Experiences with closed chest, temporary atrio-arterial, ventricular bypass with a centrifugal pump after open heart surgery

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Abstract. Twelve patients with refractory myocardial failure following open heart surgery were treated with a temporary left (L), right (R) or biventricular (B) assist circuits driven by extracorporeal pumps. Ten of 11 patients were weaned from the pump oxygenator. During left ventricular assist, maximal pump flow was $2.2 \pm 0.6 \, \text{l/min per m}^2$ at a cardiac index of $2.5 \pm 0.9 \, \text{l/min per m}^2$. Diuresis was above 1 ml/kg body weight per h in 7 of 9 patients perfused for 13–36 h. Seven patients were weaned from the assist pump after 13–33 h of ventricular bypass with 4 hospital survivors. Two patients died after circulatory assistance of multiple organ failure, 1 from cerebral damage. In the other patients, the main problems were cardiac. Three patients are currently long term survivors 12–17 months after surgery. [Eur J Cardio-thorac Surg (1989) 3: 44–51]

Key words: Assisted circulation – Low cardiac output – Cardiopulmonary bypass – Heart-assist devices

In spite of improvement in the selection of patients, anaesthetic care, myocardial preservation and surgical technique, intraoperative cardiac failure remains an important cause of death after open heart surgery. In spite of pharmacotherapy and the institution of intra-aortic balloon pumping, intraoperative deaths may occur unless more efficient circulatory assistance is given. Clinical use of a left-atrial to aortic bypass was described by Spencer et al. [31]. However, only limited experience with roller pumps has been published [15, 16, 26]. Recently, this method has been simplified by the more widespread use of centrifugal pumps [2, 3, 9, 10, 12, 14, 21, 22, 25, 28]. The purpose of this presentation is to describe our experience with ventricular bypass after open heart surgery with a centrifugal pump and equipment available in every operating room for open heart surgery.

Patient material

From August 1985 to July 1987, 12 adult patients with intractable, perioperative myocardial failure were treated with left (L), right (R) or biventricular (B) bypass with an extracorporeal centrifugal pump. All patients, 8 males and 4 females with a median age of 58 years (range 41–70), had undergone open heart surgery for acquired heart lesions. The clinical data are shown in Table 1. Heart size, preoperative haemodynamic data, details of the procedure, perfusion and ischaemic time are given in Table 2. Except for 1 patient undergoing heart transplantation, all patients had a myocardial revascularization procedure with additional valve surgery in 3 patients. Myocardial preservation included whole body hypothermia (28°C), crystalloid cardioplegia and topical cooling.

In 10 cases, cardiopulmonary bypass could not be discontinued following surgery in spite of conventional treatment with cardio- and vasoactive drugs, as well as intra-aortic (9) or intra-pulmonary balloon pumping (IABP) (1). In 1 patient, myocardial failure progressed after termination of extracorporeal circulation in spite of IABP. In 1 patient, circulatory arrest occurred in the postoperative ward, where extracorporeal circulation and intra-aortic balloon pumping were inserted during resuscitation.

Methods

Haemodynamic evaluation before atrio-arterial bypass. Adequate monitoring of pressures from the left and right sides of the heart was performed. Cardiac output was determined and derived parameters i.e. cardiac index, pulmonary and systemic vascular
Table 1. Clinical diagnosis and operations performed in 12 patients treated with temporary atrio-arterial ventricular bypass after open heart surgery

<table>
<thead>
<tr>
<th>Case</th>
<th>Age</th>
<th>Sex</th>
<th>Cardiac diagnosis</th>
<th>Complicating disease</th>
<th>Previous infarction(s)</th>
<th>NYHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51</td>
<td>m</td>
<td>Coronary artery disease</td>
<td>Cardiac graft failure</td>
<td>× 4</td>
<td>IV*</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>m</td>
<td>Valvular lesions, Coronary artery aneurysm</td>
<td>Endocarditis</td>
<td>–</td>
<td>IV</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>f</td>
<td>Coronary artery disease</td>
<td>Hypothyroidism</td>
<td>–</td>
<td>IV</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
<td>f</td>
<td>Coronary artery disease, Mild mitral regurgitation</td>
<td>–</td>
<td>–</td>
<td>III</td>
</tr>
<tr>
<td>5</td>
<td>70</td>
<td>f</td>
<td>Aortic stenosis, Coronary artery disease</td>
<td>Hypothyroidism</td>
<td>–</td>
<td>IV</td>
</tr>
<tr>
<td>6</td>
<td>58</td>
<td>m</td>
<td>Coronary artery disease, Mild mitral regurgitation</td>
<td>–</td>
<td>× 3</td>
<td>IV</td>
</tr>
<tr>
<td>7</td>
<td>58</td>
<td>m</td>
<td>Coronary artery disease, Mild aortic regurgitation</td>
<td>–</td>
<td>–</td>
<td>III</td>
</tr>
<tr>
<td>8</td>
<td>66</td>
<td>f</td>
<td>Coronary artery disease, Mitral stenosis</td>
<td>Pulmonary artery hypertension</td>
<td>–</td>
<td>IV</td>
</tr>
<tr>
<td>9</td>
<td>42</td>
<td>m</td>
<td>Coronary artery disease</td>
<td>–</td>
<td>× 2</td>
<td>III</td>
</tr>
<tr>
<td>10</td>
<td>48</td>
<td>m</td>
<td>Coronary artery disease</td>
<td>–</td>
<td>–</td>
<td>IV*</td>
</tr>
<tr>
<td>11</td>
<td>59</td>
<td>m</td>
<td>Coronary artery disease</td>
<td>Peripheral vascular disease</td>
<td>–</td>
<td>III</td>
</tr>
<tr>
<td>12</td>
<td>66</td>
<td>m</td>
<td>Coronary artery disease</td>
<td>Peripheral vascular disease</td>
<td>× 2 (acute)</td>
<td>IV*</td>
</tr>
</tbody>
</table>

f = female sex; m = male sex; NYHA = Functional classification of the New York Heart Association, * emergency operation

Table 2. Preoperative characteristics and haemodynamic data in 12 patients supported with atrio-arterial ventricular bypass following open heart surgery

<table>
<thead>
<tr>
<th>Case</th>
<th>Heart size (ml/min)</th>
<th>LV EF (%)</th>
<th>LV EDP (mm Hg)</th>
<th>PAP (mm Hg)</th>
<th>PAWP (mm Hg)</th>
<th>CI (l/m²/min)</th>
<th>Operation performed</th>
<th>Ischaemic time (min)</th>
<th>Perfusion time (min)</th>
<th>Counterpulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>630</td>
<td>40</td>
<td>40</td>
<td>55</td>
<td>33</td>
<td>1.5</td>
<td>Heart transplant</td>
<td>54</td>
<td>335</td>
<td>IPBP</td>
</tr>
<tr>
<td>2</td>
<td>450</td>
<td>58</td>
<td>20</td>
<td>–</td>
<td>–</td>
<td>(38)</td>
<td>Mitral repair</td>
<td>94</td>
<td>322</td>
<td>IABP</td>
</tr>
<tr>
<td>3</td>
<td>320</td>
<td>80</td>
<td>10</td>
<td>–</td>
<td>10</td>
<td>(2.2)</td>
<td>Exclusion of coronary aneurysm + ACB</td>
<td>95</td>
<td>305</td>
<td>IABP</td>
</tr>
<tr>
<td>4</td>
<td>525</td>
<td>81</td>
<td>28</td>
<td>18</td>
<td>12</td>
<td>1.5</td>
<td>ACB x 3</td>
<td>39</td>
<td>246</td>
<td>IABP</td>
</tr>
<tr>
<td>5</td>
<td>760</td>
<td>18</td>
<td>8</td>
<td>19</td>
<td>10</td>
<td>1.5</td>
<td>ACB x 2</td>
<td>32</td>
<td>292</td>
<td>IABP</td>
</tr>
<tr>
<td>6</td>
<td>430</td>
<td>70</td>
<td>24</td>
<td>21</td>
<td>14</td>
<td>1.5</td>
<td>ACB x 4</td>
<td>40</td>
<td>168</td>
<td>IABP</td>
</tr>
<tr>
<td>7</td>
<td>960</td>
<td>96</td>
<td>12</td>
<td>50</td>
<td>28</td>
<td>1.5</td>
<td>Mitral valve replacement ACB x 1</td>
<td>92</td>
<td>259</td>
<td>IABP</td>
</tr>
<tr>
<td>8</td>
<td>280</td>
<td>74</td>
<td>11</td>
<td>–</td>
<td>–</td>
<td>(38)</td>
<td>ACB x 3</td>
<td>35</td>
<td>175</td>
<td>IABP</td>
</tr>
<tr>
<td>9</td>
<td>410</td>
<td>87</td>
<td>10</td>
<td>–</td>
<td>–</td>
<td>(2.2)</td>
<td>ACB x 4</td>
<td>56</td>
<td>101 + 174</td>
<td>IABP</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>26</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>(38)</td>
<td>ACB x 3, IMA</td>
<td>61</td>
<td>262</td>
<td>IABP</td>
</tr>
<tr>
<td>11</td>
<td>60</td>
<td>26</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>(38)</td>
<td>ACB x 4</td>
<td>66</td>
<td>142</td>
<td>IABP</td>
</tr>
</tbody>
</table>

Results are mean ± standard deviation
ACB = aorto-coronary venous bypass; CI = cardiac index; IABP = intraaortic balloon pumping; IMA = coronary artery bypass with internal mammary artery; IPBP = intrapulmonary balloon pumping; LV EDP = left ventricular end-diastolic pressure; LV EF = left ventricular ejection fraction; PAP = mean pulmonary artery pressure; PAWP = pulmonary artery wedge pressure
resistances were calculated. Following evaluation of the pre- and intraoperative haemodynamic data, a decision was made to bypass the failing ventricle if the surgical repair and other supportive treatment was satisfactory. In general, criteria set by Litwak [15], Pennington [23] and Pierce [24] were followed.

**Surgical technique**

A 12 mm vascular graft of preclotted, woven Dacron was sutured end-to-side to the artery of the ventricle to be bypassed, most commonly the ascending aorta. The atrial cannula was inserted through the atrial appendage of the corresponding atrium (or right superior pulmonary vein). A 32 FG or 36 FG right-angle cannula (Polystan) was secured with a double purse string suture (Fig. 1). After filling with blood and removing air, both cannulae were brought out through the chest wall below the costal margins. Using standard connectors, the cannulae and graft were connected to the fluid-filled polyvinylchloride tubing and the Biopump. Flow through the heart-lung machine was then gradually reduced until standstill, while bypass flow through the assist circuit was gradually increased until the maximum was obtained. The chest was closed while bypass was maintained. If dilatation of the heart and the presence of the cannulae induced compression of the coronary artery grafts or the heart, sternal closure was postponed and the sternum splinted open (Fig. 2).

**Coagulation and anticoagulation.** The effect of heparin was slowly neutralized with protamine chloride and the activated clotting time (ACT) was aimed at 130–150 s. Treatment with appropriate blood components was used as indicated. When bleeding had subsided (blood loss < 1 ml/kg/h) or when bypass flow was less than 1 l/min, the ACT was raised to 170–180 s by intravenous heparin every hour.

**Monitoring and drug treatment on atrio-arterial bypass.** Intra-aortic balloon pumping was maintained. Treatment with inotropic and vasoactive drugs was continued in moderate doses. ECG and blood pressures were monitored continuously and complete haemodynamic studies performed hourly or as indicated. A cardiac index (pump flow + ventricular output) of 2.2–2.5 l/min per m² was considered optimal with normal systemic and pulmonary vascular resistance indices. Atrial pressures were kept between 3 and 8 mmHg to avoid insufflation of air into the circuit. After improvement in cardiac performance, reduction of bypass flow was gradually attempted. When bypass flow was less than 15% of adequate cardiac output, the assist was discontinued.

**Postperfusion care.** The arterial grafts were clamped close to the suture line, cut and sutured closed. The atrial cannulae were removed and the purse strings tied. Heparin activity was neutralized completely.

After copious irrigation, the chest wounds were closed if feasible. If cardiac enlargement persisted, sternal closure was postponed until a later date.
Table 3. Data on atrio-arterial ventricular bypass

<table>
<thead>
<tr>
<th>Case</th>
<th>Type of assist</th>
<th>Pump type</th>
<th>Duration of assist (h)</th>
<th>Drugs on VAD</th>
<th>Revision for bleeding</th>
<th>Max CI (l/m²/min)</th>
<th>Max flow VAD (l/min)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RVA</td>
<td>Roller</td>
<td>24</td>
<td>Adr. Iso. NP, PGE, NA</td>
<td>x2</td>
<td>4.2</td>
<td></td>
<td>Weaned</td>
</tr>
<tr>
<td>2</td>
<td>LVA</td>
<td>Centrifugal</td>
<td>&lt; 1</td>
<td>Adr. Dopa</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Technically unsuccessful</td>
</tr>
<tr>
<td>3</td>
<td>LVA</td>
<td>Centrifugal</td>
<td>19</td>
<td>Adr. Dopa. NP, Xylo.</td>
<td>x1</td>
<td>2.2</td>
<td>2.0</td>
<td>Weaned</td>
</tr>
<tr>
<td>4</td>
<td>LVA</td>
<td>Centrifugal</td>
<td>33</td>
<td>Adr. Dopa. NG, Xylo. NP</td>
<td>x2</td>
<td>4.4</td>
<td>4.4</td>
<td>Weaned</td>
</tr>
<tr>
<td>5</td>
<td>LVA</td>
<td>Centrifugal</td>
<td>36</td>
<td>Adr. Dopa. NP. NG</td>
<td>-</td>
<td>2.4</td>
<td>4.2</td>
<td>Died</td>
</tr>
<tr>
<td>6</td>
<td>LVA</td>
<td>Centrifugal</td>
<td>&lt; 2</td>
<td>Adr. NG</td>
<td>-</td>
<td>1.7</td>
<td>2.9</td>
<td>Cardiac arrest</td>
</tr>
<tr>
<td>7</td>
<td>LVA</td>
<td>Centrifugal</td>
<td>23</td>
<td>NP</td>
<td>x2</td>
<td>3.7</td>
<td>4.3</td>
<td>Weaned</td>
</tr>
<tr>
<td>8</td>
<td>LVA</td>
<td>Centrifugal</td>
<td>&lt; 2</td>
<td>Adr. NP</td>
<td>-</td>
<td>2.0</td>
<td>1.7</td>
<td>Cardiac arrest</td>
</tr>
<tr>
<td>9</td>
<td>BVA</td>
<td>Centrifugal + roller</td>
<td>24</td>
<td>Adr. NG. Dopa</td>
<td>x3</td>
<td>3.0</td>
<td>3.4</td>
<td>Died</td>
</tr>
</tbody>
</table>

mean ± SD 17.7±11.3 2.9±1.0 3.6±1.1

BVA = biventricular assist; RVA = right ventricular assist; LVA = left ventricular assist; Adr = adrenalin; Dopa = dopamin; Iso = Isoprenalin; NG = nitroglycerin; NP = Sodium nitroprusside; PGE = Prostaglandin E1; VAD = ventricular assist device; Xylo = xylocain

Results

In 11 of 12 patients, a stable atrio-arterial bypass could be established. Thereafter, the pump-oxygenator could be stopped almost immediately in 10 of 11 patients, while 1 patient required biventricular bypass to achieve haemodynamic stability before the heart-lung machine could be stopped. Details on the type and duration of assist, concurrent drug treatment and counterpulsation, and selected haemodynamic data are given in Table 3.

Right ventricular assistance (patient no. 1)

Following attempts at intrapulmonary artery balloon pumping after Miller [19], right ventricular bypass was performed with an arterial return to the PTFE prosthesis used for the balloon pump. Bypass could be terminated after 24 h. However, the patient succumbed with multiple organ failure on the 18th postoperative day.

Left ventricular bypass (patients nos. 2–12)

Eleven patients had bypass established from the left atrium to the aorta. In patient No. 2, a stable blood flow through the bypass circuit could not be obtained, and attempts at weaning from the heart-lung machine were unsuccessful. In patient No. 9, left ventricular assistance revealed severe right ventricular failure and institution of biventricular support was necessary before weaning from the pump-oxygenator was achieved. In the other 8 patients, cardiopulmonary bypass could be terminated and stable haemodynamics achieved as well as in patient No. 12 who went into myocardial failure after termination of bypass.

Haemostasis and coagulation

For the 9 patients assisted for more than 2 h and had the incision closed, re-exploration for mediastinal bleeding became necessary one to three times in 6 patients. When the activated clotting time (ACT) was maintained below 150 s at high bypass flow, wound haemorrhage was less of a problem.

Haemodynamics during atrio-arterial bypass

Stable haemodynamics were established for more than 1 h in 8 of the 9 patients treated with left ventricular bypass. The maximal flow obtained through the assist circuit was 2.2±0.6 l/min per m² (range 1.1–2.8) at a cardiac index (assist flow plus ventricular output) of 2.5±0.9 l/min per m² (range 1.3–3.9). The highest cardiac index measured in
Fig. 3. Diagramatic presentation of the ventricular assist material. Of a total of 12 patients, 3 are long-term survivors. The others expired during various phases of the treatment.

Table 4. Laboratory data on 6 patients weaned from atrio-ventricular assistance

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>Range</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Se-creatinine (max.)</td>
<td>286</td>
<td>130–600</td>
<td>nmol/l</td>
</tr>
<tr>
<td>Se-bilirubin (max.)</td>
<td>86</td>
<td>19–421</td>
<td>µmol/l</td>
</tr>
<tr>
<td>Se-ALAT (max.)</td>
<td>96</td>
<td>30–193</td>
<td>IU</td>
</tr>
<tr>
<td>Se-amylase (max.)</td>
<td>425</td>
<td>75–764</td>
<td>IU</td>
</tr>
</tbody>
</table>

each patient had a mean value of $2.9 \pm 1.0$ l/min per m$^2$ (range 1.7–4.0). The highest systemic vascular resistance index measured in each patient was $3012 \pm 1640$ dyn/s$^{-5}$ per m$^2$ (range 2550–4500). These values were lowered pharmacologically to less than 2300 in all patients during perfusion. Urinary output reflecting tissue perfusion was satisfactory in all patients perfused more than 2 h with left ventricular assist, mean value was 290 ml/h (range 99–588).

For those patients having right ventricular or biventricular assist, the cardiac output determinations were unsatisfactory, and a complete haemodynamic profile was difficult to obtain. Assist flow was at the most 2.0 and 2.2 l/min per m$^2$, respectively. However, in both patients oliguria progressed to anuria during perfusion.

Sternal closure

Ventricular assist with closed chest was done in 8 patients. In 5 of these, the sternum was splinted open with the skin closed only, and, if necessary, a skin defect was closed with a silastic patch.

When ventricular assist was terminated, dilatation of the heart prevented sternal closure in 3 cases. Secondary sternal closure was performed on postoperative days 3–5 without problems.

Postoperative treatment

Six patients weaned from the assist circuit were transferred to the postoperative ward. They had ventilatory support for 6–19 days, median 12 days with a median maximal inspired oxygen fraction of 0.7 (range 0.6–0.95). Intraaortic counterpulsation was performed in 5 patients, all were weaned 5–7 days after surgery.

Peritoneal dialysis was performed in 2 patients for 6 and 18 days: both patients died from multiple organ failure. All patients had one or more abnormal peak values of blood tests reflecting dysfunction of parenchymatous intraabdominal organs (Table 4).
Infectious complications

No wound or mediastinal infection occurred. Septicaemia with Gram-negative microorganism was proven and treated successfully in 1 patient and suspected in another patient.

Mortality

Five patients died of myocardial failure on cardiopulmonary bypass or ventricular assist. Seven were weaned from left (6) or right (1) ventricular bypass. Treatment was terminated in 1 patient because of ischaemic brain damage related to postoperative cardiac arrest and possible air embolism during cannulation of the left atrium.

Two additional hospital deaths from multiple organ failure could partly be related to Cyclosporin A toxicity in one and septicaemia in the other. One patient died suddenly in a rehabilitation facility. The 3 others have survived for 12–17 months with only slight cardiac and no extra-cardiac disability. The results are summarized in Fig. 3.

Comments

Myocardial dysfunction and a low output syndrome remain the leading cause of death after open heart surgery. After completion of the surgical repair, the inability to wean the patient from the pump-oxygenator is a devastating event. Use of inotropic and vaso-dilating drugs, proper volume replacement and the use of counterpulsation, is successful in approximately 80% of these cases in our experience. In the remaining patients, there is a need for an efficient, low cost and readily available method for circulatory assist. The clinical introduction of left atrial to femoral artery bypass with a roller pump was revived by Litwak et al. [15] and simplified by the popularisation of the centrifugal pump [3].

There is still a small number of cases reported, dealing with the efficacy of atrio-arterial ventricular pump bypass for postcardiomyiotomy, low cardiac output syndrome [2,3,9,10,12,14,16,21,22,25,28].

The selection of patients for this special treatment is crucial for evaluation of the results. However, in spite of strict criteria [16,23], there will always be a clinical decision when to start postsurgical ventricular assistance. When a patient is partly dependent on the pump-oxygenator, it is difficult to obtain repeatable haemodynamic values. It is our strong belief that all patients reported in this study would have died in the operating room unless atrio-arterial ventricular bypass was attempted.

The reduction of the expected mortality in this group to 50% in the operating room, with a 1-year survival of 25% is in accordance with current literature reporting a survival rate of 17%–37% [2,10,12,16,21,22,25,26]. In addition, the 3 survivors were in good clinical condition with only minor cardiac disability, as reported from centers with a larger experience [10, 21, 26].

The chance of survival is probably increased when myocardial dysfunction was unexpected following a technically efficient surgical procedure and possibly reversible within a relatively narrow time frame. Delay in the institution of ventricular assist may destroy the possibility of myocardial recovery since experimental work has shown an increased salvage of myocardium during evolving infarction by ventricular assist [11] or improved myocardial function comparing the effects of intra-aortic balloon counterpulsation and ventricular bypass [18]. Myocardial function recovered rapidly in most of our patients. It is, however, likely that a higher survival rate could have been achieved if resources had allowed a more extended perfusion.

Most of our patients had a left ventricular assist. The occurrence of biventricular failure is common, and survival is less likely unless biventricular assistance is performed [21,22]. In most cases of right ventricular failure in our material, drug treatment only was given. However, a retrospective analysis indicates that right ventricular failure was more important than initially thought, and a greater chance of success was missed.

The staged treatment approach to right ventricular failure includes drug treatment, including intrapulmonary artery administration of prostaglandin E1 and infusion of norepinephrine into the left atrium [1], use of intrapulmonary artery counterpulsation [19,30] and temporary right ventricular bypass [8,9,30]. We found the latter as easy as left-sided bypass. However, in most cases, the combination of drugs reversed the acute right ventricular failure provoked by acute vasoconstriction of the pulmonary arteries. It has been proposed that right ventricular failure occurs after left ventricular unloading [6,7]. There is a possibility that loss of normal interventricular septal function accounts for this [6,7,33]. The right ventricular failure may be unmasked in many instances after proper treatment of left ventricular failure. To avoid loss of septal force [7,33], avoid mural thrombus in the left atrium or ventricle [20], and avoid to left shunt through septal defects [17] we therefore prefer not to bypass the left ventricle completely.
The use of the centrifugal pump obviates the use of a compliant reservoir in the assist circuit, and the inflow problem is almost avoided [3]. A meticulous surgical procedure and skillful perfusion must be performed to avoid excessive bleeding, embolism of air as well as particulate matter or hypoperfusion. Following ventricular assist with paracorporeal assist devices, the thromboembolic complications were relatively few [27]. On the other hand, the need for proper anticoagulation after wound bleeding has subsided is stressed [21]. In our experience, bleeding was a problem until the level of initial anticoagulation was lowered.

The current results of this method highlights the remaining questions. To improve safety and reduce the need for initial anticoagulation, various alternatives have been proposed: coating the circuitry with heparin-graphite [12], routine change of the pump heads after 1–2 days of perfusion [21], or alternative anticoagulation with prostacyclin [32].

To improve the left ventricular unloading, an in-line ventricular cannula has been proposed after experiments in the animal laboratory [4, 5]. The decision when to start assist may be helped by more objective tests. Analysis of blood lactate is one suggestion [13] and echocardiography and isotope studies may also become useful additions to the haemodynamic profile already used. In particular, it seems rational to use transthoracic [20, 33], or transoesophageal echocardiography, as well as isotope angiography and scanning [28] to evaluate the recovery of myocardial function.

In addition, ventricular bypass may be useful in the treatment of an acute evolving infarction [11] and acute ventricular septal perforations [22] as shown in the experimental laboratory.

We conclude after 1½ years experience that temporary, closed chest atrio-arterial, ventricular bypass is a valuable method in the treatment of postperfusion cardiac failure. To improve the results, improved design of the inflow cannula and reduced thrombogenicity of the circuit with a reduced need for anticoagulation is necessary. Furthermore, more objective and easily repeatable parameters of myocardial function are required to avoid misuse of this method.

References


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Note added in proof
Since the submission of the manuscript, additional four patients have been treated. Three patients expired after being weaned from left heart bypass. One patient supported with right ventricular bypass after othotopic cardiac transplantation is alive and well.