Pneumatic pulsatile ventricular assist devices in children under 1 year of age

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Abstract

Objective: Although considerable progress has been made on ventricular assist devices (VAD) for adults, pneumatic pulsatile circulatory support in young infants is still limited. There is a need for long-term ventricular assist devices to bridge the failing myocardium of young children until recovery or transplantation. Miniaturized devices and innovative modalities need to be optimized. We report on our experience.

Methods: From 1/1992 to 6/2004, 18 infants (6 male/12 female) under 1 year of age were treated with the Berlin Heart Excor VAD. The infants were divided into two groups, depending on the year of treatment. Group A consists of eight infants resuscitated and supported with a pulsatile pneumatic ventricular assist device between 1992 and 1998 and group B consists of 10 infants treated between 1999 and 6/2004. With the pediatric-sized Berlin Heart we used miniaturized extracorporeal pneumatically driven blood pumps, the lowest stroke volume being 10 ml.

Results: In 18 children, age 3–345 (median 147) days, artificial replacement of heart function was applied for long-term support (1–64, median 10 days) as a life-saving measure in our hospital. Nine had LVAD and nine BVAD support. All were in cardiogenic shock with multiorgan failure; three had fulminant myocarditis, four cardiomyopathy, and one chronic stage of congenital heart disease. Five children were weaned from the system, three reached heart transplantation, and 10 died on the VAD. There were no differences between groups A and B regarding age, body weight or diagnosis, but the duration of mechanical support differed: Group A, median 2, range 1–16 days; group B, median 12, range 1–100 days. Since 1999 (group B), the survival rate of our small infants has increased to 70% whereas none of the infants in group A survived to be discharged.

Conclusions: The outcome of VAD support in small infants is no longer inferior to that of adult support, now optimized cannulas, modified anticoagulation and optimized surgical and intensive care management have been established.

Keywords: Ventricular assist device; Berlin Heart; Infants; Mechanical circulatory support

1. Introduction

Within the last few decades, mechanical circulatory support (MCS) with pulsatile assist devices has matured and is now being used more widely to alleviate the symptoms of acute cardiac failure or end-stage heart failure when conventional therapy fails [1–4]. Commonly this long-term support is, however, only available for adults or adolescents and not for newborns or young infants [5,6]. Congenital heart disease is the most frequent birth defect and many of the children affected have to be operated on within the first few days or months of life. When weaning from bypass in these small children fails, only non-pulsatile devices such as centrifugal pumps and ECMO have been used for very limited periods of time [7–10]. Especially in infants with cardiomyopathy or fulminant myocarditis, awaiting recovery or heart transplantation, these systems do not always offer enough time to save the child’s life. With the miniaturized Berlin Heart Excor (Berlin Heart slam, Berlin Heart AG, Berlin, Germany) we now have a ventricular assist device (VAD) that allows long-term MCS for newborn and children of all ages. In the 1990s, the results of Berlin Heart support in newborns and infants were not really satisfactory [2,11], but since 1999 the survival rates have shown great improvements. The aim of this study is to analyze the possible reasons for the improvement in mortality and morbidity rates of the infants with Berlin Heart support in their first year of life, with special regard to the indications for support, the anticoagulation and the surgical and intensive care management.
2. Patients

Between January 1992 and June 2004, 18 newborns and infants in their first year of life, 6 boys and 12 girls, underwent circulatory support with the Berlin Heart VAD in our hospital. The median age was 147 days, median body weight 5.3 kg and median supporting time 10 days (mean 15 days, range 1-64 days). At the time of VAD implantation, all were in life-threatening advanced heart failure unresponsive to further medical treatment and with critically compromised organ perfusion or they had undergone a cardiac operation and weaning from cardiopulmonary bypass had failed. In all cases, implantation of the device was performed in the operating room with cardiopulmonary bypass. All infants had inotropic support and were mechanically ventilated before implantation. The infants were divided into two groups, depending on the year of implantation. Group A consists of eight newborns and infants with Berlin Heart support between 1992 and 1998 and group B consists of 10 small infants supported between 1999 and June 2004.

2.1. The indications for mechanical support

In group A, all children underwent resuscitation and chest massage several times but by 1999 we had been able to define criteria to be fulfilled before VAD implantation and especially when impairment of renal or liver enzymes had developed. The indications for mechanical support were either unsuccessful weaning from CPB or very poor ventricle function in echocardiography combined with a cardiac index below 2, mixed venous saturation below 40%, oliguria, metabolic acidosis and poor peripheral perfusion despite combined treatment with diuretics, afterload reduction, catecholamines, phosphodiesterase inhibitors, bicarbonate, spironolacton and mechanical ventilation.

3. The Berlin Heart

For mechanical support, the biventricular assist device (Berlin Heart Excor®, Berlin Heart AG, Berlin, Germany) was used, which consists of two extracorporeal pneumatically driven polyurethane blood pumps with 10, 12, 15, 25 or 30 ml stroke volume, with a multi-layer flexible membrane that separates the blood and the air chamber. Silicone cannulas connect the blood pumps to the patient. A triple-leaflet valve prevents blood reflux. Nowadays all blood-contacting surfaces are heparin-coated (Carmeda®, Inc., Texas, USA), providing effective protection against thrombosis. The pumps are driven by a pulsatile electropneumatic system. The drive unit (IKUS 2000) has a triple operational control and pneumatic system; synchronous or asynchronous operating modes are available. The protocol of VAD support was approved by our institutional ethics committee and all parents gave written informed consent. Follow-up was complete up to June 2004.

4. Data analysis and statistics

For all quantitative data, medians and ranges have been calculated. For qualitative data frequencies are given. Differences between median values for different patient groups are evaluated using the Mann–Whitney U-test. Significance was assumed at \( P < 0.05 \). Calculations were performed with SPSS 10.2 (Chicago).

5. Results

There were no differences in diagnosis, gender, age or body weight between the two groups. However, as shown in Tables 1 and 2, there was a significant difference in the duration of support (median of 2 days in group A vs. 12 days in group B). In group A, only one infant (no. 5, Table 1, heart transplantation followed by early graft failure) survived the weaning procedure with high-dose adrenalin; he died within 36 h due to ventricular and multi-organ failure. No patient in group A was successfully discharged home. After multiple modifications of the treatment, the subsequent 10 infants (Group B), treated between 1999 and June 2004, had a survival rate until discharge of 70%. The total outcome is shown in Table 3. We compared the patients and courses between the two groups and found differences in (a) indication, (b) cannulation, (c) anticoagulation and (d) ICU management (Table 4).

5.1. Changes in indication for support

In group A, we were unsuccessful in the first three infants after cardiac surgery, in whom weaning from bypass had failed several times (Table 1, nos. 1-3). The Berlin Heart implantation was too late in these children with continuous bleeding problems and irreversible peripheral circulatory failure unresponsive to \( \alpha \)-stimulants. All three children died in multi-organ failure and/or SIRS within 48 h. As a consequence of earlier device implantation, in group B the mortality rate of this special group of post-CPB infants has been reduced: here 67% (4/6) of the post-CPB infants survived and were discharged home. Transesophageal echocardiography, when weaning from bypass is attempted, is a helpful tool to anticipate the chances for weaning and advance the decision in favor of or against mechanical support.

5.2. Changes in cannulation

In the earlier years (group A), the cannula for unloading of the left ventricle was located in the left atrium (or left ventricle with transmitsal approach), but the unloading was often insufficient. To solve this problem, miniaturized apical cannulas for small infants were constructed by the company and as a result 40% (4/10) of the children in group B were successfully weaned after recovery of the myocardium. Apical cannulation leads to better unloading, resulting in reduced wall stress and stretch and a better opportunity for the myocardium to recover. With the new cannulas we were also able to reduce the use of connectors between pump and...
cannula, resulting in reduced hemolysis and coagulation activation. If really necessary, there are new connectors made of titanium to ensure a seamless transition from pump to cannula. Another benefit is that, in the supporting systems used in infants of group B, all blood-contacting surfaces are heparin-coated (Carmeda, Inc., San Antonio, TX, USA), providing a degree of protection against thrombosis.

Another advantage of the better unloading of the left ventricle in group B is the less frequent need of an additional mechanical right heart support (62% BVAD in group A vs. 40% in group B). We have learned that good unloading of the left ventricle reduces the left ventricular enddiastolic pressure (LVEDP) and reduces the afterload of the right ventricle immediately by 15–25 mmHg.

In children with CMP or myocarditis, we now first implant a LVAD and in the next hour in the operating room we add strict pharmacological right heart treatment (with nitric oxide, iloprost, oxygen and a small amount of catecholamines) and often find that there is no longer a need for an additional mechanical right heart support. This lowers the risk for long-term complications. Our experience is that this medication is only necessary within the very first days of support.

5.3. Changes in anticoagulation

During the whole period of mechanical support, small infants have a central venous line and continuous heparin infusion. We have no experience with newborns and young infants administered warfarin while on an assist device, in contrast to the adults and older children. The measurements changed in the time interval between groups A and B. In the earlier years (group A), we measured the activated clotting time (ACT) every 2 h, the target range being 140–160 s. Too many different measurements led to too frequent changes of the heparin amount, and bleeding requiring rethoracotomy was more frequent than in the later group. In the infants of group B, we analyzed the activated partial thromboplastin time (aPTT) every 4–6 h in the first few days and after stabilization we changed to twice daily measurement, with a target range of 50–70 s. In both groups antithrombin III (heparin cofactor) was substituted below 70%. Further changes in group B are additional medication with dipyriramol and aspirin, starting after the first week of support.

### Table 1
Data, course and outcome in each patient

<table>
<thead>
<tr>
<th>No.</th>
<th>Age (days)</th>
<th>Sex</th>
<th>Implant (year)</th>
<th>Diagnosis</th>
<th>Weight (kg)</th>
<th>Length (cm)</th>
<th>Support (days)</th>
<th>LVAD/ BVAD</th>
<th>Vol. Li/Re</th>
<th>Outcome</th>
<th>Disch. home</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>14</td>
<td>M</td>
<td>1992</td>
<td>Post-CPB</td>
<td>3.7</td>
<td>50</td>
<td>1</td>
<td>LVAD</td>
<td>12/-</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>193</td>
<td>F</td>
<td>1992</td>
<td>Post-CPB</td>
<td>7.0</td>
<td>65</td>
<td>2</td>
<td>BVAD</td>
<td>12/12</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>13</td>
<td>F</td>
<td>1992</td>
<td>Post-CPB</td>
<td>3.2</td>
<td>49</td>
<td>1</td>
<td>LVAD</td>
<td>15/-</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>M</td>
<td>1993</td>
<td>Complex def</td>
<td>4.0</td>
<td>52</td>
<td>3</td>
<td>LVAD</td>
<td>12/-</td>
<td>Died</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>303</td>
<td>M</td>
<td>1993</td>
<td>Post-CPB</td>
<td>7.8</td>
<td>77</td>
<td>8</td>
<td>BVAD</td>
<td>12/12</td>
<td>Weaned</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3</td>
<td>F</td>
<td>1995</td>
<td>Myocarditis</td>
<td>2.2</td>
<td>43</td>
<td>2</td>
<td>BVAD</td>
<td>12/12</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>243</td>
<td>F</td>
<td>1995</td>
<td>Myocarditis</td>
<td>7.0</td>
<td>78</td>
<td>16</td>
<td>BVAD</td>
<td>30/25</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>172</td>
<td>F</td>
<td>1998</td>
<td></td>
<td>6.6</td>
<td>64</td>
<td>1</td>
<td>BVAD</td>
<td>30/25</td>
<td>Died</td>
</tr>
<tr>
<td>Group B</td>
<td>9</td>
<td>147</td>
<td>F</td>
<td>1999</td>
<td>Post-CPB</td>
<td>5.6</td>
<td>64</td>
<td>12</td>
<td>BVAD</td>
<td>10/10</td>
<td>HTx</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>267</td>
<td>F</td>
<td>2000</td>
<td>DCM</td>
<td>5.6</td>
<td>82</td>
<td>46</td>
<td>BVAD</td>
<td>10/10</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>345</td>
<td>F</td>
<td>2001</td>
<td>Myocarditis</td>
<td>9.5</td>
<td>76</td>
<td>10</td>
<td>LVAD</td>
<td>30/-</td>
<td>Weaned</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>187</td>
<td>M</td>
<td>2001</td>
<td>Post-CPB</td>
<td>5.3</td>
<td>63</td>
<td>1</td>
<td>BVAD</td>
<td>10/10</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>166</td>
<td>F</td>
<td>2002</td>
<td>Post-CPB</td>
<td>7.2</td>
<td>78</td>
<td>64</td>
<td>BVAD</td>
<td>25/25</td>
<td>Died</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>194</td>
<td>F</td>
<td>2002</td>
<td>DCM</td>
<td>5.8</td>
<td>60</td>
<td>30</td>
<td>LVAD</td>
<td>10/-</td>
<td>HTx</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>76</td>
<td>F</td>
<td>2002</td>
<td>DCM</td>
<td>4.8</td>
<td>55</td>
<td>52</td>
<td>LVAD</td>
<td>10/-</td>
<td>HTx</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>104</td>
<td>F</td>
<td>2003</td>
<td>Post-CPB</td>
<td>4.1</td>
<td>55</td>
<td>6</td>
<td>LVAD</td>
<td>10/-</td>
<td>Weaned</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>107</td>
<td>F</td>
<td>2004</td>
<td>Post-CPB</td>
<td>4.5</td>
<td>62</td>
<td>11</td>
<td>LVAD</td>
<td>10/-</td>
<td>Weaned</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>70</td>
<td>M</td>
<td>2004</td>
<td>LVAD</td>
<td>4.8</td>
<td>60</td>
<td>12</td>
<td>LVAD</td>
<td>10/-</td>
<td>Weaned</td>
</tr>
</tbody>
</table>

DCM, dilatative cardiomyopathy; ECMO, extracorporeal membrane oxygenation; F, female; HTx, heart transplantation; M, male; post-CPB, when weaning from cardiopulmonary bypass failed. Pts. 1-7 are also mentioned in the article by Hetzer R, et al. Ann Thorac Surg 1998 [2].

### Table 2
Median data for the two groups

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (range)</td>
<td>93 (3-303)</td>
<td>156 (70-345)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>5.3 (2.2-7.8)</td>
<td>5.4 (4.0-9.5)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>58 (43-78)</td>
<td>62 (55-82)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Support time (days)</td>
<td>2 (1-16)</td>
<td>12 (1-64)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### Table 3
Outcome in the two groups

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Death on VAD</td>
<td>7</td>
<td>3</td>
<td>0.04</td>
</tr>
<tr>
<td>Weaning</td>
<td>1</td>
<td>4</td>
<td>ns</td>
</tr>
<tr>
<td>Heart transplantation</td>
<td>0</td>
<td>3</td>
<td>ns</td>
</tr>
<tr>
<td>Discharge home</td>
<td>0%</td>
<td>70%</td>
<td>0.004</td>
</tr>
</tbody>
</table>
and the regular measurement of thrombelastograms and platelet function tests to modify the target values and the dose of the anticoagulatory drugs.

5.4. Changes in ICU management

- **Antibiotics.** Within the first week after initiation of support, all children had antibiotic prophylaxis with second generation cephalosporine. Vancomycin was added in infants with an open sternum. Since the introduction of the new silicon cannulas with a Dacron covering as a biological barrier against ascending infections, we have not seen any cases of mediastinitis in our infants, although we changed from a continuous prophylactic antibiotic regime to a more individual and critical application of antibiotics in group B.

- **Mobilization.** The first condition for successful mobilization is a surgically closed sternum to stabilize the thorax. In group A, the sternum was closed in only one infant but in group B chest closure was successful in 90%.

- **Ventilation.** In group A, no infant was extubated while on support whereas most group B infants were breathing spontaneously after the first week on VAD.

- **Afterload reduction.** Another goal promising improvement of the outcome is a difference in pharmacological support under ongoing mechanical support. In most infants in group B, we reduced the afterload with milrinone or ACE inhibitors and gave β-blockers additionally in two children. This regime ensures good protection of the myocardium and potential recovery of the myocytes, especially in infants with acute myocarditis or ALCAPA syndrome.

Additional remarks concerning the patients in Table 1 are as follows:

**Group A**

**Patient no. 1** was born with pulmonary atresia and hypoplastic right heart syndrome and large sinusoids. After surgery (modified Blalock-Taussig shunt), weaning from bypass failed due to enlarged myocardial infarction and MCS as bridge to transplantation seemed to be the only chance for survival.

**Patient no. 2** suffered myocardial failure after closure of a large VSD. Mechanical support was terminated due to brain death.

**In patient no. 3** (hypoplastic left heart) weaning from bypass failed after Norwood I surgery. Despite a pump output of more than 400 ml/kg BW per min (15 ml stroke volume×100 beats/min and 3.2 kg body weight), there was severe arterial hypotension requiring large doses of epinephrine, norepinephrine and vasopressin as a result of lost systemic vascular resistance. Finally, mechanical support was stopped because of cerebral bleeding.

**Patient no. 4** suffered from pulmonary atresia with intact ventricular septum and sinusoids and showed biventricular failure after spontaneous myocardial infarctions, which required MCS as bridge to transplantation.

In **patient no. 5** the indication for MCS was early graft failure after heart transplantation. The child was weaned after 8 days on Berlin Heart but died within 48 h due to ventricular and multi-organ failure.

**Group B**

**In patient no. 9,** most of the left ventricle was destroyed by a huge LV fibroma (3×5 cm). After reduction of the tumor, device implantation followed with weaning from bypass having failed once. Transeosophageal echocardiography was very helpful in reaching an early decision.

In **patient no. 11,** there was prolonged cardiac arrest with prolonged resuscitation during transportation to our hospital. The girl, with fulminant myocarditis, recovered from multi-organ failure while on MCS but showed signs of mental retardation and spasticity. At follow-up myocardial function was completely recovered and there was no need of further medication.

**Patient no. 12** suffered from interrupted aortic arch, aortic stenosis and a rupture of the coronary artery as a complication during heart catheterization. The child was brought into the operating room under chest massage and after biventricular corrective surgery severe myocardial failure ended in mechanical support with BVAD.

**Patient no. 13** had a double outlet right ventricle, transposition of the great arteries and an interrupted aortic arch. After Rastelli surgery, weaning from bypass was not possible.

**Patient no. 14** is shown in Fig. 1.

**Patient no. 15** had a mild cerebral infarction, most likely as a result of a thromboembolic event with mild symptoms in the form of paresis of the right arm. These symptoms disappeared entirely before discharge home.

In **patient no. 16,** weaning from bypass failed after corrective surgery, due to infarction. The child was transferred under ongoing ECMO (day 5), switched to Berlin Heart and successfully weaned but required heart transplantation 2 months later. Transient palsy of the right hand resolved within some weeks.

**Patient nos. 17 and 18** first appeared to have DCM but echocardiography revealed the underlying disease to be ALCAPA syndrome. After reinsertion of the left coronary artery, weaning from bypass failed and LV recovery allowed device explantation after 11/12 days. In a follow-up of 6 months after surgery in both patients, left ventricular
function and dimensions are normalized and the LV apical cannulation site shows no aneurysm or other defect.

Patient nos. 9, 14, 15, 17 and 18 were without any complications for the whole time on Berlin Heart. Neurological follow-up shows completely normal mental and motor development.

6. Discussion

VAD implantation is quite common in adults but so far rare in newborns and small infants. Due to a lack of appropriate pneumatically driven pulsatile assist devices of suitable size in many countries, experience with small infants is still very limited and mostly restricted to case reports or small series from Europe [3,12,13]. Adult-size paracorporeal devices, predominantly the Thoratec® VAD, are being implanted into intermediate size children, despite the often obvious discrepancy size, for lack of better fitting pumps. Despite generally good results in children with cardiomyopathy or myocarditis, this appears to be associated with an increased risk of thromboembolic complications [14]. Reinhartz et al. reported on 19 children with a mean body weight of 31 kg and an overall survival rate of 47% with the Thoratec System (Thoratec Corp., Pleasanton, CA). They assume that the application of ‘oversized’ devices in children can lead to specific complications such as thromboembolism due to stasis in the device or technical problems with adult-size cannulas not fitting well into the child’s vessels, or systemic hypertension due to large stroke volumes [14].

The Berlin Heart, with different weight-adapted miniaturized pumps and the lowest stroke volume of 10 ml, was designed to solve these problems. However, in the early years we found that, although the results in adolescents and school age children were quite good, those in newborns and small infants were less than satisfactory. This has changed tremendously within the past few years, with the survival rate in infants reaching 70% within their first year of life. In this paper, we analyze the multiple differences in indication, underlying disease, technique, anticoagulation and ICU management in newborns and infants with Berlin Heart support in order to define the possible reasons for improvement. One of the reasons is the change from atrial to apical cannulation, which has been described as reducing the risk of neurological complications by better unloading of the ventricle [5]. This was successfully performed in our older children [2,4], but in the newborns we had to wait for the production of a specialized smooth miniaturized apex cannula (Berlin Heart AG, Berlin, Germany), which was first developed at the end of the 1990s. Now we can confirm that this innovation plays an important role in the improved survival results.

Another reason for the dismal outcome in the early group was the anticoagulation regimen. Compared to ECMO, use of the Berlin Heart in children results in less blood loss and lower consumption of red blood cells, platelets and fresh frozen plasma [15]. A survey by Graves et al. [16] of 81 ECMO centers in the USA showed that all centers use heparin for anticoagulation. Four out of five centers use the ACT for anticoagulation monitoring. In our institution, we used unfractionated heparin for anticoagulation and ACT and aPTT for the dose adjustment. ACT has the advantage of bedside monitoring with a portable device whereas aPTT is determined by the hospital laboratory, resulting in a significant time delay before dose adjustment can be made. Although the ACT is used for situations requiring high doses of heparin, such as cardiopulmonary bypass surgery, we agree with De Waele et al. [17] who found that the correlation between aPTT and ACT is poor in the ICU setting. Use of the ACT for monitoring low to moderate doses of heparin in VAD children in the ICU cannot be recommended because this method cannot differentiate exactly between low and therapeutic levels of anticoagulation, with the consequence that the heparin dose is often too high. Thus, in the past few years, in the infants in group B, we have considered the aPTT to be the gold standard for anticoagulation monitoring in the ICU. After a more sophisticated anticoagulation regimen showed a reduction of hemorrhagic complications during mechanically assisted circulation in adult patients [18], we also adopted a multi-system anticoagulation protocol. Our later group profited by specific regular testing was carried out at least twice a week for platelet functions and for thrombin formation and its regulatory pathways. As a result we reduced the amount of heparin but combined it with antithrombin III and additional aspirin and dipyridamol. We realized that every small infection enhances the clotting potential and this should be anticipated early by dose adjustment.

Nowadays, with the system proving to be technically safe and reliable, earlier Berlin Heart implantation can be justified. It can be used with low device-related morbidity and satisfactory results, especially in the myocarditis and the cardiomyopathy groups. Of particular importance is our experience with myocardial recovery in infants with acute myocarditis or ALCAPA syndrome in whom the devices could be explanted. Ventricular function has remained good in most of these cases over long-term follow-up.
Bank et al. [19] reported that adult heart transplant patients treated with an LVAD as opposed to inotrope administration had improved clinical and metabolic function at the time of transplantation and showed improved survival to 6 months after transplantation without major complications. Our results in children are very similar. As reported previously [4], children receiving mechanical support before heart transplantation can expect to have an equally good outcome after transplantation as children with previous inotropic or ventilatory support.

Infants with lethal cardiac disease often die before transplantation because of the shortage of small donor hearts. In contrast to adult heart transplantation, many pediatric donor hearts remain unused because there are no recipients of appropriate size with compatible blood types on the day of offer. With long-term Berlin Heart support, the hospital mortality rate of children on the waiting list may be reduced and exploitation of the pediatric-sized donor organs optimized.

Experience with pulsatile circulatory support in infants and children is increasing and clinical results are improving. Due to the progress made in this field, VAD support in infants no longer shows inferior results to adult support. However, the number of patients and centers performing pediatric VAD support are still very small. Within the past 5 years, the miniaturized Berlin Heart Excor has matured into a reliable support with paracorporeal pneumatic ventricular assist device (VAD) in infants and children. Eur J Cardiothorac Surg 1999;5:330–3.

In conclusion, pulsatile support of the failing heart in small infants can be performed with morbidity and mortality rates similar to or even lower than those in older children or in adults. The introduction of the specially designed miniaturized Berlin Heart pulsatile pump, combined with improvements in indication, anticoagulation and ICU management, has improved the outcome, especially for young infants with cardiomyopathy or myocarditis.

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References


