Tricuspid atresia

Clinical course in 62 cases (1967-1974)

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SUMMARY Sixty-two patients with tricuspid atresia admitted for cardiac catheterisation between 1967 and 1974 have been classified according to the anatomical and radiological findings into those with normally related great arteries (type I: 39 cases) and those with transposition of the great arteries (type II: 23 cases). These types were further subdivided into group A (reduced lung vascularity), group B (normal or increased vascularity), and group C (increased vascularity initially, becoming reduced). Electrocardiograms showed a superior and leftward axis in 61.5 per cent of patients with type I and 22.7 per cent of those with type II tricuspid atresia. Correlations between P wave amplitude (> 0.25 mV) and the atrial pressures showed a better correlation with a wave gradient rather than with mean inter-atrial gradient.

Analysis of the results of palliative operations showed a high mortality (44.4%) of the Waterston shunt procedure in neonates. A Blalock-Taussig shunt is therefore preferred though another shunt is invariably required later. Postoperative haemodynamic study never showed pulmonary hypertension after an arterial shunt procedure, and hence the survivors are suitable for the Fontan operation, as was done in 2 cases. It is suggested that, because multiple operative procedures are required with high mortality (30%), it may be preferable to perform the Fontan procedure earlier. Pulmonary artery banding is recommended for patients with type II tricuspid atresia and increased pulmonary blood flow (type II B), as the initial step.

Tricuspid atresia constitutes 1 to 3 per cent of all congenital cardiac lesions (Nadas and Fyler, 1972). Diagnosis is usually obvious from electrocardiographic, radiological, and echocardiographic features. Long-term survival without palliative procedure is unlikely (Campbell, 1961). Recent advances in surgical treatment (Fontan and Baudet, 1971; Kreutzer *et al.*, 1973) have prompted us to review the outcome in a group of patients with tricuspid atresia in order to identify those suitable for a Fontan procedure.

In all the cases there was atresia of the right ventricular orifice (Anderson *et al.*, 1977). Two patients with an imperforate membrane between the right atrium and right ventricle were not

included in the study. The ventricular morphology of the larger chamber was that of the left ventricle and will be referred to as the left ventricle. The outlet chamber (Anderson *et al.*, 1977) had the morphology of a right ventricle and will be referred to as the right ventricle.

The patients

The case notes of patients admitted for haemodynamic investigations between 1967 and 1974 were available. Clinical, electrocardiographic, radiological, haemodynamic, and necropsy data were reviewed. The long-term follow-up included the results of various palliative procedures. Adequate data were available for 62 out of 71 consecutive patients. The remaining 9 patients lived overseas and there were insufficient follow-up data. Patients were divided into two groups according to the anatomy of the great arteries (Edwards and Burchell, 1949). Those with normal ventriculo-arterial connection and relation (39/62) were classi-

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*Tricuspid atresia***Table 1** *Tricuspid atresia: anatomical and radiological classification*

Anatomical type	No.	Radiological groups		
		A	B	C
Type I	39	31	2	6
Type II	23	3	16	4
Total	62	34	18	10

fied as type I tricuspid atresia, and those with transposition of the great arteries and ventriculoarterial discordance were classified as type II (23/62) (Table 1). Further classification into d- or l-transposition was not undertaken, as there were only 2 patients in whom the aorta was to the left of the pulmonary trunk. The terms d or l refer to the relation of the 2 great arteries and both these patients in fact had d-loop l-transposition of great arteries so that there was ventriculoarterial discordance. However, as pointed out by Anderson *et al.* (1977), the morphological features of the main chamber in right atrioventricular valve atresia differs in some respects from those of the left ventricle in normal hearts.

RADIOLOGICAL FEATURES

It was possible to classify cases by the radiological appearances as group A with reduced pulmonary vascularity or group B with normal or increased pulmonary vascularity, as suggested by Astley *et al.* (1953), with a further category (group C) of patients in whom the pulmonary vascularity was normal or increased initially but subsequently became reduced (Dick *et al.*, 1975) (Table 1). The change in vascularity was accounted for by the development of significant subpulmonary stenosis in 8 patients, and in 2 spontaneous closure of the ventricular septal defect was confirmed by subsequent cardiac catheterisation. The radiological appearances were assessed by two of the authors independently, the pulmonary vessels being compared with the size of adjacent bronchi on the lateral film in assessing pulmonary vascularity.

CLINICAL DATA

Of the 62 infants and children admitted for cardiac catheterisation 36 were boys and 26 were girls, a sex distribution similar to that observed by others (Taussig *et al.*, 1973; Dick *et al.*, 1975). The age at presentation of symptoms is shown in Fig. 1. Thirty-two patients (51.6%) were less than 1 week old. Of the 21 patients presenting after the neonatal period 10 had type II atresia. Cyanosis was the presenting symptom in 42 patients and congestive cardiac failure in 27. Seven patients had both

Fig. 1 *The age at presentation of 62 patients with tricuspid atresia.*

cyanosis and congestive cardiac failure. Admittedly, arterial desaturation may exist without obvious cyanosis. It was difficult to recognise the occurrence of hypercyanotic episodes in the neonates, but 7 patients had these episodes after the age of 1 year and required additional anastomotic procedures.

Arterial P_{O_2} in room air was measured in 58 patients. It was 33 ± 12 mmHg in 36 patients with type I atresia and 52 ± 7 mmHg in 22 patients with type II atresia. In the 3 radiological groups, P_{O_2} was 28 ± 14 mmHg in group A (32 patients), 56 ± 6 mmHg in group B (17 patients), and 48 ± 8 mmHg in group C (9 patients).

ELECTROCARDIOGRAPHIC DATA

The mean frontal plane QRS axis at the time of presentation has been plotted in Fig. 2. Twenty-four patients with type I atresia (61.5%) had superior and left axis, while only 5 (22.7%) with type II atresia had a superior axis. In our series a superior and left axis occurred in relatively fewer patients than in those previously reported (Gamboa *et al.*, 1966; Davachi *et al.*, 1970). However, signs

Fig. 2 *The mean frontal QRS axis in 62 patients with tricuspid atresia.*

of left ventricular hypertrophy in the praecordial leads were present in 92 per cent of cases. P wave amplitude in lead II was more than 0.25 mV in 47 cases (76%). The P wave amplitude in lead II was correlated with interatrial gradient at cardiac catheterisation. An *a* wave gradient of more than 2 mmHg was present in 48 patients (77%). Of the 32 patients with type I atresia and *a* wave gradient (> 2 mmHg), 20 had a P wave amplitude of more than 0.25 mV. The correlation was more significant in type II cases, 14 of 16 with an *a* wave gradient having P wave amplitude greater than 0.25 mV ($P < 0.005$). Mean interatrial gradients of more than 2 mmHg occurred in 23 patients (12 of whom had type II tricuspid atresia). But there was no significant correlation between P wave amplitude and the mean interatrial gradient ($P > 0.1$).

CARDIAC CATHETERISATION

This was performed in all the 62 patients. Pressures and oxygen saturations were routinely obtained in the right atrium, left atrium, left ventricle (main chamber of Anderson *et al.*, 1977), and the aorta or femoral artery. The pulmonary artery was entered at the first investigation in only 3 patients with type I tricuspid atresia; all 3 patients had a large pulmonary blood flow and the pulmonary artery pressure was at systemic level. The pulmonary artery was catheterised at a subsequent investigation in 9 of 12 patients with type I atresia. Two of these have been restudied after a Fontan procedure. Pulmonary arterial pressures did not rise after palliative anastomotic procedures (multiple operations in 3). The ventricular septal defect closed spontaneously in 2 patients after arterial shunt procedures. Blocked or inadequate shunts were found in 8 patients (Waterston (4), Blalock-Taussig (3), Potts (1)), all but one of whom had a further shunt procedure. Kinking of the left and main pulmonary artery occurred in 1 patient after a Waterston shunt. In none of the patients reinvestigated was there any evidence that the shunt was large.

Contrary to the experience with type I patients, the pulmonary artery was entered in 15 of 23 patients

with type II tricuspid atresia at the first investigation. This was important because 3 of them were found to have subpulmonary stenosis, 2 requiring Blalock-Taussig shunts. Six patients had pulmonary artery banding as there was excessive pulmonary blood flow, and the 4 survivors were reinvestigated. One of these, aged 2 years, had an interrupted aortic arch with a large ductus arteriosus supplying the descending aorta, and a high pulmonary vascular resistance ($8.6 \text{ units} \times \text{m}^2$). The remaining 3 had a low pulmonary arterial pressure distal to the band. There were 2 deaths within 24 hours of cardiac catheterisation.

ADDITIONAL CARDIOVASCULAR ABNORMALITIES

These were more common in type II cases. Coarctation of the aorta with aortic arch hypoplasia (4 cases) and interrupted aortic arch (2 cases) occurred in type II tricuspid atresia. Persistent left superior vena cava draining into the coronary sinus was found in 6 cases of type I and 5 of type II tricuspid atresia. The demonstration of a left superior vena cava is important if a Glenn or Fontan procedure is contemplated. There was dextrocardia with situs solitus and asplenia and also pulmonary atresia in 1 patient, and dextrocardia, situs inversus, and pulmonary atresia in 1 other patient. Pulmonary atresia was found in 3 other patients, classified as type I tricuspid atresia on the basis of necropsy findings, the outlet chamber being of right ventricular morphology and in potential communication with the atretic pulmonary artery.

ATRIAL SEPTOSTOMY

Rashkind atrial septostomy was performed in 12 patients (9 with type I tricuspid atresia). Though the mean interatrial gradient was abolished there was no immediate improvement in systemic arterial oxygen saturation in these patients.

Results of operation

Twenty-three patients with type I tricuspid atresia had anastomotic procedures, while 6 with type II

Table 2 *Tricuspid atresia: results in 62 patients*

	Type I			Type II		
	Alive	Dead	% Mortality	Alive	Dead	% Mortality
Operative procedure	14	12*	46.1	6‡	2	25
No operation	2†	11	84.6	4	11	73.3

*Includes 3 deaths after multiple operations and 1 pulmonary artery banding.

†Patients with large pulmonary blood flow.

‡Includes 2 patients requiring Blalock-Taussig shunts.

Table 3 *Tricuspid atresia: surgical and nonsurgical results related to anatomical and radiological classification*

	Surgical			Nonsurgical		
	Total	Alive	Dead	Total	Alive	Dead
<i>Group A</i>						
Type I	24	12	12	7	—	7
Type II	2	2	0	1	—	1
<i>Group B</i>						
Type I		—		2	2	—
Type II	6	4	2	10	3	7
<i>Group C</i>						
Type I	2	2	—	4	—	4
Type II	—	—	—	4	1	3

had pulmonary artery banding and 2 had a Blalock-Taussig operation. Coarctation of the aorta was resected in 1 who also had the pulmonary artery banded. One patient with type I tricuspid atresia and a large pulmonary blood flow also had the pulmonary artery banded but he died during the operation. The overall surgical mortality was 41.2 per cent (Table 2). The mortality rate in relation to the anatomical and radiological groupings is given in Table 3. In patients undergoing pulmonary artery banding, mortality was 33.3 per cent (2 deaths in 6 patients with type II tricuspid atresia). The operative mortality for shunt procedures was 36 per cent, excluding 3 deaths after multiple shunt procedures.

TYPE I TRICUSPID ATRESIA (39 PATIENTS)

Thirteen patients did not have any surgical procedure, but only 2 of these (both with large pulmonary blood flow) survived (Table 2). They are now aged 10 and 14 years and have severe pulmonary vascular disease confirmed at cardiac catheterisation. The other patients who did not have surgical procedures were extremely ill, acidotic, and required catecholamine support. It was felt that, without any improvement in their general condition, operation would be hazardous in these patients, all of whom died without operation.

Twenty-one patients were less than 1 year old at the time of operation, 13 of them less than 4 weeks. A Waterston anastomosis was performed in 13 patients, 9 of whom were less than 4 weeks old (Table 4). There were 4 deaths in the neonatal group (the only other death occurred in a 6-month-old infant). Necropsy showed an inadequate or 'kinked' shunt in 3 patients, including 1 of whom also had purulent meningitis. In 2 other patients, the Waterston anastomosis was patent but the clinical impression was of a patient with a large shunt who required intensive antifailure treatment. A Potts' anastomosis was performed in 2 neonates, with 1 death caused by a blocked anastomosis.

A Blalock-Taussig shunt performed after the neonatal period was more successful. In 5 patients, including 3 infants (1 month to 1 year), there was only 1 death; in the patient who died, the anastomosis was patent at necropsy. A further shunt procedure was required in all 4 survivors at an interval varying from 3 months to 9 years (Table 5). A Glenn procedure was carried out electively in 3 patients; 2 survived and 1 of these has since had a Fontan procedure.

The other 3 patients with type I tricuspid atresia had pulmonary artery banding (1), Blalock-Hanlon (1), and Brock's procedure (1).

Table 4 *Tricuspid atresia type I: operative procedures and mortality in relation to age at operation*

Type of operation	0 to 4 weeks		1 month to 1 year		Over 1 year	
	No.	Deaths	No.	Deaths	No.	Deaths
Waterston	9	4	3	1	1	0
Potts	2	1	—	—	—	—
Blalock-Taussig	—	—	3	1	2	0
Glenn	—	—	2	1	1	0
Brock procedure	—	—	—	—	1	0
Multiple operations	—	—	1	—	9	3
Blalock-Hanlon	1	0	—	—	—	—
Pulmonary artery banding	1	1	—	—	—	—

Table 5 Tricuspid atresia type I: multiple operations

1st Operation	Age	Interval	2nd Operation	Interval	3rd Operation	Outcome
Right Blalock-Taussig	1 year	9 years	Waterston	—	—	Dead
Waterston	6 months	1 year 6 months	Left Blalock-Taussig	—	—	Alive
Right Blalock-Taussig	4 years	6 months	Left Blalock-Taussig	—	—	Dead
Left Blalock-Taussig	2 years	1 year 7 months	Glenn	5 years	Right Blalock-Taussig	Alive
Left Blalock-Taussig	3 months	6 months	Glenn	11 years	Aorto-pulmonary shunt (Dacron tube)	Alive
Waterston	1 month	3 years	Potts	—	—	Alive
Brock	2 years	5 years	Right Blalock-Taussig	5 years	Fontan	Alive
Waterston	2½ years	4 years	Potts	—	—	Alive
Glenn	6 months	10 years	Fontan	—	—	Alive
Waterston	1 month	2 years 6 months	Left Blalock-Taussig	—	—	Dead

There were 17 survivors with type I tricuspid atresia after the initial operation. Multiple operations were necessary in 10 of the survivors, the main indication being progressive cyanosis and clinical deterioration after varying intervals, as listed in Table 5. There were 3 deaths, 1 at operation.

Bacterial endocarditis has occurred in 3 patients, one of whom had an arterial shunt procedure in infancy. Positive blood cultures were obtained in 2 (streptococcus). All 3 patients recovered with prolonged intravenous antibiotic therapy. Purulent meningitis occurred in 2 patients and accounted for 1 late death in a patient with Waterston anastomosis. Cerebral abscess occurred in 2 patients: both were treated surgically and survived without any significant neurological deficit. Hemiplegia occurred in 2 patients with incomplete recovery.

TYPE II TRICUSPID ATRESIA (23 PATIENTS)

Eight patients had operative procedures. Six of them required pulmonary artery banding for intractable congestive cardiac failure, and 2 of these died. The other 2, with reduced pulmonary vascularity (Type IIA), had Blalock-Taussig procedures and did well. One patient required resection of coarctation of the aorta in addition to pulmonary artery banding but died 2 days later. A patient with interrupted aortic arch and a large persistent ductus arteriosus had the pulmonary artery banded at the age of 8 months, but developed a raised pulmonary vascular resistance (8 units $\times$ m²). Fifteen patients had no operation, but only 4 of these survived beyond infancy.

Discussion

A prominent electrocardiographic feature of tricuspid atresia is a superior and left frontal plane QRS axis. This was observed in 61.5 per cent of our patients with type I tricuspid atresia and 22.7 per cent of those with type II, and was less common than previously reported (Davachi *et al.*, 1970; Dick *et al.*, 1975). However, left ventricular

hypertrophy was present in 92 per cent of cases.

Balloon atrial septostomy has been advocated by Rashkind *et al.* (1967) and Singh *et al.* (1968) for patients with mean interatrial gradient of more than 2 mmHg, but did not benefit the 12 of our patients in whom it was performed. It seems likely that this procedure may be more helpful in decompressing the right atrium than in immediately improving systemic arterial oxygen saturation. However, Williams *et al.* (1976) in a recent review of tricuspid atresia have recommended the procedure.

Cerebral abscess and bacterial endocarditis have been reported to occur frequently in surviving patients with tricuspid atresia (Taussig *et al.*, 1973). Bacterial endocarditis occurred in 3 of our patients, cerebral abscess in 2, and purulent meningitis in 2.

Long-term survival of patients with tricuspid atresia is extremely unlikely without operation (Campbell, 1961; Dick *et al.*, 1975). Palliative procedures certainly improve the survival rate (Subramanian *et al.*, 1965; Taussig *et al.*, 1973). However, left ventricular function may deteriorate after an arterial shunt as a result of diastolic volume overload (Jordan and Saunders, 1966) and hence a Glenn procedure may be preferred in older children (Edwards and Barger, 1970). But this is usually unsuccessful in early infancy and makes subsequent cardiopulmonary bypass difficult. Since the majority of patients with type I tricuspid atresia require operative procedures in early infancy (Table 4), Waterston or Blalock-Taussig shunts are commonly performed. In our series, a Waterston shunt was normally done in the neonatal group, but the surgical mortality from this procedure was high (Table 4). Three patients developed congestive cardiac failure with pericardial effusion, requiring pericardiocentesis in addition to intensive anti-failure treatment. Pulmonary hypertension after a Waterston shunt is also a recognised complication (Dick *et al.*, 1975), but in 5 of our patients reinvestigated after a Waterston procedure the pulmonary artery pressure was not unduly raised. This problem has, however, been encountered in 2 patients who

had a Waterston shunt for pulmonary atresia with intact septum. Inadequate or 'blocked' shunt was found in 4 patients with type I tricuspid atresia after a Waterston procedure, in whom a further shunt was necessary, but this problem is the result of the small size of the pulmonary arteries rather than of the specific intracardiac lesion. The Blalock-Taussig anastomosis remains the procedure of choice in patients over 1 month, and at present we prefer this procedure even in neonates. It was performed in 7 infants, with only 1 death. However, 4 patients have required additional shunts after varying time intervals (Table 5).

The Fontan procedure has been performed successfully in 2 patients at 7 and 10 years of age (Table 5). It may be more logical to perform this procedure at an earlier age to prevent left ventricular dysfunction which may occur after arterial shunt procedures (LaCorte *et al.*, 1975).

Patients with type II tricuspid atresia benefit from pulmonary artery banding in cases when the pulmonary blood flow is excessive. It is likely that the survivors would be suitable for a Fontan procedure if pulmonary artery pressure was low. Aortic arch anomalies occur commonly in patients with type II tricuspid atresia. Without surgery, the mortality is high (Marcano *et al.*, 1969; Neches *et al.*, 1973).

Pulmonary artery banding is also indicated in patients with type IB tricuspid atresia (Tinglestad *et al.*, 1971). Two such patients in our series who did not have pulmonary artery banding now have severe pulmonary vascular disease.

Deterioration in patients with tricuspid atresia may be the result of spontaneous closure of the ventricular septal defect (Roberts *et al.*, 1963); this has been confirmed in 2 patients in our series by cardiac catheterisation. In 2 others the ventricular septal defect is restrictive. In type II tricuspid atresia a restrictive ventricular septal defect leads to decreasing cardiac output as this lesion produces what is effectively subaortic stenosis.

Long-term results of treatment in patients with tricuspid atresia have been reviewed recently by Dick *et al.* (1975) and Williams *et al.* (1976). The survivors in our series have been followed up for 2 to 14 years (mean 7.6 years). The physical growth based on height and weight measurements, of 14 long-term survivors with type I and 6 with type II was plotted. Nine patients (7 from type I) remained below the 10th centile. Palliative procedures did not directly influence the growth pattern and most children have continued along the same centile as they were on at the time of initial presentation. The arterial oxygen saturations vary from 60 to 82 per cent (mean 74.5%). Apart from 2 patients with residual hemiparesis, all the other

patients lead an active life and attend normal school. Though multiple operations have been required, it is possible to enable children to survive to an age when the Fontan procedure may be performed.

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