A New Strategy for the Surgical Treatment of Aortic Coarctation Associated With Ventricular Septal Defect in Infants Using an Absorbable Pulmonary Artery Band

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OBJECTIVES

We propose a new strategy using coarctation repair together with a polidioxanone absorbable pulmonary artery banding to limit operative risk and to spare infants with aortic coarctation subsequent operations.

BACKGROUND

The alternative for the surgical management of aortic coarctation associated with ventricular septal defect (VSD) is single-stage repair versus coarctation repair with or without banding of the pulmonary artery.

METHODS

Eleven infants (mean weight 2,560 ± 1,750 g, range 1,320 to 3,800 g) underwent a coarctation repair with a polydioxanone banding. Seven had a trabecular and four a perimembranous VSD. The mean size of the VSD was 5 ± 0.7 mm (range 4 to 7 mm). The systolic pulmonary pressure was >80% of the aortic pressure in all. The pulmonary band was tightened until the systolic pulmonary pressure fell below 50% of the aortic pressure.

RESULTS

There were no hospital deaths. The reabsorption of the banding was complete after 5.7 months in all patients (3 to 6.5 months). The VSD closed completely in four infants and partially in six, in whom the pulmonary artery pressure was normal without evidence for significant left-to-right shunt. One patient with a large trabecular VSD underwent surgical closure of his defect after four months. Finally, a subsequent open-heart surgery could be avoided in 91% (10/11) of patients.

CONCLUSIONS

Provided the VSD belongs to types prone to close spontaneously, this policy may reduce the number of surgical procedures per infant as well as in-hospital mortality and morbidity rates. It should be proposed as an alternative to more complex procedures. (J Am Coll Cardiol 1999;34:866–70) © 1999 by the American College of Cardiology

Decision making for the surgical management of aortic coarctation associated with ventricular septal defect (VSD) is sometimes difficult in newborn infants (1–3). The coarctation of the aorta and the VSD may be repaired during a single-stage procedure or by initial coarctation repair with or without pulmonary artery banding. Single-stage repair is now largely applied to coarctation associated with complex intracardiac anatomy or for interrupted aortic arch with VSD (4,5). Hitherto, however, the indications for single stage repair in coarctation with isolated VSD are not clearly defined. Recent reports suggested that a successful management of the majority of the neonates with coarctation and associated VSD was possible with repair of coarctation alone (1,2). Nevertheless, it appears that more than half of the patients who underwent a coarctation repair alone had to undergo subsequent VSD closure or secondary pulmonary artery banding without delay because these patients could not be weaned from the ventilator. Conversely, the operative risk of single-stage repair might be high in low-weight infants, and pulmonary artery banding has the disadvantage of requiring a subsequent operation for debanding. Today, predictors of closure of the VSDs associated with coarctation of the aorta are scarce and contradictory (6,7). However, trabecular or muscular and perimembranous defects are prone to close spontaneously, in contrast to malalignment and infundibular VSDs (8,9).

In this study, we report on a series of selected neonates with coarctation of the aorta and either trabecular or perimembranous VSD, in whom we repaired the coarctation and put an absorbable polidioxanone pulmonary band. The objective of this study was to find a compromise
between the standard attitudes mentioned above that could be adapted for the treatment of ambiguous cases.

**METHODS**

**Population.** Over a period of three years, we selected 11 neonates (mean weight $2,560 \pm 1,750$ g, range 1,320 to 3,800 g) with coarctation of the aorta and VSD for a coarctation repair associated with an absorbable pulmonary artery banding. The selection criteria were the following: 1) coarctation of the aorta with or without aortic arch hypoplasia; 2) VSD, either trabecular or perimembranous; 3) maximum defect size $<8$ mm; and 4) nonrestrictive defects with systolic pulmonary pressure $>80\%$ of systolic aortic pressure measured at the right arm. Seven patients had a trabecular defect (five mid–trabecular, multiple in one and apical in one) and four patients had a perimembranous defect. The mean size of the VSD was $5 \pm 0.7$ mm or $2.6 \pm 0.6$ cm/m² (range 4 to 7mm; 1.7 to 3.2 cm/m²). Six patients received prostaglandin E1 (PGE1) infusion to relieve the coarctation; the ductus arteriosus was closed in the other five patients. Five patients were ventilated and had to receive inotropic support for left ventricular systolic dysfunction at admission. Patients with complex intracardiac anatomy and interrupted aortic arch were excluded. Patients with very large ($>8$ mm), infundibular VSDs and leftward malaligned outlet septum were excluded as well. Anatomic characteristics of the aortic arch and of the VSD were obtained by echocardiography. The patient data are summarized in Table 1.

**Operative technique.** Mean age at operation was $10.5 \pm 3.5$ days (range 8 to 41 days). All patients underwent an aortic arch reconstruction by extended end-to-end anastomosis through a left posterolateral thoracotomy except in one very low weight infant (1,435 g), in whom a midline sternotomy was used. A 5-mm pulmonary artery band made of interlaced fibers of polydioxanone (PDS) was tightened around the pulmonary artery trunk until the distal systolic pulmonary pressure fell below 50% of the aortic systolic pressure.

**Follow-up.** All patients were followed up for a mean of $16 \pm 11$ months (range 5 to 27 months). Clinical examination, chest roentgenogram and echocardiography were performed monthly during the first six months after operation. The procedure was considered to be successful when the VSD was closed or hemodynamically nonsignificant after the pulmonary banding was completely absorbed.
RESULTS

Mortality and morbidity. There were no hospital deaths and no late deaths. Intensive care unit stay was 3 ± 2 days. One very low weight infant (1,320 g) had to be reintubated for a chylothorax, requiring drainage for three days. One patient had a transient right ventricular failure while the pulmonary band was adequately sized. One patient (1435 g) had a recoarctation two months after surgery and underwent a successful balloon angioplasty.

Pulmonary artery banding. Three patients needed medication at hospital discharge (angiotensin-converting enzyme inhibitors and diuretics) because of failure to thrive. These three patients had persistent indirect echocardiographic measurements for a significant left-to-right shunt, while their banding was considered to be adequately sized (right ventricle-pulmonary Doppler-flow velocity >4 m/s). All three could be weaned of all medications after 4, 6 and 8 weeks, respectively. The remaining eight patients were discharged without medication.

The reabsorption of the banding was complete in all patients after a mean follow-up of 5.75 ± 1 month (range 3 to 6.5 months). At this time, no remaining trace of the banding could be found on echocardiography, and the maximum Doppler-flow velocity through the pulmonary artery was <1.5 m/s in all patients. No distortion of the pulmonary arteries could be observed in any patient.

VSD closure. One patient with a 7-mm trabecular VSD underwent surgical closure of the defect at four months of age. Indeed, after reabsorption of the pulmonary banding, he had a persistent significant left-to-right shunt and pulmonary hypertension. During surgery, no trace of the pulmonary banding could be found around the pulmonary artery.

The VSD closed completely in four patients within the delay of reabsorption of the banding. In the remaining six patients, the VSD closed partially but the pulmonary pressure was normal and there was no evidence for a significant left-to-right shunt. None of these patients received medication after reabsorption of the pulmonary banding. Finally, 10 of 11 patients (91%; CL 95% 73.7% to 100%) did not undergo a second surgical procedure.

DISCUSSION

Strategies for the treatment of coarctation with VSD. A well-defined algorithm for the treatment of the infant with coarctation of the aorta and VSD has not been clearly proposed. Issues such as the choice of intervention remain unresolved at the present time (1–5). Indeed, an alternative is coarctation repair with or without pulmonary banding or single-stage repair under cardiopulmonary bypass. These three strategies have their respective advantages and limits. Individually adapted treatment has to take into account the operative risk, the need for subsequent intervention as well as the hemodynamic, anatomic and putative evolution of the VSD.

Single-stage repair is now the treatment of choice for complex congenital heart diseases with coarctation of the aorta and VSD amenable to biventricular repair (4,5). In coarctation with VSD, the single-stage repair gives excellent results with a low mortality rate. Still, the operative risk might be much higher in low-weight or in premature infants, particularly regarding neurologic consequences of the circulatory arrest.

According to recent surgical series, it appears that most infants with coarctation of the aorta and VSD can be treated by coarctation repair alone (1–4). In these series, 40% to 45% of the patients treated with this technique did not require secondary pulmonary banding or open-heart closure of the VSD. This means that 55% to 60% of the patients in these series required a secondary operation, either VSD closure or pulmonary artery banding. It is of note that most of these subsequent procedures had to be performed within a few days after coarctation repair as a result of persistent pulmonary overflow. In addition, these secondary procedures are performed in infants in worse condition than is deemed ideal. Consequently, the mortality in this category of patients is not significantly different than the mortality of single stage repair.

In patients treated with pulmonary artery banding, the obvious inconvenience is the need for debanding with or without VSD closure. In addition, pulmonary artery scarring is a frequent complication requiring pulmonary artery angioplasty if the band is left for more than six months (10). As the resorption of the polydioxanone band occurred within the first six months in our series, we did not observe any scar on the pulmonary artery after resorption. It is of note that the surgeon who reoperated on the patient who still had a large VSD after the resorption of the banding did not find any sequelae on the pulmonary trunk.

Selection of patients for an absorbable pulmonary banding. Various criteria have been proposed to predict the need for surgical closure of VSDs associated with coarctation of the aorta. The size of the VSD is not a good predictor of spontaneous closure, as even large VSDs (>1 cm/m²) may close rapidly (11–13). The importance of the left-to-right shunt has also been proposed, but none of the patients with coarctation of the aorta and VSD is currently catheterized in our institution. Therefore, the quantification of left-to-right shunt relies on indirect clinical, radiologic and echocardiographic arguments. However, the left ventricle is often small relative to the right ventricle in coarctation of the aorta with VSD, and the lack of volume loading of these “small” ventricles does not allow a good estimation of the shunt through the VSD. Finally, the anatomic features of the VSD seems to be the best argument to predict spontaneous closure (11). Perimembranous and trabecular defects represent two-thirds of the VSDs associated with coarctation of the aorta (6). These defects are characterized by a high
incidence of spontaneous closure in contrast to malignment VSDs.

For these reasons, we hypothesized that a transient pulmonary artery banding could be useful in infants with coarctation associated with VSDs prone to spontaneous closure. Our aim was to simplify the surgical procedure and to spare these children the need for a second operation. At our institution, initial combined repair of both aortic coarctation and the VSD would be undertaken rather than pulmonary artery banding or coarctation repair alone in nonrestrictive VSDs. During the period of inclusion of this series, all patients with left inward malalignment of the outlet septum underwent a single-stage repair as well as the patients with very large VSD (>8 mm). We excluded from the study the patients with a malalignment defect with left outflow tract obstruction, as biventricular outflow tract obstruction in these cases has been proved to result in increased mortality (14). The infants with restrictive VSDs underwent coarctation repair alone. Indications for “definitive” pulmonary artery banding were mainly “huge” VSDs (>50% of the septum) and complex intracardiac anatomy. In the patients of this series, the VSD was not restrictive, and the alternative was complete repair versus coarctation repair with an absorbable pulmonary artery banding. Still, it remains difficult to predict the hemodynamic consequences of a mid-sized VSD in patients with associated coarctation of the aorta who receive PGE1 to maintain the arterial duct patent. In neonates presenting early in life, the pulmonary pressure is often systemic in such a situation and Doppler assessment across the VSD can yield a high right ventricular and pulmonary pressure in the face of a restrictive VSD. This could have happened in some of our patients. However, these echographic hemodynamic findings are still ambiguous in these patients when dealing with the best surgical technique to be applied. Our results are encouraging, as there was no mortality and only one patient had to be reoperated on for closure of the VSD at four months of age. In addition, intensive care unit stay was short and only three patients received medication for persistent pulmonary overcirculation at discharge. There was no late complication of the pulmonary banding, and the VSD closed or became hemodynamically insignificant during the delay of reabsorption of the banding. Nevertheless, the only way to determine whether or not this alternative for the treatment of VSD with associated coarctation has a significant impact on the decision process regarding VSD closure in this setting would be to perform a control study with regards to VSD size with and without pulmonary banding.

**Pulmonary artery banding: technique and perspectives.**

The surgical calibration of the banding was performed by measuring the pulmonary pressure. In our smallest patient, the banding was placed more loosely than ideal, and the pulmonary pressure was estimated to be 60% of the aortic pressure at postoperative control. It is also of note that the three patients who needed diuretics and angiotensin-converting enzyme inhibitors at discharge apparently had a sufficient obstruction of the pulmonary artery. The technique of banding with a 5-mm-large polydioxanone band may lead to underestimating the pulmonary artery pressure, as simplified Bernouilli equation might overestimate the Doppler gradient through this wide banding (Fig. 1). Notwithstanding this limitation, the pulmonary artery constriction increased in all patients with growth and led to a reduction in the left-to-right shunt. Indeed, no patient received any medication after two months. The reabsorption of the banding was progressive in all patients and the right ventricular pressure never exceeded the left ventricular pressure in the four patients in whom the VSD closed before the reabsorption was completed.

Extrathoracically adjustable pulmonary bands have been used in various indications such as training of the subpulmonary left ventricle in transposition of the great arteries or in double-discordance before a switch or a “double-switch” operation, respectively (15). Percutaneously adjustable pulmonary artery band has also been proposed in situations in which the precise adjustment for sufficient reduction of the pulmonary blood flow can cause life-threatening hemodynamic changes (16–18). Absorbable polidioxanone pulmonary band as a palliative procedure has been used successfully by Gutierrez de Loma et al. (19) in five patients with atrioventricular canal or VSD in whom pulmonary reconstruction was avoided at subsequent reoperation. Recently, Peek et al. (20) reported two cases of VSD (one associated with coarctation of the aorta) successfully treated with an absorbable pulmonary artery banding made of braided Dexon. In our series, reabsorption of the banding occurred 5.7 months after operation, and this delay might be too short to observe a sufficient closure of some VSDs. Another
alternative to our technique could be using balloon-dilatable or staged expanding pulmonary artery band (21,22).

Conclusions. Provided the VSD associated with coarcta-
tion of the aorta belongs to types characterized by a high
incidence of spontaneous closure, banding the pulmonary
artery with absorbable material may reduce the number of
surgical procedures per infant, in-hospital mortality and
morbidity rates. It should be proposed, in selected infants, as
an alternative in the panel of surgical options in the
treatment of coarctation of the aorta with isolated VSD.

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