Effect of Accessory Pulmonary Blood Flow on Survival After the Bidirectional Glenn Procedure

Richard D. Mainwaring, MD; John J. Lamberti, MD; Karen Uzark, PhD; Robert L. Spicer, MD; Mark W. Cocalis, MD; John W. Moore, MD

Background—The bidirectional Glenn procedure (BDG) is used in the staged surgical management of patients with a functional single ventricle. Controversy exists regarding whether accessory pulmonary blood flow (APBF) should be left at the time of BDG to augment systemic saturation or be eliminated to reduce volume load of the ventricle. The present study was a retrospective review of patients undergoing BDG that was conducted to assess the influence of APBF on survival rates.

Methods and Results—From 1986 through 1998, 149 patients have undergone BDG at our institution. Ninety-three patients had elimination of all sources of APBF, whereas 56 patients had either a shunt or a patent right ventricular outflow tract intentionally left in place to augment the pulmonary blood flow provided by the BDG. The operative mortality rate was 2.2% without APBF and 5.4% with APBF. The late mortality rate was 4.4% without APBF and 15.1% with APBF. Actuarial analysis demonstrates a divergence of the Kaplan-Meier curves in favor of patients in whom APBF was eliminated (P<0.02). One hundred seven patients have subsequently undergone completion of their Fontan operation, so the actuarial analysis includes the operative risk of this second operation.

Conclusions—The results suggest that the elimination of APBF at the time of BDG may confer a long-term advantage for patients with a functional single ventricle. (Circulation. 1999;100[suppl II]:II-151–II-156.)

Key Words: blood flow ■ Fontan procedure ■ mortality ■ morbidity

The bidirectional Glenn procedure (BDG) is used as the first of 2 operations to achieve separation of the systemic and pulmonary circulations in patients with a functional single ventricle. This 2-staged approach to Fontan completion has resulted in a significant reduction in mortality rates during the past decade. The original premise for this approach was based on the elimination of ventricular volume work at an early age and the stepwise accommodation of ventricular geometry to the reduction in volume load. Other factors that have favorably influenced outcome include the earlier elimination of systemic–pulmonary artery shunts and the influence of interventional cardiology techniques. Improved results have made BDG an integral part of the management of single-ventricle patients.

A number of controversies remain regarding the BDG, including the timing of the procedure and the interval to Fontan completion. In addition, there exists a controversy regarding the use or elimination of accessory pulmonary blood flow (APBF). Advocates for the provision of APBF cite more “physiological” levels of oxygen saturation, inhibition of arteriovenous malformations, and the potential to decrease the development of pulmonary arterial collateral vessel development. It has also been proposed that APBF may stimulate pulmonary artery growth, resulting in patients being better candidates for the Fontan procedure. Conversely, advocates for the elimination of APBF emphasize the importance of eliminating volume loads to allow the remodeling of the ventricle that occurs after this procedure. The elimination of APBF results in a degree of hypoxemia that is usually well tolerated in infancy and permits adequate growth of the pulmonary arteries to allow completion of the Fontan procedure. However, as a consequence of these divergent opinions and observations, there remain a variety of algorithms that have evolved regarding the management of single-ventricle patients and the use of APBF at the time of BDG.

We previously reported our experience with the BDG and the influence of APBF. This report, in which we evaluated 92 patients through mid-1994, reported that the incidence of effusions and the likelihood of prolonged hospital stay were higher when APBF was used. Actuarial analysis did not reveal a statistical difference in survival rates for the 2 groups; however, there was a trend toward improved survival rates in the patients without APBF. The purpose of this update was to evaluate the effect of APBF on survival rates after BDG in a larger cohort of patients and with a longer duration of follow-up.

Methods

This study is a retrospective review of our experience with BDG in patients with a functional single ventricle. The medical records were reviewed.
reviewed, and 2 groups were formulated based on the presence or absence of APBF, which is defined as either a systemic–pulmonary artery shunt or a patent right ventricular outflow tract. Aortopulmonary collaterals are not included in this definition of APBF.

From 1986 through August 1998, 149 patients underwent BDG at Children’s Hospital–San Diego as part of the staged surgical management leading to Fontan completion. Excluded from this analysis were 4 patients (2 with and 2 without APBF) in whom surgery failed to achieve pulmonary blood flow to both lungs secondary to technical considerations. (Details for these 4 patients are given in our previous report.12) In addition, there were 8 patients who underwent BDG as part of a one and one-half ventricle approach. This cohort was also excluded from this study because they were not patients with a functional single ventricle in which Fontan completion was contemplated.

Figure 1 shows the number of BDGs performed annually and delineates those with and without APBF. Fifty-six of the 149 patients had inclusion of APBF. The median age of these patients at time of surgery was 10 months (range, 2.5 to 195 months), and the median weight was 7.1 kg (range, 3.9 to 37 kg). The median year of surgery was 1991. Ninety-three patients had no APBF at the time of BDG; the median age for these patients was 8 months (range, 2.2 to 46 months), and the median weight was 6.1 kg (range, 3.9 to 15.8 kg). The median year of surgery for patients without APBF was 1994. The diagnoses and ventricular morphology for the 2 groups are listed in Table 1.

TABLE 1. Diagnoses and Ventricular Morphology of Patients Undergoing BDG

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>With APBF, n (%)</th>
<th>Without APBF, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLHS</td>
<td>2 (4)</td>
<td>15 (16)</td>
</tr>
<tr>
<td>DORV</td>
<td>4 (7)</td>
<td>12 (13)</td>
</tr>
<tr>
<td>PA-IVS</td>
<td>6 (11)</td>
<td>8 (9)</td>
</tr>
<tr>
<td>DILV</td>
<td>5 (9)</td>
<td>11 (12)</td>
</tr>
<tr>
<td>Tricuspid atresia</td>
<td>14 (25)</td>
<td>15 (16)</td>
</tr>
<tr>
<td>Unbalanced AV canal</td>
<td>6 (11)</td>
<td>5 (5)</td>
</tr>
<tr>
<td>Other</td>
<td>19 (34)</td>
<td>27 (29)</td>
</tr>
<tr>
<td>Total</td>
<td>56 (100)</td>
<td>93 (100)</td>
</tr>
<tr>
<td>RV morphology</td>
<td>14 (25)</td>
<td>32 (34)</td>
</tr>
<tr>
<td>LV morphology</td>
<td>36 (64)</td>
<td>52 (56)</td>
</tr>
<tr>
<td>Indeterminate</td>
<td>6 (11)</td>
<td>9 (10)</td>
</tr>
<tr>
<td>Total</td>
<td>56 (100)</td>
<td>93 (100)</td>
</tr>
</tbody>
</table>

HLHS indicates hypoplastic left heart syndrome; DORV, double-outlet right ventricle; PA-IVS, pulmonary atresia–intact ventricular septum; DILV, double-inlet left ventricle; AV, antroventricular; RV, right ventricle; and LV, left ventricle.

Pleural effusions were defined as the need for chest tube drainage for >7 days. Prolonged hospitalization was defined as a length of stay of >14 days.

Results

There were 5 operative deaths, for an overall early mortality rate of 3.3%. Three of these early deaths occurred in patients with APBF (5.4%), and 2 occurred in patients without APBF (2.2%). One hundred forty-four patients underwent successful BDG; this total included 53 with APBF and 91 without APBF. The incidence of pleural effusions was 16% with APBF and 2% without APBF. The length of hospital stay for the 2 groups is shown in Figure 2; the median length of stay was 8 days for both groups. Prolonged hospital stay occurred in 13 patients (24%) with APBF and 7 patients (8%) without APBF (P<0.05); the causes for prolonged hospital stay are listed in Table 2.

Of the 144 patients who underwent successful BDG, 142 have been followed for an average duration of 70±12 months (Figure 3). There were 2 patients who were lost to follow-up (1 in 1990 and 1 in 1992); both were from the APBF group. These 2 patients have been dropped from the actuarial curve at the point of last contact.

There were 12 late deaths: 8 patients (15.1%) with APBF and 4 patients (4.4%) without APBF. Seven of these deaths occurred in the interim between BDG and the Fontan procedure. The remaining 5 deaths either occurred perioperatively at the time of Fontan completion or were late deaths after the Fontan procedure. The causes of early and late deaths are summarized in Table 3.

Actuarial analysis was performed for patients undergoing BDG with and without APBF. Figure 4 demonstrates the actuarial survival curves when the operative mortality rate of the procedure is included. A comparison of these 2 curves demonstrates a survival advantage in the patients in whom APBF was eliminated (P<0.02). Figure 5 demonstrates the actuarial survival curves when operative mortality is excluded, again demonstrating improved survival without APBF (P<0.04).

One hundred thirty-five patients in this series (149 minus 5 operative deaths, 7 interim deaths, and 2 lost to follow-up) were potentially eligible for Fontan completion. Of these patients, 25 (9 with and 16 without APBF) have had BDG relatively recently (average follow-up, 6±1 month) and, therefore, have not had their Fontan evaluation. Three patients (2 with and 1 without APBF) in this series were deemed unsuitable candidates for Fontan completion due to elevated pulmonary vascular resistance; these 3 patients remain alive in a palliated state. One hundred seven patients have undergone completion of their Fontan procedure; this includes 36 patients with APBF (77% of surviving cohort) and 71 patients without APBF (81% of survivors in this cohort). There were 3 early deaths after the Fontan procedure, which were attributed to low cardiac output in 2 patients and a cerebrovascular
accident in 1. There also were 2 late deaths after the Fontan procedure; both were related to progressive hypoxemia and pulmonary dysfunction. The probability of undergoing BDG and ultimately achieving Fontan success was 74% with APBF and 92% without APBF (P<0.01) (Figure 6).

Discussion

The purpose of this report was to evaluate the effect of APBF on survival after BDG. One hundred forty-nine BDGs were performed at our institution from 1986 to 1998. The early mortality rate was 5.4% with APBF and 2.2% without APBF, and the late mortality rate was 15.1% with and 4.4% without APBF. These data suggest that the elimination of APBF may confer a survival advantage in patients undergoing BDG.

The reasons for the divergence of the survival curves in this series remain uncertain. The BDG results in an immediate decrease in both preload and afterload, as well as favorable alterations in ventricular geometry. It has been hypothesized that these changes may have long-term beneficial effects on the preservation of myocardial performance.13,14 The inclu-

| TABLE 2. Causes for Prolonged Hospital Stay After BDG |
|-----------------|-------|
|                 | n    | %    |
| BDG with APBF   |      |      |
| Pleural effusion| 9    | 16   |
| Poor oxygenation | 1    | 2    |
| Low cardiac output | 1   | 2    |
| Sepsis          | 1    | 2    |
| Sick sinus syndrome | 1  | 2    |
| BDG without APBF| 93   |      |
| Pleural effusion| 2    | 2    |
| Poor oxygenation | 2    | 2    |
| Low cardiac output | 2   | 2    |
| Need for pacemaker insertion | 1  | 1    |

* P<0.05 compared to BDG+APBF

Figure 2. Length of hospital stay for patients undergoing BDG with and without APBF. Filled column represents number of patients who underwent BDG with APBF. Hatched column represents number of patients who underwent BDG as sole source of pulmonary blood flow.

Figure 3. Flow chart of 149 study patients.
sion of APBF will increase the volume work of the ventricle, thereby mollifying the beneficial effects seen in the absence of APBF. The inclusion of APBF may also have an adverse effect on pulmonary vasculature, because it represents a high-pressure source of pulmonary blood flow that may lead to alterations in pulmonary vascular resistance.7 The elimination of APBF may result in an improvement in both myocardial performance and pulmonary vascular resistance, which may confer advantages not only at the time of Fontan but also in the long term. In our series, the incorporation of APBF resulted in a combined early and late mortality rate that was significantly greater than that seen in patients without APBF. Some of the late deaths were cardiac related (eg, Fontan mortality), whereas others were clearly not related to cardiac issues (eg, tracheal complication). The disparity between the actuarial curves continues to widen during the first 2 years, suggesting that APBF may have adverse effects that manifest well after the perioperative time period.

The incidence of pleural effusions requiring chest tube drainage for >7 days was 8-fold higher in patients with

<table>
<thead>
<tr>
<th>Patient Diagnosis</th>
<th>Ventricular Morphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDG with APBF</td>
<td></td>
</tr>
<tr>
<td>Myocardial dysfunction</td>
<td>DILV</td>
</tr>
<tr>
<td>Myocardial dysfunction</td>
<td>TA</td>
</tr>
<tr>
<td>Failure to oxygenate</td>
<td>HLHS</td>
</tr>
<tr>
<td>BDG without APBF</td>
<td></td>
</tr>
<tr>
<td>Myocardial dysfunction</td>
<td>PA-IVS/sinusoids</td>
</tr>
<tr>
<td>Myocardial dysfunction</td>
<td>Complex single ventricle</td>
</tr>
<tr>
<td>Late deaths (12 of 144, 8.3%)</td>
<td></td>
</tr>
<tr>
<td>BDG with APBF (8 of 53, 15.1%)</td>
<td></td>
</tr>
<tr>
<td>Fontan procedure mortality</td>
<td>HLHS</td>
</tr>
<tr>
<td>Late death after Fontan</td>
<td>TA</td>
</tr>
<tr>
<td>Late death after Fontan</td>
<td>TA</td>
</tr>
<tr>
<td>Cerebrovascular accident after Fontan</td>
<td>Complex single ventricle</td>
</tr>
<tr>
<td>Progressive pulmonary dysfunction</td>
<td>DORV</td>
</tr>
<tr>
<td>Progressive pulmonary dysfunction</td>
<td>PA-IVS</td>
</tr>
<tr>
<td>Sudden death at home</td>
<td>HLHS</td>
</tr>
<tr>
<td>Tracheal complications after repair of tracheoesophageal fistula</td>
<td>TA</td>
</tr>
<tr>
<td>BDG without APBF (4 of 91, 4.4%)</td>
<td></td>
</tr>
<tr>
<td>Fontan procedure mortality</td>
<td>Unbalanced AV canal</td>
</tr>
<tr>
<td>Late death after Fontan</td>
<td>TA</td>
</tr>
<tr>
<td>Sudden death at home</td>
<td>DILV</td>
</tr>
<tr>
<td>Clotted prosthetic AV valve</td>
<td>Complex single ventricle</td>
</tr>
</tbody>
</table>

DILV indicates double-inlet left ventricle; TA, tricuspid atresia; HLHS, hypoplastic left heart syndrome; PA-IVS, pulmonary atresia–intact ventricular septum; DORV, double-outlet right ventricle; and AV, atrioventricular.

APBF resulted in a combined early and late mortality rate that was significantly greater than that seen in patients without APBF. Some of the late deaths were cardiac related (eg, Fontan mortality), whereas others were clearly not related to cardiac issues (eg, tracheal complication). The disparity between the actuarial curves continues to widen during the first 2 years, suggesting that APBF may have adverse effects that manifest well after the perioperative time period.

The incidence of pleural effusions requiring chest tube drainage for >7 days was 8-fold higher in patients with

Figure 4. Actuarial analysis of patients undergoing BDG with and without APBF. This analysis includes operative mortality rate at time of BDG.

Figure 5. Actuarial analysis of patients undergoing BDG with and without APBF when operative mortality rate is excluded.
APBF than in those without APBF, an observation that we and others have previously reported. Similar observations relating the incidence of effusions to the presence of significant aortopulmonary artery collateral vessels have been made in patients undergoing the Fontan procedure. The cause of effusions after BDG and Fontan procedures remains uncertain, but the incidence clearly increases in the presence of left-to-right shunts. In theory, APBF or aortopulmonary collaterals provide competitive flow to the lungs and may increase pressures in the systemic venous pathways. Also, these additional sources of pulmonary blood flow represent a “steal” from the systemic circulation and thus may contribute to the incidence of low cardiac output and the endocrinologic “steal” from the systemic circulation and thus may contribute to the incidence of low cardiac output and the endocrinologic changes that have been associated with pleural effusions. Because the presence of effusions is a principal determinant of length of stay for this operation, it is not surprising that patients with APBF had longer lengths of stay in the hospital.

Oxygen saturation levels are typically in the 80% range for most infants undergoing BDG without APBF. However, saturation levels may be considerably <80% in patients <4 months old or in children >4 or 5 years old. It remains unclear why pediatric patients at either end of the age spectrum have marked differences in their physiology compared with those in the middle of the spectrum. These observations suggest that APBF may be both beneficial and necessary at the age extremes. From an institutional standpoint, we have performed most of our BDGs when the children were 6 to 12 months old. We then proceeded with Fontan completion ∼1 year later. By establishing this pragmatic approach, we have largely avoided the extreme hypoxemia that may be seen in very young infants or in older children.

Advocates for the inclusion of APBF suggest that the increase in pulmonary blood flow will result in higher levels of oxygenation and thus obviate excessive hypoxemia. Any benefit of improved oxygenation must offset the increase in ventricular volume work attendant to this approach. An inherent difficulty of including APBF is the regulation of flow through that additional source, because excessive pulmonary blood flow may have all of the adverse effects noted above. Because the eventual goal in these patients is to separate their systemic and pulmonary circulations, it seems that success in achieving this would be a logical end point. The present series provides midterm follow-up of the BDG and suggests that survival is appreciably higher in patients in whom APBF is eliminated.

Pulmonary artery growth patterns have been a theoretical concern in terms of the interim between the BDG and completion of the Fontan procedure. It is not surprising that pulmonary artery growth is diminished after BDG, because the pulmonary-to-systemic flow ratio is appreciably <1. Pulmonary artery growth patterns are improved when APBF is included, and this has been presented as a plausible argument for APBF. Some reports have correlated pulmonary artery size with successful Fontan outcome, whereas others have found it not to be predictive of operative survival. If pulmonary artery size were universally accepted as an indicator of survival, then inclusion of APBF would be a way to achieve this end. In our experience, 97% of the patients who were evaluated for completion of their Fontan procedure subsequently underwent this operation with a <3% operative mortality rate. None of our patients have been turned down for Fontan completion due to pulmonary artery size criteria; therefore, our experience suggests that pulmonary artery growth is satisfactory for Fontan completion regardless of whether APBF is used.

The development of pulmonary arteriovenous malformations (AVMs) has been another theoretical concern after BDG. Pulmonary AVMs have been seen after a classic Glenn shunt and after the Kawashima operation. Both of these procedures exclude hepatic venous circulation to the lungs on the first pass, suggesting a “hepatic factor” in the cause of pulmonary AVMs. Advocates for APBF have suggested that the accessory source will allow sufficient hepatic venous blood to pass through the lungs to prevent pulmonary AVM formation. However, we have seen the development of pulmonary AVMs only in the setting of heterotaxy with interrupted venous connection (eg, polysplenia or left isomerism). There were 4 patients in our series with this anatomy, 2 of whom subsequently developed pulmonary AVMs. One of these 2 patients had APBF, indicating that a source of APBF may not protect from AVM formation. More importantly, none of our BDG patients with situs solitus have developed pulmonary AVMs detectable either clinically or with echocardiography and pulmonary angiography, which were routinely performed before Fontan completion. It is conceivable that the presence of small AVMs could have been overlooked in this evaluation, but none have surfaced during follow-up of the Fontan patients. Thus, we believe that pulmonary AVM formation is not an indication for inclusion of APBF.

One limitation of this study relates to the retrospective and nonrandomized design. This study format may always be subject to criticism insofar as there is the potential for a selection process or learning curve that could bias the results. The inclusion of APBF was our preferred surgical approach from 1986 to 1990, whereas from 1991 to 1998, we have usually, but not always, eliminated APBF. Since 1991, the use of APBF has related to referral source (eg, cardiologist preference) rather than to patient diagnosis or physiology. The 2 groups were similar with regard to age and weight at surgery, duration of follow-up, and percentage of patients who have completed their Fontan procedure. The groups were

![Figure 6. Probability of achieving Fontan survival based on presence or absence of APBF at time of BDG.](chart.png)
dissimilar in the year of surgery, because the group with APBF tended to be earlier in the series. There also was some dissimilarity with regard to diagnoses, because most of our experience with hypoplastic left heart accrued in the 1990s. As a consequence, the group without APBF had a disproportionate number of patients with hypoplastic left heart syndrome and a higher percentage of patients with right ventricular morphology. This dissimilarity potentially may have favored the group with APBF, because hypoplastic left heart syndrome and right ventricular morphology have been considered risk factors in some studies. All of the procedures (149 BDG and 107 Fontan) were performed by the 2 surgeons (R.D.M. and J.J.L.); we believe that the disparity between the actuarial curves is indicative of the effect of APBF on survival and not a function of the study design. The only way to prove this point would be to embark on a prospective, multi-institutional trial. This type of study not only could evaluate the influence of APBF on survival but also could assess some of the factors that may ultimately contribute to survivability, such as the effect of APBF on ventricular cavity size, pressure, and wall thickness and the influence of APBF on native aortopulmonary collateral vessel development.

In summary, the results of this study demonstrate a significant survival advantage when APBF is eliminated at the time of BDG. In addition, the probability of continuing to a successful Fontan procedure completion was higher in the patients without APBF. We postulate that this survival advantage may be based on improvement in pulmonary resistance and ventricular function. It is our belief that the elimination of APBF at the time of BDG will improve the long-term outlook after Fontan procedure completion.

References

Effect of Accessory Pulmonary Blood Flow on Survival After the Bidirectional Glenn Procedure
Richard D. Mainwaring, John J. Lamberti, Karen Uzark, Robert L. Spicer, Mark W. Cocalis and John W. Moore

_Circulation_. 1999;100:II-151-II-156
doi: 10.1161/01.CIR.100.suppl_2.II-151

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1999 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/100/suppl_2/II-151

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to _Circulation_ is online at:
http://circ.ahajournals.org/subscriptions/