SURGERY FOR CONGENITAL HEART DISEASE

REGRESSION OF TRICUSPID REGURGITATION AFTER TWO-STAGE ARTERIAL SWITCH OPERATION FOR FAILING SYSTEMIC VENTRICLE AFTER ATRIAL INVERSION OPERATION

The cases of five patients with previous Senning ($n = 4$) or Mustard ($n = 1$) operations and failing systemic ventricles in whom banding of the pulmonary artery was performed as an interim step toward an arterial switch procedure are reported. The rise in the ratio of left to right mean systolic ventricular pressure, from 0.35 before operation to 0.90 during operation and 0.80 on the first postoperative day, caused a shift of the ventricular septum from a leftward to a midline or nearly midline position. This shift was associated with a reduction of tricuspid regurgitation. At a median interval of 5.1 months after pulmonary artery banding, the mean left ventricular posterior wall thickness had increased to 8.2 mm, versus 5 mm before operation, and the mean left ventricular myocardial mass index had increased to 90 gm/m², versus 55.6 gm/m² before operation. After the arterial switch operation, which was performed in four patients, the tricuspid regurgitation decreased to a trivial amount ($n = 1$) or disappeared completely ($n = 3$). (*J THORAC CARDIOVASC SURG* 1996;111:342-7)

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Although important tricuspid regurgitation (TR) occurs uncommonly after the atrial switch operation for simple transposition of the great arteries (TGA {S,D,D}),¹⁻⁴ the incidence is reported to be substantial among some patients after concomitant repair of an associated ventricular septal defect (VSD).^{5,6} The TR is often associated with systemic (morphologically right) ventricular failure. In these patients, it is not clear whether the TR causes or is caused by this right ventricular failure. Recently, we observed a reduction in TR among such patients at the time of pulmonary artery band (PAB) placement in preparation for an arterial switch procedure, as originally reported by Mee and colleagues.^{7,8}

Patients and methods

Patients. We reviewed the records of five patients (two male and three female) who had TGA and VSD after previous Senning ($n = 4$) or Mustard ($n = 1$) operations with VSD closure and underwent placement of a PAB ($n = 5$) followed by arterial switch operation ($n = 4$). In one patient the arterial switch procedure has been scheduled. The median age of the patients was 11 years (range 5 to 24 years; Table I). All patients had significantly decreased systemic ventricular function (median right ventricular ejection fraction, 42%; median right ventricular end-diastolic pressure, 9 mm Hg; mean right ventricular end-diastolic pressure, 11 mm Hg) and moderate ($n = 2$) or severe ($n = 3$) TR. The median left ventricular ejection fraction was 59%. Symptoms consisted of decreased exercise tolerance ($n = 5$), peripheral edema ($n = 2$), atrioventricular nodal reentry tachycardia ($n = 1$), and venous stasis ulcers ($n = 1$). All patients underwent preoperative cardiac catheterization and preoperative, intraoperative, and postoperative two-dimensional echocardiographic studies.

Operative techniques. The pulmonary artery was approached through a median sternotomy because this is the most certain route for precise placement of a PAB and avoidance of distortion of the pulmonary artery bifurcation. The banding material we used was silicone rubber reinforced with a Dacron polyester fabric mesh. A 5 mm wide PAB was placed midway between the top of the pulmonary valve and the pulmonary artery bifurcation and was gradually tightened; we strove for a systolic left to

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Table I. Patient data

Patient	Sex	Age (yr)	Additional diagnosis	Previous operation
1	F	5	VSD, mild subpulmonary stenosis, anomalous origin LAD from RCA	Senning operation; VSD closure
2	F	5	VSD	Senning operation; VSD closure
3	F	11	VSD	Senning operation; VSD closure
4	M	12	VSD	Senning operation; VSD closure
5	M	24	VSD, single coronary artery from left aortic sinus, sinus of Valsalva aneurysm	Mustard operation; VSD closure

VSD, Ventricular septal defect; LAD, left anterior descending coronary artery; RCA, right coronary artery.

right ventricular pressure ratio ($P_{LV/RV}$) of approximately 0.8.⁸⁻¹⁰ Two interrupted sutures were used to produce the initial circumference of the PAB, and then large hemoclips were used to tighten it gradually. The central venous pressure and the pressures in the pulmonary artery proximal to the PAB (reflecting left ventricular pressure) and distal to the PAB were continuously monitored. In addition, transesophageal echocardiography (TEE) allowed continuous monitoring of right and left ventricular function, ventricular septal position, and competence of tricuspid and mitral valves. If the banding was insufficient, as evidenced by a $P_{LV/RV}$ lower than 0.8, low pressure difference across the PAB, or both, the PAB was tightened further. A substantial rise in the central venous pressure, reduction in left ventricular function, or the presence of bradycardia or other arrhythmias, regardless of the $P_{LV/RV}$, indicated that the PAB had to be loosened. When the desired $P_{LV/RV}$ was reached, two sutures were placed through the band material and the adventitia on opposite sides of the pulmonary artery to prevent migration of the PAB. The $P_{LV/RV}$ was continuously monitored during the first 24 to 48 hours in the intensive care unit. A TEE study was routinely performed during the first 24 to 48 hours after operation to assess ventricular function and competence of the tricuspid and mitral valves.

The arterial switch operation was performed in a routine fashion; in all cases in this report, the main pulmonary artery and its confluence were translocated anterior to the ascending aorta. After takedown of the Senning baffle, the atria were septated with a polytetrafluoroethylene patch,* which left the coronary sinus in the right atrium.

Results

The mean intraoperative gradient across the PAB was 58 mm Hg (range 46 to 73 mm Hg). Intraoperative TEE demonstrated an immediate shift of the ventricular septum from a leftward to a midline or nearly midline position, with a concomitant decrease in TR from severe or moderate before PAB placement to moderate or mild after PAB placement. The mean values for systolic $P_{LV/RV}$ before operation, in the operating room, and in the intensive care unit during the first 24 to 48 hours were

0.35, 0.90, and 0.80, respectively. Two patients underwent rebanding at 3 and 5 months after initial PAB placement because of inadequate increase in left ventricular myocardial mass, despite an adequately tight PAB at the first operation. At a median follow-up of 5.1 months after the last PAB procedure, we observed an increase in left ventricular posterior wall thickness (mean 8.2 mm versus 5 mm before operation) and an increase in calculated left ventricular myocardial mass index (mean 90 gm/m² versus 55.6 gm/m² before operation). Further preoperative and postoperative hemodynamic data are summarized in Table II. None of the patients had mitral regurgitation after PAB placement.

After the arterial switch operation, which was performed in four patients at a median interval of 6.2 months after PAB placement, we observed a further shift of the ventricular septum from the midline to a rightward position, with concomitant increase in left ventricular end-diastolic and end-systolic dimensions, decrease in right ventricular end-diastolic and end-systolic dimensions, and abolition ($n = 3$) or regression of TR from moderate to trivial ($n = 1$; Fig. 1). The median right and left ventricular ejection fractions after the arterial switch operation were 52% and 64%, respectively.

Discussion

TR is the result of failure of systolic leaflet coaptation. This failure may be multifactorial in origin. It may be caused by structural alterations of one or all of the components of the tricuspid valve apparatus (leaflets, chordae tendineae, papillary muscles, adjacent right ventricular myocardium) or by abnormal function of a structurally normal valve (dilated annulus, right ventricular or papillary muscle dysfunction).¹¹⁻¹³

Important postoperative TR after an atrial switch operation for TGA is generally infrequent when the ventricular septum is intact and the intraatrial baffle

*Gore-Tex vascular patch; W. L. Gore & Associates, Inc., Elkton, Md.

Table II. Preoperative and postoperative hemodynamic data

Pt	$P_{LV/RV}$			TR			LVPW thickness (mm)		LV myocardial mass index (gm/m ²)	
	Before PAB	During PAB	24-48 hr after PAB	Before PAB	After PAB	After ASO	Before PAB	Late after PAB*	Before PAB	Late after PAB*
1	0.33	0.92	0.84	Severe	Moderate	Absent	3	5	45	78
2	0.25	0.83	0.75	Severe	Mild	Absent	4	7	40	75
3	0.31	1.10	0.95	Moderate	Mild	Absent	6	12	66	126
4	0.54	0.81	0.75	Severe	Moderate	Trivial	6	9	75	90
5	0.34	0.82	0.70	Moderate	Mild	—	6	8	52	81
Mean	0.35	0.90	0.80				5	8.2	55.6	90

LVPW, Left ventricular posterior wall; LV, left ventricular; ASO, arterial switch operation.

*Median interval after PAB placement was 5.1 months.

is sutured clear of the tricuspid valve.¹⁻⁴ The reported incidence of TR is higher in some patients with TGA and VSD after concomitant atrial baffle and VSD closure.^{5,6} Factors that may lead to primary TR in this group of patients include adherence of the septal leaflet or chordae to the VSD patch, asynchronous papillary muscle contraction in association with right bundle branch block (frequently occurring after VSD closure), and supraventricular or ventricular arrhythmias.

Secondary TR may occur from dilation or decreased systolic function of the right ventricle, which may cause annular dilation or distraction of papillary muscles. A vicious cycle of failure of tricuspid leaflet coaptation and right ventricular dysfunction predisposes the patient toward further right ventricular dilation and secondary dilation of the tricuspid anulus, with failure of the tricuspid anulus to shorten adequately during systole.¹⁴ The septal leaflet portion of the anulus lengthens least in this process because it is fixed between the right and left fibrous trigones and the atrial and ventricular septa. The remaining two thirds of the anulus may lengthen greatly, particularly that part giving rise to the posterior leaflet.^{12,15} A second effect of right ventricular dilation consists of relative chordal shortening, with the tricuspid leaflets being pulled toward the apex. This is particularly true for the septal leaflet because a major portion of its chordae are short and attached directly to the ventricular septum.¹⁶

In the patients described in this report, we observed a regression of TR after PAB placement as preparation for an arterial switch procedure. The intraoperative observations made by TEE after PAB placement included the following: (1) a shift of the ventricular septum from a leftward to a midline or nearly midline position, and (2) decrease in right

ventricular end-diastolic and end-systolic volumes, with improved coaptation of the tricuspid valve leaflets and resultant decrease in TR. After subsequent arterial switch operation, the TR disappeared completely or regressed to a trivial level because of improved coaptation of the tricuspid valve caused by the marked afterload-reducing effect on the right ventricle (with resultant systolic $P_{LV/RV} > 1$) and the concomitant shift of the ventricular septum from a midline position (or slightly leftward position) to a rightward position. This observation was made in all patients in this series who underwent an arterial switch operation. Perfect tricuspid valve competence may not always be achieved, however; this is especially the case when the TR is long-standing and the tricuspid valve is structurally altered. In such cases, additional tricuspid valve repair may be indicated to restore valve competence. The observations made in the five cases in this series suggest that the most important mechanism in the development of TR is right ventricular dilation (with or without structural abnormalities of the tricuspid valve after VSD closure), which leads to the feedback loop of further TR and further right ventricular dilation.

In occasional patients, a seemingly adequate PAB does not result in substantial increase of left ventricular myocardial mass. Two patients in this series had to undergo rebanding for that reason, with ultimately adequate left ventricular myocardial mass. This sometimes unpredictable effect of the PAB with regard to increase in left ventricular myocardial mass mainly reflects the difficulty in achieving appropriate tightness of the band. Poiseuille's law predicts that blood flow is related to the fourth power of the radius of the vessel, so a minor alteration in the diameter of the band, which acts as a fixed resistor, has a large impact on flow and pressure gradient across the band site. It must also

Fig. 1. **A** and **B**, Images taken in the early systolic frame before PAB placement. **A**, Apical four-chamber (*A 4 Ch*) view showing the large right ventricle (*RV*) and the compressed left ventricle (*LV*). The pulmonary venous atrium (*PVA*) is enlarged because of TR. A small portion of the supramitral baffle of the systemic venous atrium (*SVA*) is seen. **B**, Corresponding Doppler color flow image shows the severe TR with two branches of the jet in the PVA. A well-marked area of proximal isovelocity acceleration is visible, with the Doppler signal changing from dark blue to bright yellow. **C** and **D**, Status after takedown of the Senning baffle, removal of PAB, and arterial switch operation, taken in the early systolic frame in the apical four-chamber view for comparison with **A** and **B**. **C**, The LV is increased in dimension and the interventricular septum has assumed a more normal position. The RV has diminished in size. The right atrium (*RA*) is correspondingly smaller as well. **D**, The Doppler color flow study shows interrogation of the tricuspid area and RA. The jet area and intensity are markedly diminished, and the velocity is found to reflect a normal pulmonary artery pressure. *LA*, Left atrium.

be recalled that intraoperative hemodynamic measurements are made in an anesthetized, mechanically ventilated patient with an open chest; the physiology is clearly quite different from that in an awake and spontaneously breathing patient.

We recommend the two-stage arterial switch operation as the procedure of choice for patients with documented progression of right ventricular failure (which is almost always accompanied by TR) after previous atrial inversion operation. Although ex-

act hemodynamic parameters cannot be provided as indications for operation, it is our experience that deteriorating right ventricular function should be addressed early rather than late to preserve not only right ventricular and tricuspid valve function but also left ventricular function. The timing of performance of the arterial switch operation after PAB placement is arbitrary; in our series, the median interval was 6.2 months. Although we believe that measurement of left ventricular wall thickness and calculation of left ventricular myocardial mass provide useful guides with regard to readiness of the left ventricle to serve as the systemic ventricle, the decision to perform the arterial switch operation can be made adequately only with invasively obtained hemodynamic data. Our data and those of Cochrane and colleagues⁸ suggest that the systolic $P_{LV/RV}$ should be at least 0.8 at the time of conversion. In occasional patients with pulmonary venous obstruction after atrial inversion operation, the left ventricle may already be well trained and thus able to support the systemic circulation without the need for a PAB; in such cases, a one-stage arterial switch operation may be feasible.¹⁷ In patients with inadequate left ventricular function, cardiac transplantation remains the only alternative.⁸

A two-stage arterial switch procedure complemented by an atrial inversion operation (double switch) is also a viable option in patients with corrected TGA ($\{S,L,L\}$ or $\{I,D,D\}$) with systemic (morphologically right) ventricular dysfunction and systemic atrioventricular (morphologically tricuspid) valve dysfunction. Even though the tricuspid valve in corrected TGA is almost always morphologically abnormal (an Ebstein-like anomaly being the most frequently observed malformation¹⁸⁻²⁰), TR has been reported to regress after a double switch operation.^{8, 21, 22} Alternatively, particularly when dysfunction of the pulmonary (morphologically left) ventricle precludes a double switch operation, the regurgitant tricuspid valve may have to be replaced.²⁰

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