CONGENITAL HEART DISEASE

Doppler Evaluation of Homograft Valved Conduits in Children

Jon N. Meliones, MD, A. Rebecca Snider, MD, Edward L. Bove, MD, Gerald A. Server, MD, Jane Peters, Samuel J. Lacina, MD, Michael S. Florentine, MD, and Amnon Rosenthal, MD

To assess the flow characteristics of homograft valved conduits in the immediate postoperative period, 69 children with 71 homograft conduits underwent 2-dimensional and Doppler echocardiographic examination at 1 to 40 days (mean 8) after surgery. Of the 71 conduits studied, 19 were aortic and 52 were pulmonary homograft valved conduits. Two aortic homograft valved conduits were inserted in the aortic position, whereas all remaining homografts were placed in the pulmonary position. On the Immediate postoperative echocardiogram, 25 (35%) of the conduit valves had no regurgitation and 44 (62%) had 1+ (mild) regurgitation. Two pulmonary valved conduits (3%) in the pulmonary position had 2+ (moderate) regurgitation and right ventricular dimensions >95% for body surface area. The peak velocity across the homograft valve was normal (<1.3 m/s) in 58 valves (82%). In the remaining 13 valves, peak velocity ranged from 1.4 to 2.6 m/s. No homograft valve had a peak velocity >2.6 m/s in the immediate postoperative period.

To assess the fate of homograft valved conduits in the intermediate-term follow-up period, 38 children with 38 conduits had a repeat echocardiogram at 6 to 25 months (mean 15 ± 6) after surgery. Of the 38 conduits examined, 10 (26%) had no regurgitation, 25 (66%) had 1+ regurgitation and 3 (8%) had 2+ regurgitation. Progression of the amount of regurgitation occurred in 11 (29%) patients.

At the follow-up examination, peak velocity was ≤1.4 m/s across 34 conduit valves, between 1.4 and 2.6 m/s across 3 valves and >2.6 m/s across 1 valve. This latter patient had a 3.2-m/s jet across the proximal insertion of the conduit and no further increase across the valve itself. Thus, no patient had evidence of conduit valve stenosis. Of the 38 patients, 9 had Doppler evidence of obstruction at the conduit insertion (8 at the distal end and 1 with the aforementioned proximal obstruction). Most obstructions were of mild to moderate severity and only 2 patients (5%) had severe conduit stenosis.

Thus, in the immediate postoperative period, normally functioning homograft valved conduits frequently have mild regurgitation (62%) and rarely have moderate or severe regurgitation (3%), with peak velocities reaching <2.6 m/s. In the intermediate-term follow-up period, normally functioning homograft valved conduits frequently have mild regurgitation (62%) and rarely have moderate or severe regurgitation (3%), with peak velocities reaching <2.6 m/s. In the intermediate-term follow-up period, homograft valved conduits may develop an additional degree of regurgitation (29%), frequently continue to have conduit peak velocities <2.6 m/s (97%) and uncommonly develop hemodynamically significant obstruction, usually at the ends of the conduit (5%).

(Ann J Cardiol 1989;64:354-358)

In infants and children with congenital heart disease, valved conduits are widely used, especially for the repair of defects with right ventricular-pulmonary artery discontinuity. In 1966, Ross and Somerville1 introduced the use of fresh aortic homograft valved conduits; however, because of problems with limited availability and early calcification of these irradiated conduits, alternative valved conduits were sought.2,3 In 1973, the use of a porcine heterograft valve mounted in a woven Dacron® tube was proposed,4 and, because of its ready availability, it soon became the most widely used conduit.5,6 Long-term follow-up studies of children with heterograft porcine valved conduits showed, however, a disappointing rate of development of obstruction at the porcine valve and in the Dacron conduit itself.7-10 As a result of these studies and because of the development of improved techniques for preparation and preservation of homograft valves, antibiotic-sterilized homograft valves are now being widely used in children and are favored by most surgeons because of their lower antigenicity compared with porcine valved conduits.11-20

From the Departments of Pediatrics and Surgery, C.S. Mott Children's Hospital, University of Michigan Medical Center, Ann Arbor, and Butterworth Hospital, Grand Rapids, Michigan. Manuscript received February 6, 1989; revised manuscript received May 4, 1989, and accepted May 5.

Address for reprints: A. Rebecca Snider, MD, Division of Pediatric Cardiology, Room F1115, Box 0204, C.S. Mott Children's Hospital, Ann Arbor, Michigan 48109-0204.
The continuing search for the optimal extracardiac conduit requires accurate information on the long-term fate of these conduits. Although the Doppler flow characteristics of normally-functioning mechanical and heterograft prosthetic valves have been well described,21-29 there are no descriptions of the Doppler flow characteristics of the normally-functioning homograft valve in the immediate postoperative period. The purposes of this study were to determine the characteristics of flow through the normally functioning homograft valve in the immediate postoperative period using Doppler echocardiography and to evaluate the fate of these conduits at the intermediate postoperative follow-up echocardiographic examination.

METHODS

Patients: From September 1985 to October 1988, 74 homograft valved conduits were placed in 72 children (2 children had 2 homograft valved conduits each). Sixty-nine of the 72 children underwent 2-dimensional and Doppler echocardiographic examination in the immediate postoperative period. Three patients died before a postoperative echocardiographic examination could be performed. The study group comprised the 69 surviving children, who had a total of 71 homograft valved conduits. Their diagnoses are listed in Table I.

The study group included 35 girls and 34 boys. Age at operation ranged from 1 day to 40 years (mean ± standard deviation 5.8 ± 2.0 years). Eight patients were <1 month old, 6 were 1 month to 2 years old, 32 were 2 to 6 years old and 23 were >6 years old. Their weight at operation ranged from 2 to 96 kg (mean 21.6 ± 4.0).

Homograft valves: Of the 71 homograft valved conduits studied, 19 were aortic and 52 were pulmonary homograft valves. All pulmonary homograft valves were inserted in the pulmonary position. Seventeen aortic homograft valves were inserted into the pulmonary position and 2 were inserted into the aortic position. The valves ranged from 8 to 27 mm in diameter. Six valves measured between 8 and 14 mm, 18 between 15 and 20 mm and 47 between 20 and 27 mm.

Operative techniques: Cryopreserved homografts (Cryolife) were used in all patients. Valves were harvested from cadavers in whom perfusion was being maintained. The valves were cultured, sized, trimmed of excess tissue and frozen to −197°C in liquid nitrogen for subsequent use. In the initial patients, aortic homografts were primarily used. In later patients, pulmonary homografts were preferred because of their thinner walls and superior suturing characteristics. Selection of homograft size was determined by patient size and graft availability. No deliberate effort was made to "over-size" the conduit for any patient. A knitted Dacron tube soaked in albumen or plasma was autoclaved to minimize bleeding and then used to lengthen the homograft proximally to provide a hood for the ventricular anastomosis. Whenever possible, the Dacron extension was sharply beveled, leaving only a 2- to 3-mm rim posteriorly to reduce the circumferential Dacron to a minimum. When pulmonary artery branch stenosis was present, the distal end of the conduit was used as an onlay patch.

Echocardiographic examination: All 69 patients underwent a complete 2-dimensional and Doppler echocardiographic examination in the immediate postoperative period. The initial postoperative examination was obtained from 1 to 40 days (mean 8) after surgery. In addition, 38 patients (with 38 conduits) had a repeat echocardiogram in the intermediate postoperative follow-up period. The follow-up examinations were obtained from 6 to 25 months (mean 15 ± 6) after surgery. Thirteen patients were examined from 6 to 12 months after surgery and 25 were examined from 12 to 25 months after surgery.

Ventricular dimensions were measured from an M-mode echocardiogram generated from the 2-dimensional sector scan. Homograft valve stenosis was assessed by measuring the peak flow velocity through the homograft valve from multiple transducer positions using pulsed, high-pulse repetition frequency and continuous-wave Doppler techniques. The highest value for the peak velocity was used in the simplified Bernoulli equation (gradient = 4 X peak velocity^2) to calculate the peak instantaneous pressure gradient across the homograft valve. The proximal and distal conduit insertions also were examined for evidence of obstruction.

Pulsed and color flow Doppler mapping techniques were used to detect homograft valve regurgitation. Regurgitation was diagnosed when Doppler signals arising from blood flow passing retrogradely across the valve in diastole were present. The amount of regurgitation was graded according to the following parameters: (1) mild (1+) = small, narrow jet of low amplitude detected near the valve origin with normal cardiac chamber dimensions; (2) moderate (2+) = easily detected, high amplitude jet associated with cardiac chamber enlargement; and (3) severe (3 to 4+) = wide, easily-detected, high amplitude jet with marked cardiac chamber enlargement and with evidence of marked diastolic runoff of blood from the aorta or pulmonary artery.

RESULTS

Immediate postoperative examination: Of the 71 conduits evaluated in the immediate postoperative period, 25 (35%) had no homograft valve regurgitation, 44
(62%) had 1+ regurgitation and 2 pulmonary homograft valves in the pulmonary position (3%) had 2+ regurgitation. The 2 patients with 2+ regurgitation had right ventricular diastolic dimensions >95% for body surface area.

Evaluation of the velocity profile across the homograft valve showed a normal peak flow velocity (<1.3 m/s) across 58 valves (82%). In the remaining 13 valves (all with 0 or 1+ regurgitation), the peak velocity ranged from 1.4 to 2.6 m/s. No homograft valve had a peak velocity >2.6 m/s in the immediate postoperative period. For the entire group, the peak velocity was 1.6 ± 0.3 m/s. Doppler evaluation of the proximal and distal insertions of the homograft valve conduit showed no patient with obstruction at the ends of the conduit in the immediate postoperative period.

Intermediate follow-up examination: Thirty-eight patients with 38 conduits had intermediate-term follow-up echocardiographic examinations. Of the 38 conduits examined, 10 (26%) had no regurgitation, 25 (66%) had 1+ regurgitation and 3 (8%) had 2+ regurgitation (Table II). No patient had >2+ regurgitation. Of the 10 patients with no regurgitation, 6 had no regurgitation in the immediate postoperative period, 3 had 1+ regurgitation and 1 had 2+ regurgitation. Of the 25 patients with 1+ regurgitation, 8 had no regurgitation on the immediate postoperative examination, 16 had 1+ regurgitation and 1 had 2+ regurgitation. All 3 patients with 2+ regurgitation had pulmonary valve conduits in the pulmonary position. Their right ventricular diastolic dimensions were larger than the 95% for body surface area. All 3 patients had an increase in the amount of regurgitation from the immediate postoperative echocardiogram. One patient had no regurgitation on the immediate postoperative echocardiogram, whereas the other 2 patients had 1+ regurgitation in this period.

At the follow-up examination, the peak flow velocity was ≤1.4 m/s across 34 conduit valves, it ranged between 1.4 and 2.6 m/s across 3 valves, and was >2.6 m/s across 1 valve. One patient with a 14-mm Hg peak gradient across the conduit valve (1.9 m/s) had a predicted right ventricular systolic pressure of 74 mm Hg (predicted by Doppler from the tricuspid regurgitation jet). This finding suggested severe distal conduit stenosis; however, due to limited echocardiographic access, the distal conduit insertion could not be examined directly with Doppler echocardiography. At catheterization, this patient had severe stenosis at the distal insertion of the conduit and no gradient across the conduit valve. No other patient had evidence of unexplained right ventricular hypertension in the face of normal peak flow velocity across the conduit valve. One patient with a peak velocity of 3.2 m/s across the conduit valve had a 3.2-m/s jet across the proximal insertion of the conduit. In this patient, the increased velocity across the conduit valve was due to the persistence of a high-velocity jet originating at the proximal obstruction (pulsed Doppler examination showed no further increase in peak flow velocity across the valve itself). Evidence of obstruction at the proximal or distal conduit insertions was found in 9 patients at the intermediate follow-up examination (Table III). The peak velocity across the obstruction in these patients ranged from 2.0 to 4.0 m/s. One patient with truncus arteriosus had a 64-mm Hg gradient across the distal conduit insertion. The conduit valve in this patient appeared normal and had a peak flow velocity of 1.5 m/s. At catheterization, this patient had severe obstruction at the distal insertion of the conduit and no gradient across the conduit valve. The other patient in this group who has had cardiac catheterization is the one with right ventricular hypertension predicted from the tricuspid regurgitation jet mentioned previously. No other patient in the study group has had a postoperative cardiac catheterization.

**DISCUSSION**

With the recent development of improved cryopreservation and surgical techniques, the use of homograft valved conduits has become the preferred method for establishing ventricular-great artery continuity in many centers. The long-term follow-up studies of children who have received fresh, antibiotic-sterilized aortic homograft valves show that 70% can be expected to be free of conduit obstruction at 15 years after operation. In Kay and Ross’s experience, only 13% (3 patients) required conduit replacement by 10 years. The obstruction in these children was within the Dacron tube and not at the homograft valve. This type of obstruction can probably be avoided with the use of autologous pericardial tubes or extended pulmonary valve homograft conduits. Little follow-up data are available concerning the fate of cryopreserved aortic or pulmonary homograft valved conduits.

**TABLE II** Change in Amount of Homograft Valve Regurgitation from Immediate Postoperative to Intermediate Follow-Up Examination

<table>
<thead>
<tr>
<th>Amount of Regurgitation at Postoperative Examination</th>
<th>Amount of Regurgitation at Follow-Up Examination</th>
<th>No. of Pts (n = 38)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>0</td>
<td>1+</td>
<td>8</td>
</tr>
<tr>
<td>0</td>
<td>2+</td>
<td>1</td>
</tr>
<tr>
<td>1+</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>1+</td>
<td>1+</td>
<td>16</td>
</tr>
<tr>
<td>1+</td>
<td>2+</td>
<td>2</td>
</tr>
<tr>
<td>2+</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2+</td>
<td>1+</td>
<td>1</td>
</tr>
<tr>
<td>2+</td>
<td>2+</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE III Patients with Conduit Obstruction at the Intermediate Follow-Up Examination

<table>
<thead>
<tr>
<th>Dx</th>
<th>Age at Surgery (yrs)</th>
<th>Conduit Type</th>
<th>Location of Obstruction</th>
<th>Velocity (m/s) and Gradient (mm Hg)</th>
<th>Regurgitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Across Obstruction</td>
<td>Across Valve</td>
</tr>
<tr>
<td>Truncus</td>
<td>0.08</td>
<td>PUL</td>
<td>PUL</td>
<td>Proximal</td>
<td>3.2 (41)</td>
</tr>
<tr>
<td>Truncus</td>
<td>3.6</td>
<td>Ao</td>
<td>PUL</td>
<td>Distal</td>
<td>3.1 (35)</td>
</tr>
<tr>
<td>Truncus</td>
<td>5.8</td>
<td>Ao</td>
<td>PUL</td>
<td>Distal</td>
<td>4.0 (64)</td>
</tr>
<tr>
<td>Truncus</td>
<td>9</td>
<td>Ao</td>
<td>PUL</td>
<td>Distal</td>
<td>3.0 (36)</td>
</tr>
<tr>
<td>Truncus</td>
<td>9</td>
<td>Ao</td>
<td>PUL</td>
<td>Distal</td>
<td>3.0 (49)</td>
</tr>
<tr>
<td>PA/VSD</td>
<td>6.5</td>
<td>Ao</td>
<td>PUL</td>
<td>Distal</td>
<td>3.0 (36)</td>
</tr>
<tr>
<td>PA/VSD</td>
<td>7</td>
<td>PUL</td>
<td>PUL</td>
<td>Distal</td>
<td>3.2 (41)</td>
</tr>
<tr>
<td>PA/VSD</td>
<td>14</td>
<td>Ao</td>
<td>PUL</td>
<td>Distal</td>
<td>3.0 (36)</td>
</tr>
<tr>
<td>DORV/PS</td>
<td>7</td>
<td>PUL</td>
<td>PUL</td>
<td>Distal</td>
<td>3.0 (38)</td>
</tr>
</tbody>
</table>

* This patient had persistence of the proximal jet across the valve and no further increase across the valve itself.

Ao = aorta; DORV = double outlet right ventricle; Dx = diagnosis; PA = pulmonary artery; PS = pulmonary stenosis; Pul = pulmonary; RVSP = right ventricular systolic pressure estimated from the tricuspid insufficiency jet; Truncus = truncus arteriosus; VSD = ventricular septal defect.

TABLE III Patients with Conduit Obstruction at the Intermediate Follow-Up Examination

The occurrence and progression of homograft valve regurgitation is worrisome. Lamberti et al.\(^1\) noted early pulmonary homograft valve regurgitation in 61% of their patients and progression of regurgitation in 6% (1 of 18). Predisposing factors to the development and progression of regurgitation were incompletely relieved pulmonary branch stenosis, pulmonary vascular obstructive disease and mechanical distortion of the valve caused by a conduit that was twisted or too small. Attention to mechanical details or predisposing patient factors may lead to techniques for eliminating or reducing the amount of conduit valve regurgitation.

At the intermediate follow-up examination, only 2 of our 38 patients (5%) have developed severe homograft valved conduit obstruction, both at the distal conduit insertion. No patient has developed significant stenosis at the homograft valve itself. The incidence and site of obstruction in our series is in agreement with reports from other centers.\(^19,30\) Predisposing factors for the development of obstruction at the proximal and distal conduit insertions include the length of the conduit necessary for the repair as well as the age of the child at the time of surgery;\(^19,30\) thus, very young infants undergoing
DOPPLER EVALUATION OF HOMOGRAFT VALVES

primary repair of truncus arteriosus are particularly prone to development of conduit obstruction.

Acknowledgment: We thank Steven Spillan and Kathy Chuniewski for editorial assistance in the preparation of this manuscript.

REFERENCES


5. Bailey WW, Kirklin JW, Burgeron LM Jr, Pacileo AD, Kouchoukos NT. Late results with synthetic valved external conduits from venous to pulmonary arteries. Circulation 1977;56(suppl VI);73-78.


