Staged surgical repair of functional single ventricle in infants with unobstructed pulmonary blood flow

Mark D. Rodefelda, Mark Ruzmetova, Marcus S. Schambergerb, Donald A. Girodb, Mark W. Turrentinea, John W. Browna,*

aSection of Cardiothoracic Surgery, Indiana University School of Medicine, James W. Riley Hospital for Children, 545 Barnhill Dr., EH 215, Indianapolis, IN 46202-5123, USA
bSection of Pediatric Cardiology, Indiana University School of Medicine, James W. Riley Hospital for Children, Indianapolis, IN, USA

Received 13 September 2004; received in revised form 12 January 2005; accepted 17 January 2005

Abstract

Objective: The infant with a functional single ventricle (SV) and unobstructed pulmonary blood flow (UPBF) requires early protection of the pulmonary vascular bed to ensure suitability for a subsequent Fontan procedure. Systemic obstruction by aortic arch obstruction, subaortic stenosis, or combination of both, has been widely recognized as an important risk factor for poor outcome in children with SV-UPBF who are palliated with pulmonary artery banding (PAB). We reviewed our experience with primary PAB in the subset of patients with SV-UPBF to identify risk factors for subsequent palliative procedures and Fontan completion. Methods: Between January 1990 and May 2004, 80 patients (median age, 14 days) with functional SV and UPBF underwent PAB as their primary palliative procedure. Thirty-five neonates had concomitant aortic coarctation or interrupted aortic arch repair (44%). A Damus-Kaye-Stansel procedure was subsequently performed in 19 patients, and subaortic resection or ventricular septal defect or bulboventricular foramen enlargement was performed in five. Results: There were 4 operative deaths, and 15 late deaths. The actuarial overall survival is 84% at 1 year, 76% at 5 and 15 years. Follow-up is complete in all but six children at a mean interval of 4.9 ± 3.7 years (range, 2 months–15 years). Thirty-seven patients (49%; 37 of 76) have undergone the hemi-Fontan procedure (with three hospital deaths) and 40 patients (53%; 40 of 76; 12 children without previous hemi-Fontan) have undergone the completion Fontan procedure without mortality or Fontan takedown. Conclusion: In infants with single ventricle physiology with or without systemic outflow obstruction and unobstructed pulmonary blood flow, a strategy of pulmonary artery banding carries acceptable operative and mid-term mortality in a high-risk group of patients. Pulmonary artery banding does not compromise performance of subsequent Damus-Kaye-Stansel procedure or completion Fontan palliation.

Keywords: Pediatric; Congenital heart disease; Fontan; Univentricular heart

1. Introduction

Management of patients with functional single ventricle (SV) is influenced by the adequacy at any time of both systemic and pulmonary blood flow, and the effect of the combined volume load on ventricular function and presence of ventricular outflow obstruction [1-4]. One of the most important anatomic factors which impacts negatively on survival in patients with functional SV and unobstructed pulmonary blood flow (UPBF) is the presence or development of systemic ventricular outflow obstruction, or subaortic stenosis (SAS), which occurs when the aorta arises from the rudimentary outlet chamber. This includes patients with double inlet left ventricle (DILV) and discordant ventriculoarterial connection, those with tricuspid atresia and discordant ventriculoarterial connection, and those with mitral atresia and double outlet right ventricle and discordant ventriculoarterial connection.

Systemic ventricular outflow obstruction generally is caused by a restrictive ventricular septal defect (VSD), which is the only pathway for blood flow into the rudimentary subaortic outlet chamber. When the VSD is small at birth, aortic hypoplasia, frequently with coarctation and occasionally with interrupted aortic arch (IAA), may be present. Even when the VSD is non-restrictive at birth, it may significantly narrow over time, and subaortic obstruction then becomes apparent [5]. The tendency for systemic outflow obstruction to progress after some forms of palliation, most notably pulmonary artery banding, has been well recognized [3,4,6-8]. More recently, it has been clearly documented that a palliative strategy which increases afterload and reduces the ventricular filling volume of a SV heart is accompanied by geometric changes...
characterized by increased wall thickness and mass-to-volume ratio, and diminution in the size of the bulboventricular foramen or subaortic VSD, if present [9]. This can occur at any stage of palliation or following a Fontan operation. The purpose of this study was to analyze the impact of palliative management of patients with SV-UPBF using primary pulmonary artery banding (PAB) on subsequent intracardiac repair and univentricular palliation. We report our operative and mid-term results with a staged approach based on initial palliation with a PAB, and assessed the factors that influenced outcomes.

2. Materials and methods

We retrospectively reviewed the medical and surgical records of 80 consecutive patients with functional single ventricle associated with UPBF who underwent pulmonary artery banding at Riley Children’s Hospital, Indianapolis, IN, between January 1990 and May 2004. Patients with complete atrioventricular communication, VSD with/or without interrupted aortic arch, double outlet right ventricle and Taussig-Bing anomaly, d-transposition of the great arteries, and truncus arteriosus who underwent PAB were excluded. Nine patients with functional SV who underwent a modified Norwood procedure also were excluded; in these patients, obvious severe subaortic obstruction was present at birth, and Norwood palliation was the preferred management strategy.

The mean age at the time of first surgery (PAB ± concomitant procedure) was 38.2 ± 52 days (median, 14 days; range, 2 days–8 months). Forty-eight infants (48/80, 60%) were male and 32 were female (32/80, 40%). The specific anatomic lesions in this analysis with functional SV physiology are listed in Table 1. PAB was the initial palliation in all cases; no patient had undergone previous operation. Concomitant procedures that were performed at the time of PAB, such as ligation or division of a patent ductus arteriosus, coarctation repair, atrial septectomy, or interrupted aortic arch repair, and atrial septectomy, are summarized in Table 2. The operation. The purpose of this study was to analyze the impact of palliative management of patients with SV-UPBF using primary pulmonary artery banding (PAB) on subsequent intracardiac repair and univentricular palliation. We report our operative and mid-term results with a staged approach based on initial palliation with a PAB, and assessed the factors that influenced outcomes.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>%</td>
</tr>
<tr>
<td>Patien ductus arteriosus ligation or division</td>
<td>68</td>
</tr>
<tr>
<td>Aortic coarctation repair</td>
<td>32</td>
</tr>
<tr>
<td>Atrial septectomy</td>
<td>4</td>
</tr>
<tr>
<td>Interrupted aortic arch repair</td>
<td>3</td>
</tr>
<tr>
<td>Repair total anomalous pulmonary venous return</td>
<td>1</td>
</tr>
<tr>
<td>Systemic-to-pulmonary arterial shunt</td>
<td>1</td>
</tr>
<tr>
<td>Bulboventricular foramen enlargement</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1

<table>
<thead>
<tr>
<th>Anatomic lesion</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double inlet ventricle</td>
<td>39</td>
</tr>
<tr>
<td>Unbalanced common atroioventricular canal defect</td>
<td>16</td>
</tr>
<tr>
<td>Tricuspid atresia</td>
<td>11</td>
</tr>
<tr>
<td>Mitr al atresia</td>
<td>7</td>
</tr>
<tr>
<td>Heterotaxy syndrome</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 2

Surgical procedures performed concurrent with pulmonary artery banding in patients with functional single ventricle and unobstructed pulmonary blood flow

2.1. Operative procedures

Pulmonary artery banding was done through a left anterior thoracotomy in the 2nd or 3rd intercostal space in the majority of patients (82%). The inferior aspect of the left thymic lobe is mobilized and an incision is made in the pericardium anterior to the left phrenic nerve and pericardial stay sutures are placed on the margins in order to provide adequate exposure. The pulmonary artery band was tightened over a Hegar dilator (range 5-7 mm), and secured with a silk tie. Our protocol for band sizing has developed from clinical experience, and is principally based on patient weight: 2-3 kg ~5 mm band, 3-4 kg ~6 mm band. After initial band placement, we carefully assess hemodynamics and adjust the band accordingly. Generally, we aim for a distal pulmonary artery pressure that is approximately one-third to one-half systemic pressure, with systemic oxygen saturations greater than 80% on FiO2 1.0. Fine non-absorbable anchoring sutures were placed in the pulmonary artery adventitia to prevent migration of the band. Distal pulmonary artery pressure, systemic arterial pressure, and transcutaneous oxygen saturation were monitored during the procedure. At operation, adequacy of the PAB was defined by a decrease in systolic pulmonary artery pressure to less than half of systemic arterial pressure (optimally less than <30 mmHg) without producing either bradycardia or excessive arterial oxygen desaturation (SaO2 > 75-80%).

Postoperative assessment of the PAB was determined by clinical hemodynamic status and by echocardiographic findings. The PAB was defined as inadequate whenever there was persistence of refractory congestive cardiac failure (evaluated clinically), and/or ineffective protection of the pulmonary circulation (systolic pulmonary arterial pressure greater than 45 mmHg at follow-up).

In 35 of these 80 patients, a coarctation repair (17 subclavian flap, 12 direct anastomosis between ascending and descending aortic segments, 2 combination of subclavian flap with direct anastomosis, and 1 synthetic patch aortoplasty) or IAA repair (two direct anastomosis and one left carotid artery swing down) were performed at the time of PAB.

There were four surgical pathways to the endpoint of Fontan completion: (1) PAB followed by Fontan completion (n = 10, early in our series); (2) PAB followed by bidirectional shunt or hemi-Fontan procedure was performed as an interim palliative procedure.
Glenn or hemi-Fontan, followed by completion Fontan (n=25); (3) PAB followed by Damus-Kaye-Stansel (DKS) and systemic-to-pulmonary arterial shunt, followed by bidirectional Glenn, followed by completion Fontan (n=7); and (4) PAB followed by DKS and bidirectional Glenn or completion Fontan in the same procedure (n=13).

2.2. Statistical analysis

Measured and calculated data are expressed as mean±SD. Comparison between two groups was performed using Student’s t-test. The Kaplan-Meier product limit method and Cox proportional hazards regression methods were used for analysis of survival and freedom from subaortic stenosis. Multiple regression analysis was performed as conditional backward stepwise proportional hazards regression. In the analysis of risk factors for mortality, freedom from subaortic stenosis, variables with significance levels of 0.1 in univariate analysis were submitted to a multivariate logistic regression model. Early mortality was defined as death during initial hospitalization or within 30 days of operation. Any deaths later than that were defined as late mortality. A P-value of less than 0.05 was considered significant. Specific statistical software SPSS for Windows version 10 (SPSS, Inc., Chicago, IL) was used for data analysis.

3. Results

3.1. Mortality

The management and outcomes for 80 patients with a functional SV and unobstructed pulmonary blood flow are shown in Fig. 1. There were a total of 19 deaths (24%), with four early deaths occurring after initial PAB, seven late deaths occurring before undergoing definitive repair (mean 6.8 months after initial PAB), five occurring early after DKS with systemic-to-pulmonary arterial shunt, and three late deaths occurring after cavopulmonary shunts. Five risk factors for death were significant on univariate analysis: (1) presence of coarctation or interruption of the aorta (P=0.004), (2) presence of DKS procedure with systemic-to-pulmonary arterial shunt (P=0.001), (3) presence of systemic ventricular outflow obstruction (P=0.01), (4) presence of hypoplastic left ventricle (P=0.03), and (5) the performance of surgery prior to 1996 (P=0.04). Of these five factors, only the presence of coarctation or interruption of the aorta (P=0.004), presence of DKS procedure with systemic-to-pulmonary arterial shunt (P=0.001), and the presence of systemic ventricular outflow obstruction (P=0.001) remain significant by multivariate analysis.

Details of early and late deaths are shown in Table 3. Overall survival is 84% at 1 year, 76% at 5 and 15 years (Fig. 2). 3.2. Follow-up

The mean follow-up period for children with functional SV and UPBF was 4.9±3.7 years (range, 2 months–15 years). Seventy survivors of the initial PAB procedure (70 of 76; 92%) were available for follow-up. Six patients were lost to follow-up. Two patients had revision of the PAB either in the same hospital admission (n=1; 8 days after initial surgery) or in a subsequent admission (n=1; 10 months after initial surgery), because of loosening of PAB or formation of pulmonary artery pseudoaneurysm secondary to endocarditis. Three patients underwent reoperative coarctation repair (two with direct anastomosis and one with subclavian flap) with polytetrafluoroethylene (PTFE) patch enlargement (2 weeks, 4 and 5 months after initial surgery). One child required late heart transplantation and three patients required pacemaker implantation.

3.3. Subaortic stenosis

Twenty-five patients (31%) had systemic outflow obstruction recognized and treated surgically (27 procedures) at
a mean age of 1.3 years (range from 10 weeks to 5 years); one initial procedure (with PAB), one 6 days after PAB, and 25 operations for relief of systemic outflow obstruction ranged from 2 to 36 months (average 13.8 months). The diagnosis was established by echocardiography in all. Our general criteria for diagnosis of systemic outflow obstruction were a bulboventricular foramen (BVF) significantly smaller (less than half diameter) than the aortic valve annulus, a measurable gradient (peak instantaneous gradient >20 mmHg) from the dominant ventricle to aorta, or both. Eighteen patients (72%; 18 of 25) had associated aortic arch obstruction consisting of IAA (n=2) or coarctation plus hypoplastic transverse arch (n=16).

Relief of systemic outflow obstruction involved two techniques. If the pulmonary valve had no anatomic deformity, the DKS procedure was performed (n=20). The main pulmonary artery was divided at the previously banded site. Construction of the aortopulmonary anastomosis was performed in a ‘classic’ end-to-side fashion (n=9) with a sufficient length of pulmonary artery. VSD enlargement and SAS resection were performed concomitantly in two of these nine patients. In the remaining patients (n=11), the aorta was transected at a corresponding level above the sinuses of Valsalva and half of both facing great arteries was anastomosed in side-to-side fashion, and the distal aorta was sutured to the new bivalved artery without any prosthetic material (‘double-barrel’ anastomosis) [10]. When the pulmonary valve was deformed or the pulmonary trunk was too short, resection of subaortic muscle or enlargement of VSD or BVF was performed (n=5). DKS with systemic-to-pulmonary arterial shunt was performed in seven, DKS concomitantly with superior cavopulmonary anastomosis in nine, and concomitantly with completion Fontan procedure in four. Univariate and multivariate analysis showed coarctation or interruption of the aorta (P=0.001) and presence of DILV (P=0.002) as the best preoperative predictors of SAS obstruction in survivors. Cumulative freedom from systemic outflow obstruction (Kaplan-Meier) at 6 months, 2 and 5 years were 86, 73, and 66%, respectively (Fig. 3).

3.4. Fontan palliation

Thirty-seven patients (49%; 37 of 76) have undergone hemi-Fontan, bidirectional Glenn shunt, or Kawashima procedure and 40 patients (53%; 40/76; 12 children without previous hemi-Fontan) have undergone Fontan completion. The type of cavopulmonary anastomoses used was hemi-Fontan procedure (n=27), bidirectional or bilateral bidirectional Glenn shunt (n=7), or Kawashima procedure (n=3). The interval between PAB and cavopulmonary anastomosis ranged from 2 months to 3 years (average 14.3 months) and the age of children ranged from 4 months to 5 years (average 16.8 months). The type of Fontan connection used was atriopulmonary anastomosis (n=2), lateral caval tunnel (n=34), and extracardiac conduit (n=4). The interval between PAB or cavopulmonary anastomoses and completion Fontan ranged from 6 months to 5 years (average 2.6 years) and the age of children ranged from 2 to 7 years (average 3.6 years). Sixteen patients (21%, 16 of 76) had main (n=12) or right (n=4) pulmonary arterioplasty at the time of hemi-Fontan or completion Fontan. In those patients undergoing completion Fontan without prior cavopulmonary anastomosis (12/76, 16%), we felt comfortable that these patients had a protected pulmonary vascular bed and therefore we proceeded directly to completion Fontan. This occurred early in our series. We have not observed any difference in early or late outcome in this subgroup of patients. In recent years, we have favored staging the Fontan as patients have had a shorter and more benign postoperative course.

Early postoperative Fontan complications were uncommon and included pleural effusion (n=4), tachyarrhythmia (n=4), and complete heart block (n=3). Late complications developed in 10 patients (22%), including arrhythmia in four, ventricular failure or dysfunction in two, thromboembolic events in two, protein losing enteropathy in one, and hemiparesis secondary to right middle cerebral artery stroke in one.

Of the 80 study patients, 51 children (64%) underwent the hemi-Fontan and Fontan operation; six patients were awaiting the Fontan palliation.

4. Discussion

In recent years, there has been a trend to proceed with definitive intracardiac repair of congenital heart diseases in younger and smaller children. The usefulness of palliative PAB has been questioned, and its role has become increasingly limited. However, there is still an important place for PAB in infants with functional SV and UPBF [11]. In this group of patients, primary intracardiac repair may involve complex anatomy and long cardiopulmonary bypass times with associated morbidity and mortality (i.e. Norwood). For this subgroup of patients, we continue to favor performing initial palliation with a PAB, deferring definitive anatomical correction requiring cardiopulmonary bypass at an older age [12]. In our experience, PAB is protective of the pulmonary vascular bed, thus retaining optimal health of the pulmonary vascular bed for ultimate Fontan palliation. The relatively low incidence of significant acquired left ventricular outflow tract obstruction in our experience has continued to suggest that this is a reasonable approach.
Primary PAB has fallen out of favor since the report by Freedom [13] which demonstrated a high incidence of systemic outflow obstruction in patients with functional SV treated initially with band placement [3,4,14,15]. In support of this shift, others have documented adverse effects of increased ventricular mass after banding and its implications on ventricular diastolic function [15,16]. There are no large studies that adequately address the relative risk of acute systemic outflow obstruction after PAB placement compared with the risk of early surgical mortality from a DKS procedure and central systemic-to-pulmonary arterial shunt (our highest mortality group) [8]. Additional concerns after band placement are related to pulmonary artery distortion, and incomplete protection of pulmonary vascular bed. We recognize these limitations, especially after long-term band placement. The benefits of early PAB include the relative simplicity and low mortality rate of the procedure, particularly when additional interventions such as arch reconstruction or repair are required. PAB thus allows improved survival and does not preclude performance of more complex surgical interventions, such as the DKS procedure, at a later time when they may be better tolerated from a physiologic and technical standpoint. We believe and agree with some authors [8,10,17] that PAB carries lower risk than a primary DKS procedure during the neonatal period. Depending upon individual patient characteristics, if pulmonary vascular resistance has fallen to acceptable levels, pulmonary artery debanding can be followed by a DKS procedure while, at the same time, constructing a cavopulmonary shunt as a satisfactory source of pulmonary blood flow. Thus, PAB followed by the DKS-cavopulmonary shunt operation makes it possible to convert SV patients to presumably more stable physiology with a systemic venous source of pulmonary blood flow, and avoid SV-systemic arterial shunt physiology, in the first year of life. The DKS procedure reduces or eliminates afterload, and the cavopulmonary shunt provides adequate pulmonary blood flow from a systemic venous source, avoiding excessive volume load on the SV.

The BVF may be restrictive at birth, or may narrow insidiously over time. Matitiau et al. [18] examined the progression of obstruction of the BVF in 28 infants with double inlet left ventricle or tricuspid atresia with transposition of the great arteries, and found that the most important determinant of late BVF obstruction was its initial size. In that report, the mean initial BVF area index was significantly smaller in those patients with associated arch obstruction. Although the BVF appeared to grow, the growth did not parallel somatic growth and the BVF tended to become obstructed with time [17]. Others [19,20] have also proposed that if the ratio between the BVF and aortic valve areas is less than 1, the patient can be considered a candidate for potential development of subaortic stenosis. However, we have not been convinced that an objective strategy has been described that is uniformly and repeatedly applicable in every patient.

A variety of methods have been proposed to relieve systemic outflow obstruction including the arterial switch procedure [19,21], enlargement of the VSD or BVF [20], and placement of an apico-aortic conduit (AAC) [22]. There is limited experience in performing the arterial switch procedure for patients with this set of anomalies. The arterial switch is actually a complex modification of the simpler DKS approach. Enlargement of the VSD has been the most commonly utilized strategy employed by many groups. It has the advantages of a direct solution to the problem and a high rate of success. However, there is a higher risk of injury to the conduction system because of the variability of its position in these patients with complex anatomy [23]. Recurrent obstruction can also occur, particularly when a straddling atrioventricular valve apparatus is involved and limits the amount of muscle that can be safely resected. None of our patients with BVF enlargement required permanent pacemaker implantation. Apicoaortic conduits have the obvious disadvantage of requiring valved conduit replacement at intervals, need for long-term anticoagulation, or both. Before the 1990s, we had experience with apicoaortic conduits in four children with functional SV; one died early postoperatively; two died late (6 months and 1 year) due to arrhythmia and sepsis; and the last patient underwent enlargement of the BVF, takedown of the apicoaortic conduit, and Fontan procedure 5 years after initial apicoaortic conduit insertion and is still alive.

A modified Norwood procedure is another surgical alternative. The results for the modified Norwood procedure in this subpopulation of infants without hypoplastic left heart syndrome have improved over time, particularly in centers with high volume and experience [24,25]. Mosca et al. [24] reported an early mortality of 8% in a group of 38 patients with tricuspid atresia or DILV and atrioventricular discordance undergoing a modified Norwood operation. The majority of these infants had aortic arch anomalies. Our results using the modified Norwood procedure in this subgroup of patients (nine infants with 33% mortality (3/9), all of whom had aortic arch anomalies and systemic ventricular outflow obstruction) has led us to maintain our preference for primary PAB because it is less invasive, perioperative morbidity and mortality is lower, and growth of the pulmonary arteries after PAB appears to be better than after a systemic-to-pulmonary artery shunt.

The relationship between PAB and development or progression of preexisting systemic ventricular outflow obstruction appears to be significant [3,13]. Thus, some groups have advocated avoidance of primary PAB and have instead favored early intracardiac repair [3,26]. Whether this will lead to improved results remains to be seen in the long term. Presently, we manage infants without evidence of ventricular outflow obstruction or serious ventricular hypertrophy initially with a PAB. Anatomic placement of the band is critically important in these patients to prevent sequelae, which would render subsequent repair difficult. Distally placed bands facilitate the DKS procedure but may lead to pulmonary artery distortion, which must be repaired at the subsequent Fontan procedure. Proximally placed bands facilitate the Fontan procedure but may lead to pulmonary valve distortion and insufficiency, which is a contraindication to a DKS procedure. Hence, the band should be carefully positioned in the middle of the pulmonary artery, with any error toward a more distal band.
After PAB, these children should be followed closely for the development of systemic outflow obstruction. If evidence of increasing obstruction is identified, we carefully evaluate patients for suitability for cavopulmonary diversion. In children greater than 18 months of age, if no risk factors for the Fontan procedure are identified, a Fontan procedure may be performed. If risk factors are identified, or the patient is less than 18 months old, a DKS procedure and bidirectional Glenn shunt or systemic-to-pulmonary arterial shunt should be performed. We recognize the long-term risk of subaortic obstruction and its sequelae in infants with SV–UPBF, and recommend early debanding and conversion to the DKS and cavo pulmonary anastomosis before critical subaortic stenosis and ventricular hypertrophy occur. This is reflected in the relatively early age at operation in our patient population, particularly for those who underwent a bidirectional Glenn shunt/hemi-Fontan or completion Fontan repair at the time of the DKS procedure.

In summary, we have presented a complex group of 80 patients with SV–UPBF. Many presented with no or mild systemic outflow obstruction, which did not increase significantly after PAB. Some did increase their level of systemic outflow obstruction and underwent a DKS at the time of subsequent semi-Fontan or completion Fontan. Systemic outflow tract obstruction is known to increase in some patients with SV with or without a PAB. In our experience, PAB has been associated with low mortality (5%). Mid-term outcomes with the PAB approach have yielded comparable if not superior outcomes.

References


Appendix A. Conference discussion

Dr M. Wojtalik: I have two questions.

One, did you make banding according to the formula, or you just measured the pressures before and after banding?

Dr M. Wojtalik: Regarding your second question, we have not had any problems with severe pulmonary insufficiency after placement of the PA band, although, as stated in the manuscript, we feel that it’s fairly important to be
precise about anatomic placement of the PA band. This subject has been looked at in several previous papers, whether the PA band does, in fact, have a negative impact on subsequent DKS procedure, and we feel, in our experience, that it has not.

Regarding your first question, was the question related to whether we use a formula to assess risk for subaortic obstruction or subsequent subaortic stenosis?

Dr Wojtalik: Just to make the banding, it’s 20 mm plus body weight—the formula that is used to adjust the banding size.

Dr Rodefeld: For the PA banding, we don’t use, for example, the Trusler formula. Historically, at our institution, we’ve used a Hegar dilator to guide the initial band size and then subsequently adjust the band depending on the hemodynamics that are measured intraoperatively.

Dr C. Fassy (Shanghai, China): I noticed that you do the PA banding, the oldest age year is 8 months. What is the oldest age for functional ventricle and with the excessive pulmonary blood flow, what’s the oldest age to do the PA banding?

Dr Rodefeld: There were a few patients in our series that presented late, beyond 4 months of age, and we felt that due to high PA pressures and high PVR that these patients would be poor candidates for an initial cavopulmonary shunt procedure. Therefore we staged these patients with a PA band at that time and then brought them back at a later time for a Glenn or hemi-Fontan connection.

Dr V. Hrasha (Hamburg, Germany): Don’t you think that the pulmonary artery banding is basically contraindicated in the patient with underlying interruption of aortic arch or hypoplasia of aortic arch or very borderline BVF? Because you perform this procedure in this group of patients, don’t you think in these days it’s actually contraindication to proceed in this way?

Dr Rodefeld: I think your point is well taken. Our series is retrospective and includes an older era of patients who were treated with aggressive arch reconstruction or extended end-to-end repair or, in some cases, subclavian flap aortoplasty. We feel that if we have adequately addressed the arch obstruction we can successfully band these patients. But I do share your concern.

Dr A. Meskishvilli (Berlin, Germany): I would like to ask what are your criteria for subaortic obstruction from a surgical point of view? Do you use pressure gradient, ratio between aorta and the VSD, or color-Doppler?

Dr Rodefeld: There’s been controversy in the literature regarding that. We do not have specific criteria to grade subaortic obstruction. Some of it is subjectively based upon demonstration of any gradient across the VSD, which, in our institution, would constitute evidence of obstruction. But I don’t think there is a consensus in terms of how subaortic obstruction should be evaluated.