Total anomalous pulmonary venous connection *Repair using deep hypothermia and circulatory arrest in 44 consecutive infants*

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SUMMARY Forty four consecutive infants aged from 3 days to 10 months underwent repair of total anomalous pulmonary venous connection using deep hypothermia with circulatory arrest. There were eight (18%) early hospital deaths. Using multivariate analysis no significant association could be shown between early mortality and age or weight at operation, preoperative pulmonary or systemic pressure, and preoperative condition for patients undergoing operation during the most recent five year period. Late pulmonary venous obstruction developed in four (11%) of the survivors and all of these patients died.

Total anomalous pulmonary venous connection is a relatively uncommon cardiac malformation representing less than 1% of all congenital cardiac anomalies.^{1,2} Without surgical treatment, the mortality within the first year of life is high,³ and those who survive may develop progressive pulmonary vascular disease.^{4,5} Early surgical intervention is therefore indicated in the majority of patients. Successful surgical correction was first reported by Muller in 1951⁶ and subsequently others described their experience in the surgical management of this lesion, using either hypothermia with inflow occlusion,⁷ or standard cardiopulmonary bypass.^{8,9} It is only with the adoption of deep hypothermia and circulatory arrest, however, that satisfactory results have been achieved in infancy.¹⁰⁻¹³

In this paper, we review our experience during the last 12 years of single stage correction of total anomalous pulmonary venous connection in infancy using this latter technique.

Patients and methods

During the period January 1970 to December 1981, 44 consecutive infants under one year of age with total anomalous pulmonary venous connection underwent

single stage surgical correction at the Royal Liverpool Children's Hospital, using deep hypothermia and circulatory arrest. Four infants who were operated on in 1970 and 1971 using standard cardiopulmonary bypass and previously reported¹³ are not included in this report. One further case also included in the previous report,¹³ with infracardiac total anomalous pulmonary venous connection occurring as part of a complex malformation associated with the asplenia syndrome is excluded since the operation was an attempt at palliation rather than correction.

The patients are grouped according to the site of pulmonary venous connection (Fig. 1). Twenty-two patients had supracardiac total anomalous pulmonary venous connection and nine had infracardiac total anomalous pulmonary venous connection. The group of eight patients with intracardiac total anomalous pulmonary venous connection includes six with drainage entirely to the coronary sinus and two with drainage direct to the right atrium. Five patients had a mixed type of total anomalous pulmonary venous connection. In four, part of the left upper lobe drained into the innominate vein, while the remaining veins entered the coronary sinus. The fifth patient had both upper lobe veins entering the superior vena cava while the lower lobe veins entered the right atrium via a common venous channel.

There were 22 male and 22 female patients ranging in age from 3 to 312 days (mean 77 days) at the time of operation. The weight at operation varied from 2.3 kg

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Fig. 1 Age at operation and anatomical type in 44 infants with total anomalous pulmonary venous connection.

to 8.7 kg (mean 3.9 kg). One patient was known to have a ventricular septal defect and the ductus arteriosus was patent in a further 14 patients. Balloon septostomy was performed at the time of diagnostic catheterisation in nine patients: four with a supracardiac connection, three with drainage to the coronary sinus, and two with mixed total anomalous pulmonary venous connection.

PREOPERATIVE CONDITION

Each patient was assigned retrospectively to one of three groups according to the clinical condition at the time of diagnosis. Group 1 consisted of four infants whose symptoms were well controlled on medical treatment and who underwent operation electively at a mean interval of 122 days (range 95 to 155 days) from the time of presentation. In group 2 there were 27 infants with severe symptoms but no acute deterioration in whom operation seemed advisable without undue delay. These infants underwent surgery two to 54 days (mean 13 days) from the time of diagnosis. Group 3 consisted of 13 critically ill infants who underwent emergency operation at a mean interval of 2.8 days from the time of diagnosis (range less than one to eight days). Five patients in this group had supracardiac and eight had infracardiac total anomalous pulmonary venous connection. Eight of these patients were ventilated electively before operation because of respiratory failure. Critical preoperative status was correlated significantly with young age and with raised pulmonary and lowered systemic pressures at the time of cardiac catheterisation ($p = 0.05$ to 0.01 in each case; t tests, confirmed by Mann-Whitney tests).

All cases were operated on using deep hypothermia induced with core cooling, and total circulatory arrest using techniques described previously.^{13,14} For patients with supra- and infracardiac total anomalous pulmonary venous connection a left anterolateral thoracotomy with transternal extension was used.¹⁵

Fig. 2 Preoperative pulmonary to systemic pressure ratio and anatomical type in 37 infants with total anomalous pulmonary venous connection. Key as for Fig. 1.

Patients with cardiac or mixed types of total anomalous pulmonary venous connection were repaired through a median sternotomy. In three most recent patients with mixed total anomalous pulmonary venous connection predominantly to the coronary sinus the operation suggested by Van Praagh *et al.*¹⁶ for total anomalous pulmonary venous connection to the coronary sinus was used.

Preoperative measurements of pulmonary and systemic pressure were made in 37 patients and the pulmonary to systemic pressure ratios for each anatomical group are shown in Fig. 2.

STATISTICAL ANALYSIS

Seven factors were selected as having a possible influence on early mortality: anatomical type, age and weight at operation, preoperative condition, preoperative P_{CO_2} (without assisted ventilation), preoperative pulmonary and systemic pressures, and the duration of circulatory arrest. Complete data were available for 29 consecutive patients operated on during the most recent five year period. These data were tabulated and the *Statistical package for the social sciences*¹⁷ was used for cross-tabulation, unpaired Student's t test and discriminant analysis predicting early death or survival. Where necessary, transformation to a logarithmic scale was performed to normalise data before using Student's t test.

Results

EARLY MORTALITY

Eight infants (18%) died within 30 days of the operation. During the most recent five year period, 29 consecutive infants (11 supracardiac, eight infracardiac, seven cardiac, and three mixed) have undergone operation, with four early deaths (14%), compared with four early deaths among 15 infants (27%) during the

preceding seven years. This difference is not statistically significant. Two of the deaths in the earlier period were the result of avoidable technical errors at the time of operation.

For the 29 patients undergoing operation during the most recent five year period, no significant association could be established between early death and anatomical type, age or weight at operation, preoperative condition, pulmonary or systemic pressures, Pco_2 , or duration of circulatory arrest. None of these variables was significantly different for early deaths as compared with other cases (unpaired Student's *t* test confirmed by Mann-Whitney rank sum test). Nor was any pattern discernible among the four early death cases on any two dimensional plot of any pair of continuous variables except in the case of the age/weight plot where they lay very closely on a straight line. The probability of early death, computed from a linear function on the logit scale by using the generalised linear interactive modelling package,¹⁸ did not depend significantly on any of the above mentioned variables. Linear discriminant analysis between the early deaths and the remaining patients using logarithmic transformations of age, weight, pulmonary and systemic pressure, and duration of circulatory arrest was also ineffective in predicting early death. During this period early death appeared to be a random event not clearly connected with any of the variables studied, either individually or in combination.

LATE RESULTS

Four patients developed pulmonary venous obstruction,

all within three months of the initial operation and all subsequently died. Postoperative cardiac catheterisation data on these patients are summarised in the Table. Case 1 underwent a second operation three months after the initial procedure. The orifices of three of the four pulmonary veins were found to be partly obstructed by intimal proliferation. An angioplastic procedure was performed to enlarge the pulmonary veins but the infant died four months later, with clinical evidence of reobstruction of the pulmonary veins. Case 2 was readmitted one month after the first operation. He deteriorated rapidly after investigation and died before a second operation could be performed. Consent for a necropsy was refused. Case 3 had total anomalous pulmonary venous connection to the coronary sinus. At the second operation the opening between the coronary sinus and the left atrium was severely stenotic with thickening of the tissue surrounding this ostium and shrinkage of the Dacron patch placed at the mouth of the coronary sinus. The original operation was revised but the patient died suddenly two months later. At necropsy the inlet of the coronary sinus to the left atrium was widely patent, but the four pulmonary veins entered the apex of the coronary sinus via a single stenotic orifice of less than 4 mm diameter. Case 4 had drainage of the pulmonary veins direct to the right atrium. He died before a second operation could be performed and at necropsy it was found that the right pulmonary veins were totally occluded by shrinkage and thickening of the original Dacron baffle used to redirect pulmonary venous blood into the left atrium.

The 32 longer term survivors have been reviewed

Table Postoperative cardiac catheterisation data in 11 patients

Case No.	Anatomical type	Interval after operation (mth)	Pressures (mmHg)		Pulmonary to systemic flow ratio	Comment
			Pulmonary	Systemic		
1	Supracardiac	3	100	65	1	Pulmonary venous obstruction; reoperation; died
2	Infracardiac	1	65	120	1	Pulmonary venous obstruction; died
3	Cardiac	3	80	75	1	Pulmonary venous obstruction; reoperation; died
4	Cardiac	2	90	75	1	Pulmonary venous obstruction; died
5	Supracardiac	59	21	100	2	Residual ASD; successful operation
6	Supracardiac	16	78	84	1.8	Residual VSD; successful operation
7	Infracardiac	1	35	80	1	Transient pericardial effusion; good result
8	Cardiac	13	36	80	1	Good haemodynamic result; atrioventricular block
9	Cardiac	12	28	100	1	Good result
10	Cardiac	26	23	110	1	Good result
11	Mixed	3	28	95	2.2	Residual ASD; awaiting reoperation

ASD, atrial septal defect; VSD, ventricular septal defect.

regularly with a follow up ranging from three months to 10 years (mean 5.1 years). One child (case 5, Table) required a second operation to close a residual atrial septal defect and a second (case 6, Table) has had a second operation to close a ventricular septal defect. A further five patients have been investigated postoperatively (Table). Four have a good haemodynamic result but one has atrioventricular block and one had a transient pericardial effusion at the time of investigation. Two of these patients were investigated because of a slight suspicion on clinical grounds that pulmonary venous obstruction was developing but these suspicions were unfounded. Pulmonary venous obstruction has not been identified in any patient as a later post-operative complication. The last patient (case 11, Table) has a residual atrial shunt after repair of a mixed type of total anomalous pulmonary venous connection and will need a second operation in the future.

The remaining patients are clinically well with no abnormal signs in the cardiovascular system other than wide splitting of the second heart sound and mild cardiomegaly on chest x-ray.

Discussion

Before 1970, the surgical mortality for correction of total anomalous pulmonary venous connection in infancy was significantly higher than in older patients and some authors regarded young age as a major factor in determining early mortality.¹⁹ During the past decade, improved results have been achieved particularly in infants under 1 year of age.^{11-13 20-22} In these series, young age at operation has not been confirmed as a risk factor and our present results substantiate this view. During the 12 year period reviewed, there were no deaths among five patients operated on during the first week of life showing that even the youngest patients can be corrected successfully. Though we were unable to show a correlation between preoperative condition and early mortality this is only likely to be the case if the operation is performed with an appropriate degree of urgency. We agree with the view expressed by many authors^{11 12 20 21} that any delay in the effective surgical treatment of symptomatic infants, particularly when pulmonary venous return is obstructed, may result in a higher operative mortality rate.

Surgical mortality in the patients reported by Clarke *et al.*¹² and Turley *et al.*²⁰ was most closely related to the anatomical type of total anomalous pulmonary venous connection present. During our most recent experience no such correlation was present with survival of all three patients with mixed total anomalous pulmonary venous connection. It should

be noted, however, that these patients had a relatively simple type of mixed total anomalous pulmonary venous connection predominantly to the coronary sinus. In more complex types a higher mortality might be expected.²¹ It is interesting that the anatomical type carrying the highest mortality in the series of Clarke *et al.*,¹² Turley *et al.*,²⁰ and Hammon *et al.*²² (infracardiac) carried the lowest mortality among our patients. Conversely, we have experienced a relatively high early mortality among patients with the intracardiac type of the anomaly, a defect which in other hands^{11 12 20} carries a low mortality. The number of deaths in each series, however, is small and many deaths were related to factors individual to each patient rather than specific for a particular anatomical type. For example, two deaths in the present series and two deaths among the patients reported by Whight *et al.*¹¹ were mainly the result of avoidable technical errors unrelated to the particular anatomical type present. Reviewing the combined recent experience of the groups in Auckland, Boston, and Birmingham, Katz *et al.*²¹ concluded that anatomical type was not a determinant of early mortality except in the case of patients with the complicated mixed type of total anomalous pulmonary venous connection. Our results show that an early mortality of less than 15% should be expected in patients with the supra- and infracardiac types. Others^{11 12 20} have shown that a similar or lower mortality can be achieved with total anomalous pulmonary venous connection to the right atrium or coronary sinus.

Though late mortality after correction of total anomalous pulmonary venous connection is low,²³ in many recently reported series there has been significant mortality and morbidity associated with the development of pulmonary venous obstruction.^{11 20 24} Four (11%) of the 36 hospital survivors in our series developed this complication, all within three months of the original operation. In one case, the main reason for obstruction appeared to be related to shrinkage and thickening of a synthetic Dacron patch, but in two cases, one with supracardiac drainage and one with the coronary sinus type, obstruction developed at the orifices of the pulmonary veins at a site remote from any suture line. The cause of obstruction in the fourth case was not determined. Though pulmonary venous obstruction has been described in patients with total anomalous pulmonary venous connection before surgical treatment,³ there was no evidence of this in any of our patients. Similar findings have been reported by other authors. Both Turley *et al.*²⁰ and Fleming *et al.*²⁴ reported cases of infradiaphragmatic total anomalous pulmonary venous connection developing pulmonary venous obstruction at a site proximal to the original anastomosis. In the study of Whight *et al.*¹¹ three patients with

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total anomalous pulmonary venous connection to the coronary sinus developed pulmonary venous obstruction, caused in one case by thickening of a pericardial patch and in two further cases by partial obliteration of the ostia of the pulmonary veins by fibrosis. Surgical treatment of pulmonary vein obstruction is difficult^{11 20} and the problem may recur even after apparently successful reoperation.²⁰ Its occurrence is unpredictable and though it appears to be more common after repair of the infradiaphragmatic type, it is by no means confined to that group.

Several approaches have been used to gain optimal exposure of the anomalous venous channels in supra- and infracardiac total anomalous pulmonary venous connection. Throughout the 12 year period, we have used the left anterolateral thoracotomy advocated by Roe.¹⁵ It has been suggested that aortic cannulation might prove to be difficult using this approach and that cannulation of the descending aorta might be necessary.¹⁵ With trans-sternal extension of the incision, however, we have not found this to be the case. In our experience, the left anterolateral thoracotomy gives excellent exposure of the left atrium and common pulmonary vein and facilitates the construction of the largest possible anastomosis in spite of the small size of the left atrium in this anomaly.^{25 26} If necessary, the incision can be extended onto the left atrial appendage which is usually of relatively normal size.²⁶ We have not found it necessary during this 12 year period to enlarge the size of the atrial cavity in any patient either by using a patch or by moving the interatrial septum to the right. No problems with kinking of the anastomosis have been encountered and pulmonary venous obstruction at the suture line has not been recognised as a late complication in any patient with these anatomical types of total anomalous pulmonary venous connection.

Several authors^{11 22 25} have published their findings at cardiac catheterisation carried out one to six years after operation for total anomalous pulmonary venous connection. Their findings show normal or near normal right and left ventricular and left atrial volumes, with normal right ventricular pressures in the majority of asymptomatic survivors. Unexpected major residual defects were not identified. In view of these encouraging reports, we have studied our postoperative patients only when specific clinical indications were present.

Conventional repair of total anomalous pulmonary venous connection to the coronary sinus involves incising the margin of the coronary sinus and carrying the incision back through the foramen ovale into the left atrium. A large patch is then used to roof over the combined orifice of the coronary sinus and fossa ovale. An alternative procedure was suggested by Van Praagh *et al.*¹⁶ in 1972. Though the procedure was

originally devised to avoid damage to internodal conduction pathways, its main advantage appears to be the avoidance of prosthetic material within the atrium of a small infant. In view of the problems encountered after patch shrinkage both in our patients and those reported by Whight *et al.*,¹¹ this advantage appears to be considerable. We have used this method in three recent cases with mixed type total anomalous pulmonary venous connection predominantly to the coronary sinus and intend to use it more extensively in the future.

The role of balloon atrial septostomy in the management of the infant with total anomalous pulmonary venous connection remains a subject for debate. Left heart filling in this condition is entirely dependent on a right to left atrial shunt, and the atrial septum may be a site of obstruction even in patients with no pressure gradients between left and right atrium.²⁶ Balloon septostomy has therefore been recommended for all infants with total anomalous pulmonary venous connection as a means of palliating the symptomatic infant.^{27 28} Patients with pulmonary venous obstruction are unlikely to be benefited. The procedure, however, may be helpful in infants in whom the pulmonary venous return is unobstructed, pulmonary artery pressure is less than half systemic, and postponement of operation for a short period is desired. Whight *et al.*¹¹ have drawn attention to a possible disadvantage of balloon septostomy in patients with total anomalous pulmonary venous connection to the coronary sinus in whom the Van Praagh technique¹⁶ is to be used for repair, in that closure of the atrial septum may be easier if the fossa ovale is intact. We have used balloon atrial septostomy in nine patients in an attempt to improve left heart filling preoperatively. Though it has been suggested that septostomy may be difficult in total anomalous pulmonary venous connection,²⁷ using biplane screening facilities, the procedure has not been accompanied by any morbidity in our patients. We do not, however, regard this procedure as a substitute for urgent surgical treatment in the majority of patients.

Our experience with the management of infants with total anomalous pulmonary venous connection during the past 12 years suggests that the best results are obtained when referral to a specialised paediatric cardiac unit is made as soon as the diagnosis is suspected, preferably during the first weeks of life. Since surgical mortality is not correlated with young age, operation should be performed on an emergency or semi-emergency basis as the patient's condition demands. Unnecessary delay is likely to lead to acute deterioration particularly when pulmonary venous obstruction is present. The long term results and excellent health of the surviving children are just reward to the medical and surgical team who accept

the considerable challenge which these seriously ill infants present on admission to hospital.

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