythmias after the Blalock Hanlon operation (Hamilton *et al.*, 1968), but permanent abnormal rhythm has not been reported after balloon septostomy.

During the first few septostomies we measured the pressure in the atria before and after rupturing the septum. Our experience suggested that a rise in the right atrial oxygen saturation indicated that a good tear had been made and that left atrial hypertension had been relieved. Subsequently we used a rise in right atrial saturation as a guide to satisfactory completion of the procedure. The size of the defect that has been created can also be estimated by observing the ease with which a partially filled balloon can be passed in both directions through the septum.

The use of balloon septostomy is not restricted to transposition. We have also used this palliative technique in tricuspid atresia and in total anomalous pulmonary venous drainage. Its use has been recommended for other conditions such as Ebstein's anomaly, mitral atresia, and pulmonary atresia with intact ventricular septum (W. J. Rashkind, 1967, personal communication).

SUMMARY

The technique and results of Rashkind's procedure of balloon septostomy for creating an atrial septal defect have been reviewed from experience with 38 cases of transposition of the great arteries. Of the 38 infants, 34 survived balloon septostomy. There were 5 more delayed deaths in the hospital and 29 patients (76%) left the hospital. There are 24 (63%) long-term survivals. These results show that this method of creating an atrial septal defect is safer than the Blalock Hanlon operation.

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