Improved early postoperative outcome for extracardiac Fontan operation without cardiopulmonary bypass: a single-centre experience

Stanislav Ovroutski*, Christian Sohn†, Oliver Miera, Björn Peters, Vladimir Alexi-Meskishvili, Roland Hetzer, Felix Berger and Michael Hübler

* Department of Congenital Heart Diseases, Deutsches Herzzentrum Berlin (German Heart Institute Berlin), Berlin, Germany
† Department of Cardiothoracic and Vascular Surgery, Deutsches Herzzentrum Berlin (German Heart Institute Berlin), Berlin, Germany

* Corresponding author. Deutsches Herzzentrum Berlin, Augustenburger Platz 1, 13533 Berlin, Germany. Tel: +49-30-45932800; fax: +49-30-45932900; e-mail: ovroutski@dhzb.de (S. Ovroutski).

Received 26 April 2012; received in revised form 18 August 2012; accepted 22 August 2012

Abstract

OBJECTIVES: The use of modified extracardiac Fontan operation (ECFO) for total cavo-pulmonary connection allows cardiopulmonary bypass (CPB) to be avoided and seems to improve early postoperative results. We evaluated our experience with the off-pump technique for ECFO.

METHODS: Since 2009, the last 17 consecutive patients of 137 (median age 3.2 years, median weight 14.5 kg) in whom no intracardiac surgery was necessary underwent ECFO without CPB. The non-fenestrated graft was connected end-to-side to the pulmonary artery without bypass; subsequently temporary passive inferior vena cava (IVC)-to-atrial bypass was used for the anastomosis between IVC and graft. The peroperative and postoperative course was compared between consecutive paediatric patients operated on using the CPB vs off-pump technique.

RESULTS: There was no mortality in the off-pump group, with a total early mortality of 3.0%. Overall operation time for the Fontan operation using the off-pump technique was significantly reduced (160 vs 200 min, P < 0.001). The median Fontan pressure 24 and 48 h postoperatively was significantly lower in the off-pump group (P = 0.002/0.042). Duration of mechanical ventilation (9 vs 14 h, P = 0.016), pleural effusions (4 vs 8 days, P < 0.001) as well as the median intensive care unit (2 vs 4 days, P = 0.013) and hospital stay (median 10 vs 15 days, P < 0.001) was significantly shorter in patients who underwent the off-pump Fontan operation. The necessity of blood transfusions was significantly reduced with the off-pump in comparison with the on-pump technique (14 of 17 vs 34 of 84 patients, P = 0.003).

CONCLUSIONS: The ECFO without CPB is an established low-risk surgical procedure that improves the early postoperative course and significantly reduces the use of blood products and the duration of pleural effusions in selected patients.

Keywords: Extracardiac Fontan • Cardiopulmonary bypass • Off-pump

INTRODUCTION

Nowadays, the extracardiac Fontan operation (ECFO) is established in many centres for cardiothoracic surgery for the palliation of the different types of single ventricle due to its gentle technique and low incidence of early and late complications. Different authors have described the advantages of ECFO with short bypass time and the avoidance of cardioplegia and intracardiac surgery, resulting in low incidence of arrhythmias and laminar blood flow within the Fontan pathway [1–3]. The short bypass time, in particular, was termed a factor in the improved early postoperative course with a reduced necessity of fenestration and lower rates of thromboembolic and arrhythmic incidents [4].

Advances in surgical technique and postoperative management have led to a broader inclusion of patients for the Fontan operation. Improved results in patients with heterotaxia and hypoplastic left heart syndrome were reported through the stages of univentricular palliation in recent decades [5]. Although short-term morbidity and mortality have declined, different pre-, intra- and postoperative variables are still under discussion as factors contributing to early failure or death after a Fontan operation. Certain procedural modifications have led to a decrease in postoperative mortality and some causes of morbidity. However, pleural effusions developing after the Fontan procedure still contribute to morbidity and prolonged hospitalization [6].

Extracardiac modification, performed without cardioplegia and with reduced bypass time, has been established at our institution since 1995. As a logical implication of the intention to further improve patients’ postoperative outcome, we initiated an off-pump Fontan procedure by using temporary passive bypass from the inferior vena cava (IVC) to the atrium with the complete avoidance of CPB.

In the current study, we analyse whether the off-pump Fontan procedure improves the postoperative course with regard to the incidence of early Fontan failure, the necessity of blood
transfusions, the duration of pleural and peritoneal effusions and the hospital stay.

**MATERIALS AND METHODS**

**Preoperative data and patient selection**

One hundred and thirty-seven consecutive patients underwent ECFO at our institution between 1995 and 2010. The last 17 consecutive patients, in whom no intracardiac surgery was necessary, were operated on without CPB. The first off-pump Fontan operation was performed at our institution in December 2009. The patients of the on-pump group in whom intracardiac procedures were necessary during the Fontan procedure (n = 26) were excluded from the study to avoid the negative effects of cardiopulmonary bypass in the analysis. Adults and adolescent CPB patients (older than 14 years at the time of operation; n = 10) were also excluded because of the absence of age-matched off-pump patients.

Therefore, 101 patients were comparatively analysed. For comparative analysis, the remaining patient population was divided into two subgroups, namely with (n = 84) and without CPB. All patients included in the study fulfilled our pre-Fontan selection criteria (published elsewhere [7]). The preoperative data and the main diagnoses of the total population are given in Tables 1 and 2.

**Anaesthetic management**

Perioperative monitoring was performed by continuous recording of arterial and central venous pressure (in the superior vena cava (SVC) and IVC), pulse-oximetric oxygen saturation, heart rate and temperature. Arterial blood gases and lactate concentrations were analysed at different perioperative steps. In the CPB group, anaesthetic management was geared towards a blood-sparing approach using body weight-adjusted miniaturized CPB circuits, as well as cell salvage techniques and retransfusion of autologous red blood cells.

**Surgical procedure**

The technique for the Fontan operation with CPB is described elsewhere [8]. All operations were performed through a standard median sternotomy. During the first step of the off-pump Fontan completion, the non-fenestrated Gore-Tex® graft (16–20 mm) was connected end-to-side to the pulmonary artery (PA) without any cardiopulmonary bypass (CPB; Fig. 1). For this procedure, the right pulmonary artery (RPA) was clamped at an angle, allowing free blood flow from the SVC to the left pulmonary artery (LPA) and the suture lines were placed at the right side of the anastomosis between the conduit and the RPA. The clamp was then moved to the left using the same blood flow principle, and the suture line was continued to the left part of the anastomosis (Fig. 1A and B). In 1 patient (with body weight of 11.3 kg), the off-pump surgical procedure had to be converted intraoperatively in an on-pump procedure because of the low oxygen saturation during the initial clamping of the SVC/LPA. The deep IVC clamping was performed as described elsewhere, and the inferior caval vein was transected from the atrium with the small rim of the atrial wall [8]. The anastomosis between IVC and graft as the second step of the Fontan completion was performed using temporary passive IVC-to-atrial bypass through the 18 or 22-Fr cannula (Fig. 2). The duration of the IVC clamp was of a median of 28 (17–44) min. In two children, primary complete total cavopulmonary connection without prior Glenn operation could be performed with the off-pump technique, combined with intraoperative transcatheter stenting in one of them (Fig. 3).

**Selective data collection**

All medical and surgical records of the patients were reviewed for demographic and preoperative data and procedures,
intraoperative data and postoperative course. We considered the following as appropriate markers for the comparison of the early postoperative course between the groups: mean postoperative pulmonary artery pressure (PAP) 4, 24 and 48 h postoperatively, volume resuscitation in the first 24 h postoperatively, inotropic support for longer than 48 h, inotropic score [9], duration of mechanical ventilation, necessity of blood transfusions, duration of the pleural effusions as well as the length of intensive care unit (ICU) and overall hospital stay.

Statistical analysis

SPSS for windows, version 18.0 (IBM SPPS Inc., Chicago, IL, USA), was used to perform statistical calculations. Data are expressed as median and ranges. Categorical data are presented as the number of cases and corresponding percentages and tested using Fisher’s exact test and the chi-square test. Mann–Whitney tests were used to compare continuous pre-, peri- and postoperative data. A value of $P < 0.05$ was considered statistically significant.

Statistical analysis was implemented with the approval of our biostatistician.

RESULTS

Preoperative data

There were no significant differences between the two groups regarding the major cardiac diagnoses, preoperative demographic
data, systemic ventricle morphology and number of high risk patients, such as those with heterotaxy syndrome (Tables 1 and 2).

Perioperative data

During the IVC clamping in the off-pump group, arterial pressure drop [in median mean arterial pressure (MAP) drop of 12 mmHg (4–24)], as well as IVC pressure increase of 8 mmHg median (range: 4–19) mmHg occurred, MAP before clamping had a median of 55 (48–84) mmHg with an IVC pressure of 8 (4–9) mmHg; after clamping MAP decreased to 43 mmHg (35–63) and IVC pressure rose to up to 16 mmHg (11–28). The overall operation time for the Fontan operation using the off-pump technique was significantly reduced, and the necessity of intraoperative blood transfusions in the off-pump group was significantly lower than in patients operated on with CPB. The precise comparative data are given in Table 3.

Early postoperative course

The overall early postoperative results were encouraging, with low overall mortality of 3% (n = 3). No mortality was noted in the off-pump group. The necessity for prolonged inotropic support and the necessity of additional nitric oxide ventilation did not differ significantly between the two groups. The ventilation time of the whole patient population including the perioperative ventilation time had a median of 14 (1–738) h.

Children who could be extubated during the first 24 h (n = 66) were older than the total study population (median 4.3 vs 3.5 years, P = 0.002). The adaptation of the PAP during the first and second postoperative day was faster (Fig. 4A), and the duration of mechanical ventilation was significantly shorter in patients operated on without CPB compared with the conventional CPB Fontan.

No perioperative arrhythmias were documented after the operation without CPB. Using the off-pump technique, we were able to diminish blood transfusions considerably. In 14 of the 17 patients, there was no need for blood transfusions at all. The lowest haemoglobin (Hb) level on discharge was 9.1 g/dl in the off-pump and 9.4 g/dl in the on-pump group (Fig. 4B). The total ICU stay was 3.0 (1–77) days, and the total hospital stay was 14 (6–107) days.

The postoperative data are summarized in Table 4.

DISCUSSION

The ‘off-pump’ Fontan operation was successfully established in our institution as a feasible surgical procedure associated with overall favourable haemodynamics and a promising postoperative course. In line with the improving worldwide results in the early postoperative course after the Fontan operation, our patients were mostly transferred to the intermediary care unit after a short period of mechanical ventilation during the first or second postoperative day. Nevertheless, the duration of the ICU stay; durations of pleural effusions and of total hospital stay were significantly shorter in the off-pump group than in the conventional CPB Fontan group. Furthermore, no perioperative or postoperative blood transfusions were necessary in the majority of off-pump patients.

Postoperative mortality and severe early morbidity, including early Fontan failure, severe arrhythmia, prolonged ventilation and prolonged early postoperative pleural and peritoneal effusions were clearly avoided in the off-pump group.

Different studies presented in the past decade demonstrated significantly decreased early and long-term mortalities, decreased severe morbidity after Fontan operation and improved overall results [3, 10, 11]. The extracardiac conduit was particularly favoured due to its gentle technique, short CPB time and low incidence of postoperative complications in different centres. Nevertheless, many authors describe the negative influence of the heart-lung machine on the occurrence of pulmonary injury, systemic inflammatory response syndrome, fluid retention, myocardial dysfunction, thromboembolic events and necessity for blood transfusions, and reveal a direct association of CPB duration with worse early outcome [4, 11–14]. The postoperative development of pleural effusion is multifactorial, including inflammatory, hydrostatic and hormonal mechanisms [15, 16]. The inflammatory changes, resulting in capillary leakage and subsequent fluid retention, may consequently lead to increased pulmonary vascular resistance and decreased pulmonary blood flow [17, 18]. Decreased ventricular compliance contributes to the development of persistent pleural effusion and ascites or even of early Fontan failure, especially in borderline Fontan candidates [4, 6, 19]. Not only might the overall CPB time be decisive, but also the general usage of an oxygenator seems to make an important impact through the activation of the complement system and induction of a systemic inflammatory reaction [15, 17]. Contact activation by allogenic material stimulates the release of toxic oxygen species and granulate contents including elastase [20]. Due to our novel surgical technique with the complete avoidance of external bypass for the superior vena cava to PA anastomosis, the duration of the blood contact with the synthetic cannulas was further reduced, which could probably reduce the inflammatory reaction. The perioperative fenestration of the Fontan connection for reduced transpulmonary flow and improved ventricular filling, and therefore better early postoperative haemodynamics is still widely discussed [21]. We would speculate that, due to the avoidance of CPB and preservation of the PVR increase, fenestration could be avoided with diminished risk of thromboembolic complications and persistent cyanosis.

### Table 3: Operation-related data

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Off-pump (n = 17)</th>
<th>On-pump (n = 84)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation time (min)</td>
<td>160 (105–350)†</td>
<td>200 (110–420)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intraoperative blood transfusion</td>
<td>3/17 (18%)†</td>
<td>4/84 (57%)</td>
<td>0.003</td>
</tr>
<tr>
<td>Hb (g/dl) 4 h postoperative</td>
<td>13.6 (10.2–17.7)</td>
<td>13.6 (7.9–19.7) n.s.</td>
<td></td>
</tr>
<tr>
<td>Intraoperative PAP (mmHg)</td>
<td>13 (8–18)</td>
<td>15 (6–26)</td>
<td>0.023</td>
</tr>
<tr>
<td>Number of fenestrations</td>
<td>0/17 (0%)</td>
<td>24/84 (28.5%)</td>
<td>0.012</td>
</tr>
</tbody>
</table>

Hb: haemoglobin; PAP: pulmonary artery pressure. n.s.: not significant.
†In one case primary Fontan operation and transcatheter hybrid procedure (RPA stenting) were performed, causing total operation time of 350 min.
One-stage Fontan in special cases with favourable haemodynamics and anatomy is sometimes possible. We hope that avoidance of CPB may help to improve the postoperative course and to reduce possible early complications, as in two of our patients. Although well-developed pulmonary arteries are one of the main selection tools for optimal Fontan circulation [22–24],

Table 4: Postoperative data

<table>
<thead>
<tr>
<th></th>
<th>Off-pump (n = 17)</th>
<th>On-pump (n = 84)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean PAP 4 h postop (mmHg)</td>
<td>14 (6–18)</td>
<td>14 (9–25)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Mean PAP 24 h postop (mmHg)</td>
<td>11 (6–16)</td>
<td>14 (5–25)</td>
<td>0.002</td>
</tr>
<tr>
<td>Mean PAP 48 h postop (mmHg)</td>
<td>10.5 (6–16)</td>
<td>13 (7–21)</td>
<td>0.042</td>
</tr>
<tr>
<td>Volume resuscitation 24 h (ml/m²)</td>
<td>2881 (1494–5495)</td>
<td>3907 (1408–17450)</td>
<td>0.021</td>
</tr>
<tr>
<td>Hb (g/dl) at discharge</td>
<td>12.1 (9.1–17.7)</td>
<td>12.7 (9.4–17.6)</td>
<td>n.s.</td>
</tr>
<tr>
<td>NO ventilation (n)</td>
<td>2/17 (11.8%)</td>
<td>27/84 (32.1%)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Inotropic score 24 h (μg/kg/min)</td>
<td>0 (0–114)</td>
<td>0 (0–316)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Inotropic score 48 h (μg/kg/min)</td>
<td>0 (0–89)</td>
<td>0 (0–291)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Suprarenin support &gt;48 h (n)</td>
<td>3/17 (18%)</td>
<td>21/83 (25%)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Chest tube duration (days)</td>
<td>4 (0–10)</td>
<td>8 (2–100)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total ventilation support (h)</td>
<td>9 (3–94)</td>
<td>14 (4–738)</td>
<td>0.016</td>
</tr>
<tr>
<td>Median ICU stay (days)</td>
<td>2 (1–5)</td>
<td>4 (1–77)</td>
<td>0.013</td>
</tr>
<tr>
<td>Median hospital stay (days)</td>
<td>10 (6–19)</td>
<td>15 (9–107)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Early mortality (n)</td>
<td>0/17 (0%)</td>
<td>3/84 (3.5%)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

PAP: pulmonary artery pressure; Hb: haemoglobin; NO: nitric oxide. ICU: intensive care unit; n.s.: not significant.
technically simplified use of off-pump Fontan combined with a hybrid approach for transcatheter PA stenting allows us to perform single-stage Fontan also in patients with PA stenosis. It is apparent that the feasibility of performing the off-pump Fontan carries the advantages of the extracardiac conduit Fontan operation (ECFO). Therefore, we should add this point to the other certain advantages over the intracardiac modifications, such as avoidance of aortic cross-clamping [25], better flow characteristics [1] and avoidance of atrial incisions and suture lines with lower rates of arrhythmia. However, feasibility of the off-pump procedure is utterly restricted by the need for intracardiac surgery. Furthermore, small pulmonary arteries may limit the PA clamping without CPB because of low perioperative oxygen saturation.

Considering our promising results, the non-use of CPB for completion of the ECFO represents an option for further improvement of the early postoperative outcome in this complex and delicate patient group.

Limitations of the study

Although patients in the current series had basically matched and comparable ages, body weights, diagnosis and preoperatively parameters, the main limitation remains the juxtaposition with a historical patient population. We therefore suggest that larger numbers of patients should be analysed in a prospective study.

CONCLUSION

In our experience, the ECFO without CPB is an established and gentle surgical procedure with low surgical risk, leads to improved early postoperative course and, therefore, should be recommended for completion of the ECFO in selected patients.

ACKNOWLEDGEMENT

We are grateful to Anne M. Gale for editorial assistance.

Conflict of interest: none declared.

REFERENCES