Revival of the Senning operation in the treatment of transposition of the great arteries

Preliminary report on recent experience

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Quaeghebur, J. M., Rohmer, J., and Brom, A. G. (1977). Thorax, 32, 517-524. Revival of the Senning operation in the treatment of transposition of the great arteries. This preliminary report presents recent experience with the Senning operation for transposition of the great arteries. Reasons are given why the traditional Mustard procedure was abandoned in favour of the Senning operation. Technical details are presented and the advantages and disadvantages of the procedure are discussed.

When in 1969 we saw two patients whose transposition we had treated in 1962 and 1963, respectively, by an operation described by Senning (1959) we were impressed by their good haemodynamic condition. There was no sign of venous stenosis either in the right or left half of the heart. One of us (AGB) has since tried to apply the principles of the Senning operation (trapeziform roof over the pulmonary veins and two channels for the venae cavae) to the Mustard procedure (Geldof and Aytug, 1975). In view of the fact that the original Senning operation involves the use of only a small amount of foreign material, the logical next step was to revert to this procedure. The following is a preliminary report on our recent experience in the revival of this operation.

Patients

From December 1975 to March 1977, 20 patients with transposition of the great arteries were treated by the operation described by Senning

(1959). There were 15 males and five females. In all patients except one a balloon septostomy had been performed at the time of the diagnostic cardiac catheterisation in the neonatal period. In six patients the Senning operation was performed electively, whereas in the remaining 14 patients operation was deemed necessary because of rapid increase in haemoglobin and haematocrit values, severe symptoms, failure to thrive, or the combination of these factors. The weights of our patients at the time of operation varied from 4.5 to 16.0 kg, their ages from 5 months to 3½ years, their haemoglobin values from 7.8 to 13.2 g/dl, and their haematocrit values from 43 to 72%. Ten patients were under the age of 1 year. Eight patients had other cardiac anomalies in addition to transposition of the great arteries (Table 1). Five patients had had a previous Blalock-Hanlon operation (Table 1). Their ages ranged from 2 to 3½ years. Preoperative cardiac catheterisation data are presented in Table 2. All patients were in sinus rhythm at the time of operation.

Table 1 Summary of diagnoses, previous operations, mortality, and postoperative rhythm

Diagnosis	No. of patients	Previous Blalock-Hanlon	Hospital death	Sinus rhythm	Junctional rhythm
TGA	12	2	1	10	1
TGA + PS	4	2	0	3	1
TGA + VSD + PS	3	0	1	1	1
TGA + VSD + banding PA	1	1	0	1	0

TGA = transposition of the great arteries; PA = pulmonary artery; PS = pulmonary stenosis; VSD = ventricular septal defect.

Table 2 Preoperative cardiac catheterisation data

Patient	Oxygen saturation (%)									Pressure (mmHg)					
	SVC	IVC	RA	RV	Ao	PV	LA	LV	PA	RA (mean)	RV	Ao	LA (mean)	LV	PA
1 MS	62	67	70	78	78	96	95	85	—	5	80/0-5	80/40	6	25/0-2	—
2 HB	53	59	72	71	71	—	99	98	95	4	105/0-6	—	4	40/0-6	22/10
3 MvdM	46	59	72	68	68	99	97	91	—	1	70/0-4	70/35	1	25/0-1	—
4 PL	57	68	74	76	76	100	100	91	—	2	80/0-5	80/50	2	25/0-5	—
5 KH	55	52	73	74	73	100	93	94	—	2	90/0-5	90/60	2	28/0-4	—
6 DvW	63	62	73	71	70	—	—	96	96	—	80/0-6	80/50	—	40/0-4	15/7
7 WV	50	52	65	71	71	100	96	96	96	2	75/0-3	75/42	3	34/0-2	28/8
8 JvW	52	63	86	74	76	96	91	84	82	4	90/0-8	90/45	4	30/0-5	25/10
9 MvR	68	64	73	79	80	100	100	99	—	5	75/0-7	75/45	5	32/0-6	—
10 JBo	57	62	75	73	72	99	97	89	86	5	70/0-9	70/50	5	18/0-7	12/6
11 ER	57	66	68	84	82	100	99	100	—	5	85/0-5	85/60	4	35/0-5	—
12 JB	51	57	66	74	74	99	89	89	86	4	75/0-8	70/40	4	34/0-4	21/9
13 JD	44	56	63	68	67	97	—	92	90	1	75/0-5	75/45	3	65/0-5	20/7
14 RS	50	—	55	64	—	—	—	94	—	6	80/0-10	—	8	60/0-8	20/10
15 RA	58	62	74	72	73	100	100	88	86	4	110/0-7	110/65	3	80/0-5	20/5
16 CD	68	67	80	77	76	100	86	85	—	7	85/0-10	75/15	7	75/0-10	—
17 IvS	52	53	52	—	70	98	91	98	90	4	80/0-10	80/45	6	80/0-10	22/14
18 JK	53	60	58	—	78	100	100	100	97	3	100/0-10	100/65	8	100/0-12	26/15
19 RS	47	52	86	72	76	83	85	89	85	5	90/0-8	80/45	7	80/0-12	45/20
20 HV	60	65	71	69	72	—	98	90	—	4	65/0-7	65/40	4	65/0-4	—

Patients 1-12 had TGA; Patients 13-16 had TGA + PS; Patients 17-19 had TGA + VSD + PS; and Patient 20 had TGA + VSD + PA banding. Patients 1, 8, 15, 16, and 20 had had previous Blalock-Hanlon operations.

SVC = superior vena cava; IVC = inferior vena cava; RA = right atrium; RV = right ventricle; Ao = aorta; PV = pulmonary vein; LA = left atrium; LV = left ventricle; PA = pulmonary artery.

During the same period three Mustard operations were performed. The first, in the early phase of our experience, was on a 6-month-old infant (weight 4.8 kg) who, at the time, was believed to be too small for a Senning operation. With our increased experience with the technique we can now no longer subscribe to this notion. The two other patients had developed extensive pericardial adhesions after a Blalock-Hanlon operation. In order to minimise the risk for these patients we opted for a Mustard procedure. These three patients made an uneventful recovery and showed sinus rhythm when discharged.

Technique

PRINCIPLES

The principles of the Senning operation are the same as those of the Mustard procedure.

(1) A new right wall for the new 'right' atrium has to be formed. In the Mustard operation this is done via the midportion of the patch, whereas in the Senning operation it is done via the remnants of the atrial septum and that part of the former right atrium that is localised behind the crista terminalis.

(2) The blood from the two venae cavae has to be guided to the left ventricle without obstruction. In the Mustard operation this is done via the 'legs' of the patch, whereas in the Senning operation it is done via two tubes fashioned from the same dorsal part of the right atrium as that used in (1).

(3) The blood from the left pulmonary veins has to be enabled to join the blood from the right pulmonary veins without obstruction, behind the new right atrium, so that it can flow to the right ventricle via a common opening. In the Mustard operation this is effected along the right lateral aspect of the patch *within* the heart, whereas in the Senning operation it is done along the posterior aspect of the old atrial septum and laterally to the right of the venae cavae along the *outside* of the heart.

(4) Any direct trauma to the sinoatrial node, its artery, and the atrioventricular node must be avoided.

PROCEDURE

Perfusion is started with a cannula in the right atrium. The patient's body temperature is reduced to about 20°C. During cooling, the venae cavae are cannulated as far away from the heart as possible. Perfusion then takes place via the cannulae in the venae cavae.

Figure 1 shows a craniocaudal incision a few millimetres ventral to the terminal crest. The sinoatrial node (a) is localised in the crest, and this site should not be touched with instruments during the operation. The incision A-B extends to three-quarters of the distance from both venae cavae. This incision is later to be extended (B¹) in the direction of the lateral insertion of the valve of the inferior vena cava (Eustachian valve).

After opening the right atrium (Fig. 2) one can

gain an impression of the atrial septum. As a rule, only the fossa ovalis cordis has been opened during the balloon septostomy. After a Blalock-Hanlon procedure the septum is largely absent. In both cases, a trapeziform roof must be constructed to be sutured above the left pulmonary veins (comparable to the trapeziform mid-portion of the Mustard patch). The procedure after a Rashkind operation is as follows. The first incision begins in the foramen ovale and runs parallel to the tricuspid valve ring in a caudocranial direction over a distance of about 7 mm (C-D). From D, the incision extends to the junction of the superior vena cava with the atrial septum (E). Next, the same is done with the inferior vena cava, but this time the incision begins in the lower corner of the fossa ovalis cordis. At this site tissue is sometimes absent, in which case this incision, F-G, is unnecessary. At the site at which the incisions have opened the endocardium (and myocardium) on the lateral atrial wall, the cut surfaces are repaired with a few interrupted sutures.

We now have a flap of atrial septum, which in infants aged 6-12 months nearly always has the same size. Its base is formed by the heart itself, ie, the distance between the two venae cavae (about 3 cm). Its height is about 2 cm. Meanwhile the dimensions of the pulmonary veins have been measured with a Hegar dilator (these veins usually admit Hegar size 6 or 8, which means that the distance above the two left pulmonary veins is about 1.5-2 cm). This, then, has to be the length of the top side of the trapezium (Fig. 2).

However, the upper caudal portion of this septal flap is absent due to the presence of the foramen ovale. This absent part is replaced by a small patch so that the top side of the trapezium is exactly large enough to be sutured above the left pulmonary veins, ie, 1.5-2 cm (allowing for loss of length due to suturing).

After a Blalock-Hanlon operation atrial septal remnants (if any) must be resected completely. The absent atrial septum is then replaced by a trapeziform Dacron patch of the same dimensions as the atrial septal flap already discussed—base 3 cm, top side 1.5-2 cm, height 2 cm.

The interatrial groove is opened in front of the right pulmonary veins (Fig. 3), thus exposing the anterior aspect of the left atrium. The left atrium is opened by a craniocaudal incision as close to the mid-line as possible (E^1-G^1). The caudal (E^1) and cranial (G^1) ends of this incision actually correspond with points E and G in Figure 2. However, E^1 and G^1 are situated *outside* the heart, whereas E and G are situated *within* the heart. The distance E^1-G^1 is likewise about 3 cm. The opening

in the atrium is made slightly larger by a small transverse incision made perpendicular to incision E^1-G^1 , exactly between the two right pulmonary veins.

The prepared trapezium, like the patch in the Mustard procedure, is sutured in front of the left pulmonary veins and along the posterior wall of the left atrium (Fig. 4).

At this time in the course of the operation the inferior vena caval cannula is usually replaced by one which has been introduced into the inferior vena cava via the former left auricle of the heart. This provides an ample view of the (usually large) valve of the inferior vena cava (Eustachian valve), which indicates the ventral boundary of the inferior vena cava (Fig. 4).

Incision A-B is extended to point B^1 , where it reaches the attachment of the Eustachian valve to the lateral wall of the right atrium (Fig. 5). The posterior part of the right atrium (ie, the part dorsal to the terminal crest) is then sutured to the atrial septal remnants between the A-V valves, making use caudally of the Eustachian valve. Cranially, where the sinoatrial node is situated, the sutures are placed in the endocardial layers of the atrial wall, because the sinoatrial node lies immediately below the epicardium.

The last stage of the operation is the creation of a new left atrium. For this purpose the ventral part of the right atrium (ie, the tissue ventral to incision A- B^1) is sutured to the right side of incision E^1-G^1 (Fig. 6). The suture line, therefore, necessarily extends over both venae cavae (A- E^1 and B^1-G^1); both distances are usually 1.5 cm. Since distance E^1-G^1 slightly exceeds 3 cm, the same length must be available in the mid-portion of A- B^1 on the right atrium. Cranial and caudal to this there should be sufficient tissue to invest the superior vena cava (A- E^1) and the inferior vena cava (B^1-G^1). The incision A- B^1 , therefore, should have a minimum length of $1.5+1.5+3$ cm; in our experience, A- B^1 is always about 7 cm and therefore of ample length. When suturing over the superior vena cava caution to avoid damage to the sinoatrial node is imperative; the sutures should be very superficial.

Assuming that the optimal blood flow through a given vessel is proportional to the transsectional surface of that vessel, the space behind the trapezium should admit a Hegar size 12 dilator if one pulmonary vein has a diameter of Hegar size 8; the space between the lateral wall of the new right atrium and the right side of E^1 and G^1 (Fig. 5) should then be at least Hegar size 17.

If E^1-G^1 is slightly longer than 3 cm (always the case in our experience), then this space is suffi-

(1)

(2)

(3)

(4)

(5)

(6)

Figs. 1 to 6 For explanation see text.

ently large. When these criteria are fulfilled there is an unobstructed passage of blood from the four pulmonary veins to the right ventricle.

Since zone E¹-G¹ is the only site at which stenosis could occur during growth, interrupted silk sutures are used at this site.

Results

Two patients (Nos. 6 and 18) died (Tables 1 and 2). One of these (No. 6) was a 7-month-old baby with simple transposition. A cerebrovascular accident at the age of 5 months had left the baby with severe hemiparesis. The infant was in poor condition. Low arterial oxygen saturations were consistently found before operation. The operation was uneventful and the initial postoperative course was smooth. On the second day marked thrombocytopenia was noted. A few hours later a sudden and massive tracheal haemorrhage led to untreatable hypoxia and death. The other patient (No. 18) was a 15-month-old baby with transposition, ventricular septal defect, and pulmonary stenosis. At operation subvalvar pulmonary stenosis was resected by a pulmonary artery approach, and the ventricular septal defect was closed with a Dacron patch from the right atrium. After operation junctional tachycardia was present. Death followed on the first postoperative day from low cardiac output.

The 18 surviving patients have been followed for periods ranging from a few weeks to well over a year. All patients are greatly improved with disappearances of cyanosis and fatigue. Fifteen

patients are in sinus rhythm, and three have junctional rhythm (Table 1).

Patient 2, a boy operated on at the age of 15 months, experienced an episode of congestive heart failure six months later. He responded well to treatment with diuretics. However, his right ventriculogram showed poor contractions. His chest radiograph showed marked cardiomegaly before operation and since operation his heart size has not decreased. Patient 10, a boy operated on at the age of 1 year, also showed signs of congestive heart failure shortly after operation. He responded well to treatment with diuretics. Both patients are doing well at the moment but still require daily diuretics.

One patient (No. 13), operated on at the age of 6 months, had one episode of junctional tachycardia three months later. He responded well to digitalis. He is now 15 months old and still requires a small daily dose of digoxin. He has junctional rhythm with a rate of 120 beats per minute.

The remaining 15 patients are not taking any drugs.

Two to three weeks after operation cardiac catheterisation was carried out in all patients except one (No. 20). Data are summarised in Table 3. Mean pressure differences between venae cavae and new right atrium did not exceed 4 mm Hg. The pressure tracings of the new right atrium showed a shallow x-trough and a steep y-descent in every instance (Fig. 7a). In one patient (No. 7) the new left atrium and the right ventricle were entered from the new right atrium. An angiocar-

Fig. 7 Pressure tracings from right atrium in patients (a) after Senning's operation, (b) after Mustard's operation, and (c) after transatrial closure of ventricular septal defect. The tracings show high v-waves and deep y-troughs. No clinical or angiocardiographic sign of incompetence of the corresponding atrioventricular valves was present.

Table 3 Postoperative cardiac catheterisation data

Patient	Oxygen saturation (%)										Pressure (mmHg)						
	SVC					IVC					RA		RV		LA		PV
	RA	RV	PA	SA ₁	SA ₂	RA	RV	PA	SA ₁	SA ₂	(mean)	(mean)	(mean)	(mean)	(mean)	(mean)	
1 MS	69	81	68	68	70	69	69	69	100	100	9	9	20/0-4	16/9	85/50	—	(12)
2 HB	69	73	68	70	70	70	70	70	94	94	4	4	34/0-2	12/5	100/55	6	(7)
3 MydM	62	77	67	74	77	77	77	77	97	97	10	8	30/0-8	26/14	75/50	—	(10)
4 PL	58	74	58	59	57	57	57	57	95	95	8	6	20/1-5	15/9	80/55	—	(7)
5 KH	69	76	68	69	68	68	68	68	100	100	11	7	38/0-8	22/12	90/55	—	(8)
7 WV	18	79	72	73	80	80	80	80	100	100	8	7	33/0-4	30/15	90/55	6	—
8 JvW	69	80	66	63	66	66	66	66	92	92	6	5	23/0-4	18/8	75/40	—	(5)
9 MvR	60	75	63	59	61	61	61	61	97	97	4	5	25/0-4	15/6	70/40	—	(4)
10 JBo	62	74	64	64	56	56	56	56	89	89	9	9	25/0-10	25/12	75/50	—	(10)
11 ER	19	49	52	52	52	52	52	52	95	95	5	4	4	15/6	45/45	—	(4)
12 JB	59	66	59	70	76	73	73	73	16	16	9	8	40/0-7	32/12	90/50	—	(12)
13 JD	66	43	59	60	56	56	56	56	90	90	11	9	60/0-10	23/13	100/45	—	—
14 RS	63	65	63	62	65	65	65	65	96	96	7	7	45/0-4	20/13	85/55	—	(12)
15 RA	78	90	77	71	71	71	71	71	98	98	6	6	50/0-3	18/14	90/65	—	(3)
16 CD	70	55	—	70	71	96	96	96	96	96	9	11	50/0-10	18/11	80/60	10	(13)
17 IvS	59	68	54	54	55	55	55	55	91	91	12	9	30/3-7	25/10	85/55	—	—
19 RS	71	67	73	72	72	72	72	72	91	91	11	8	42/0-6	30/16	90/40	—	—
20 HV	No catheterisation performed										—	—	—	—	—	—	—

Abbreviations as in Tables 1 and 2. SA₁ = systemic artery. The values in parentheses in the last column pertain to pulmonary artery wedge pressure. Patients 6 and 18 died after the operation.

diagram with injection of contrast medium into the superior vena cava did not show a right-to-left shunt or a left-to-right shunt.

Frontal cineangiocardiograms were performed with injection of contrast medium into the superior vena cava. In all patients there was an unimpeded flow from the superior vena cava into the new right atrium. During ventricular systole the contrast medium also filled a short distance of the inferior vena cava in all patients. The junction of the superior vena cava with the right atrium was wide in all instances and of about equal width to the junction of the inferior vena cava with the new right atrium. In two patients (Nos. 7 and 17) a striking filling of the azygos vein occurred. In one patient (No. 2) a small bidirectional shunt at atrial level was observed. In two other patients (Nos. 3 and 8) a small left-to-right shunt was seen. So far as can be judged from a cineangiocardiogram, the new right and left atria of all patients in sinus rhythm seemed to contract vigorously.

Discussion

It may be that in the near future arterial switch will become the treatment of choice in transposition of the great arteries (Baffes *et al.*, 1961; Jatene *et al.*, 1976; Ross *et al.*, 1976; Yacoub *et al.*, 1976). Meanwhile it is useful to consider the operation still most widely used—venous reversal.

In our hands the mortality of Senning's operation is approximately the same as that of Mustard's operation. The incidence of junctional rhythm in the survivors seems to be slightly less after the former operation. So far, junctional tachycardia has been encountered in only one patient after Senning's operation. The improvement in the condition of the patients is striking after either operation. Evaluation by cardiac catheterisation a few weeks after surgery revealed no differences between the two operations. Pressure gradients between venae cavae and the new right atrium were small or absent (Table 3). The same holds true after our Mustard operations. Pulmonary artery wedge pressures or, in a few instances, pulmonary venous pressures were not raised. So far we have not encountered evidence of either systemic or pulmonary vein obstruction after these Senning operations. The remarkable filling of the azygos vein after injection of contrast material into the superior vena cava in two patients can be explained by the position of the catheter holes during contrast injection. The peculiar wave form of the pressure in the new right atrium after Senning's operation (Fig. 7a) is not different from that obtained after Mustard's

operation (Fig. 7b) and probably is not specific for either procedure, as such wave forms can also be found after repair of simple ventricular septal defect by the right atrial approach (Fig. 7c).

Two patients require treatment with diuretics because of a tendency to congestive heart failure. Angiocardiography incriminates poor right ventricular function as the cause thereof rather than the Senning repair itself.

It is difficult to decide which of the two procedures—Mustard or Senning—is the best. The differences between the two procedures are as follows:

(1) A large patch is used in the Mustard and a very small one (slightly larger after a Blalock-Hanlon operation in the Senning procedure.

(2) In the Mustard procedure the decussation of the blood flows takes place at the level of the former atrial septum, whereas in the Senning procedure additional space is found outside (to the right of) the heart.

(3) Even if we assume that atrial function is far less important than ventricular function in maintaining cardiac output, we must consider the question which atria function better—those which contract against a stiff, immobile prosthesis, as in the Mustard procedure, or those in which the new right atrium contracts normally while the left contracts against a yielding right atrium, as in the Senning procedure.

DISADVANTAGES OF SENNING OPERATION

(1) We believe that postoperative arrhythmias result from direct injury of the sinus node, its artery, or the A-V node. Since in a Senning operation the sinus node (located immediately beneath the epicardium) (Janse and Anderson, 1974) is vulnerable, it may be difficult to avoid damaging it. Although in this series only a few patients showed arrhythmias, a larger series might show a different result.

(2) The Senning operation is technically more difficult than the Mustard procedure, but with increasing experience the technical differences will be more readily overcome.

ADVANTAGES OF SENNING OPERATION

(1) The amount of foreign material used is very small. Even after a Blalock-Hanlon operation the trapeziform patch required does not measure more than $30 \times (15-20) \times 15$ mm.

(2) The geometry of the operation is such that it is nearly impossible to cause stenosis of the venae cavae. Given adequate technical skill and careful measuring, stenosis of the pulmonary veins is probably also exceedingly rare.

(3) In the Mustard procedure the size of the intra-atrial baffle has to be determined with great accuracy lest it be too large (causing obstruction of pulmonary veins) or too small (causing stenosis of the superior vena cava or the new right atrium). In the Senning operation this problem is eliminated because the heart itself determines the size of the baffle.

After a Senning operation the new atria can be expected to grow as the patient grows—an expectation based on the fact that virtually no foreign material is used. Long-term results in this group of children will have to show whether this expectation is in fact fulfilled.

Conclusions

Since we believe that the Senning operation affords a more logical solution to the problem of venous reversal in the treatment of transposition than the Mustard procedure, we have reverted to the Senning operation in the treatment of 20 children, two of whom died.

The technique in this operation may be slightly more complicated than that of the Mustard procedure, but only a very small amount of foreign material is used; stenoses of the venae cavae are virtually eliminated.

Fifteen patients are in sinus rhythm after the operation. The new right atrium contracts normally, and the new left atrium contracts against the right.

Future findings will have to show which of the two procedures, the Mustard or the Senning operation, is the better (other than arterial reversal).

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