Continuous systemic perfusion improves outcome in one stage repair of obstructed aortic arch and associated cardiac malformation

Hideki Uemura*, Toshikatsu Yagihara, Youichi Kawahira, Yoshiro Yoshikawa, Soichiro Kitamura

Department of Cardiovascular Surgery, National Cardiovascular Center, 5-7-1 Fujishirodai, Suita, Osaka 565-8565, Japan

Received 9 October 2000; received in revised form 4 May 2001; accepted 31 May 2001

Abstract

Objective: To determine whether continuous systemic perfusion is of effective use when establishing primary repair of the aortic obstruction and associated cardiac malformations. Methods: Since 1991, 56 infants have undergone reconstruction of interrupted (in 28) or coarctated (in 28) aorta, concomitantly with closure of ventricular septal defects in 37, and repair of other malformations in the remaining 19. Of these, total circulatory arrest (30 ± 11 min) was employed in 23. In another 21 patients, perfusion was maintained for the carotid arteries with the descending aorta cross-clamped (31 ± 15 min). The bodily organs were perfused throughout the operative procedures by placing dual aortic cannulae in the remaining 12 patients. Results: The postoperative courses were less eventful in the non-circulatory arrest group than other groups of patients undergoing total or partial circulatory arrest, although these groups were operated in different time periods, and consequently, a general progress might be one reason for improvements in the surgical outcomes. All patients undergoing no circulatory arrest survived the primary repair, could have the sternum primarily closed, and had no episodes of cerebral bleeding. Prolonged tracheal intubation was needed just in one patient of this group. The amount of urine output during cardiopulmonary bypass was significantly greater in the non-circulatory arrest group than in the others. The maximal concentrations of urinary β-microglobulin, serum creatinine, creatine phosphokinase, and glutamic oxaloacetic transaminase were lower in this setting. Conclusions: Continuous systemic perfusion was considered less invasive when concomitantly repairing the obstructed aorta and intracardiac malformations. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Coarctation or interruption of the aorta; One stage repair; Circulatory arrest; Cardiopulmonary bypass; Ischemia of the organs

1. Introduction

When achieving primary repair in patients with obstructed aortic arch and associated cardiac malformation, some surgeons have employed total circulatory arrest [1,2] and others prefer continuous perfusion via the branches originating from the aortic arch [3,4]. Although the management of cardiopulmonary bypass is rather simple and the surgical field is excellent when operative procedures are to be carried out in circumstances of total circulatory arrest, some impediments could be noted after surgical repair. It is known that circulatory arrest in neonates may unfavorably affect the postoperative development of cerebral function in the longer term [5–7]. It is also reported, in patients with cardiac malformations and either coarctation or interruption of the aortic arch, that one stage repair can be established in a less invasive fashion by maintaining partial perfusion to the upper body and thus avoiding total circulatory arrest [3,4]. To augment this advantageous aspect still further, we have striven to maintain perfusion not only to the upper body but also to the lower body throughout the operative procedures by placement of dual arterial cannulae for cardiopulmonary bypass [8]. The present study was arranged to determine the efficacy of this modification in terms of postoperative findings immediately after the extensive procedure.

2. Materials and methods

Since 1991, 56 infants with either coarctation of the aorta (in 28) or interruption of the aortic arch (in 28) and associated intracardiac malformations, have undergone one stage repair via a median approach. No additional incision was made on the lateral thoracic wall. Before 1997, total...
circulatory arrest was employed in 23 cases, just during reconstruction of the aortic arch, and, in another 21, perfusion to the lower body was discontinued during aortic reconstruction with the upper body being continuously perfused throughout the operative procedures. The number of postneonates was greater in the group of patients undergoing the latter surgical option (Table 1), because, during this period, total circulatory arrest was intentionally avoided in seven patients with a body weight of more than 4 kg. Also in patients with a diameter of the ascending aorta of greater than 6 mm, we have strived to maintain perfusion to the upper body and the heart itself during aortic reconstruction. The higher incidence of interrupted aortic arch in the total circulatory arrest group reflects this selection of operative options (Table 1). For subsequent intracardiac maneuvers, all of the systemic organs were re-perfused except for the heart. In the recent consecutive 12 patients after 1998, in contrast, perfusion was maintained not only to the upper body but also to the lower body during reconstruction of the aorta; thus, no circulatory arrest was employed.

In all of the patients, the aortic obstruction was hemodynamically significant, and aortic reconstruction was carried out by extended direct anastomosis, without the use of a prosthetic tube, between the aortic arch and the descending aorta. In those undergoing repair beyond the neonatal period, the arterial duct remained patent with or without the administration of Prostaglandin, and they were submitted to our surgical department late because of their stable clinical conditions. Malaligned ventricular septal defect was the major intracardiac malformation in 37, while other complicated malformations were present in the other 19 patients (Table 1).

To maintain continuous systemic perfusion to the upper body, the heart, and the lower body on cardiopulmonary bypass, the first arterial cannula was placed at either a 3.5 mm-diameter polytetrafluoroethylene tube anastomosed to the right subclavian artery or the ascending aorta directly using a 1.8 mm-diameter tube (Fig. 1). The second cannula, a straight 8 or 10 French-sized tube, was directly inserted into the descending aorta beyond the pulmonary arteries. To make this maneuver secure, the descending aorta was extensively dissected and mobilized. The branches from the aortic arch were also dissected considerably for better mobilization. The amount of flow, as well as blood temperature, perfused by cardiopulmonary bypass, were maintained as standard perfusion in patients without aortic obstruction.

![Fig. 1. Schema of the operative maneuvers for placement of dual arterial cannulae during aortic reconstruction. The upper body and the heart were perfused via either a 3.5 mm-diameter polytetrafluoroethylene tube anastomosed to the right subclavian artery or the arterial cannula directly placed into the ascending aorta. The second cannula was placed directly into the descending aorta beyond the pulmonary arteries. Extensive dissection and mobilization of the descending aorta and the branches from the aortic arch were essential in order to readily achieve direct anastomosis. Even after sufficient resection of the ductal tissues, the cannula into the descending aorta did not interfere with the anastomotic maneuver.](https://academic.oup.com/ejcts/article-abstract/20/3/603/366383)
The time consumed on cardiopulmonary bypass and that for the operative procedures are also shown in Table 2. Hemofiltration was carried out as a routine maneuver during cardiopulmonary bypass. A peritoneal tube was put in place for postoperative use, such as peritoneal drainage or dialysis. We made it a rule to carry out peritoneal dialysis when the urine output was lower than 3ml/kg per h within the first postoperative 24 h.

Continuous data were presented as means ± standard deviation. To evaluate an incidence, the Chi-square test was employed. For comparison of the amount of urine output and the postoperative laboratory data, a non-parametric test between three groups was carried out by the Kruskal–Wallis method, since the data were far from normally distributed.

3. Results

The postoperative courses were less eventful in the non-circulatory arrest group than other groups of patients undergoing total or partial circulatory arrest (Table 3). The causes of early death seen in five patients were as follows: cerebral damage because of intracranial hemorrhage, low cardiac output related to either obstruction across the left ventricular outflow tract or regurgitation across the valve of the common arterial trunk, mediastinitis related to sternal splintage, and ileus associated with prolonged peritoneal dialysis for renal dysfunction. Intracranial hemorrhage occurred in another two patients undergoing circulatory arrest, with no functional deficiency noted in the longer term. No episode of convulsion was found in the groups of patients in whom total circulatory arrest was avoided. Sternal splintage was not needed in the non-circulatory arrest group. Prolonged tracheal intubation and the employment of peritoneal dialysis were less common in this group.

The amount of urine output during cardiopulmonary bypass was significantly greater in the non-circulatory arrest group than in the other groups (Fig. 2). In the intensive care unit, in contrast, the amount of urine output did not differ between these groups, being almost sufficient and stable during the first and the second postoperative 12 h. The postoperative laboratory data in the intensive care unit showed better results in the non-circulatory arrest group than in the other two groups (Fig. 3). In particular, the maximal concentration of creatine phosphokinase and glutamic oxaloacetic transaminase in the serum were significantly lower in this setting. The urinary concentration of β-microglobulin, which reflects acute tubular injury of the kidney after cardiopulmonary bypass [9], was slightly lower in the non-circulatory group.

Extensive dissection of the descending aorta, as well as the branches from the aortic arch, provided excellent mobilization, producing no tension at all between the ascending and the descending portions of the aorta during aortic reconstruction. Even after sufficient resection of the ductal tissues from the descending aorta, anastomosis was readily achieved without any major interference posed by the additionally placed arterial cannula.

<table>
<thead>
<tr>
<th>Group</th>
<th>TCA (n = 23)</th>
<th>DAX (n = 21)</th>
<th>NCA (n = 12)</th>
<th>P value (χ² test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at repair (days)</td>
<td>17 ± 16</td>
<td>76 ± 88</td>
<td>23 ± 22</td>
<td></td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>3.0 ± 0.4</td>
<td>3.7 ± 1.1</td>
<td>3.5 ± 0.8</td>
<td></td>
</tr>
<tr>
<td>Minimal CPB flow (ml/kg per min)</td>
<td>0</td>
<td>20</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Lowest blood temperature (°C)</td>
<td>18</td>
<td>19</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>TCA time (min)</td>
<td>30 ± 11</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Ischemia of lower body (min)</td>
<td>–</td>
<td>34 ± 11</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Ischemia of heart (min)</td>
<td>78 ± 28</td>
<td>70 ± 37</td>
<td>48 ± 21</td>
<td></td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>180 ± 46</td>
<td>167 ± 41</td>
<td>162 ± 44</td>
<td></td>
</tr>
<tr>
<td>Operation time (min)</td>
<td>536 ± 116</td>
<td>481 ± 114</td>
<td>445 ± 89</td>
<td></td>
</tr>
<tr>
<td>Amount of effluent by HF (ml)</td>
<td>728 ± 422</td>
<td>609 ± 336</td>
<td>612 ± 220</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>TCA (n = 23)</th>
<th>DAX (n = 21)</th>
<th>NCA (n = 12)</th>
<th>P value (χ² test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early death</td>
<td>4 (17)</td>
<td>1 (5)</td>
<td>–</td>
<td>0.161</td>
</tr>
<tr>
<td>Cerebral bleeding or convulsion</td>
<td>3 (13)</td>
<td>–</td>
<td>–</td>
<td>0.103</td>
</tr>
<tr>
<td>Sternal splintage needed</td>
<td>7 (30)</td>
<td>3 (15)</td>
<td>–</td>
<td>0.072</td>
</tr>
<tr>
<td>Prolonged tracheal intubation</td>
<td>12 (52)</td>
<td>8 (38)</td>
<td>1 (8)</td>
<td>0.039</td>
</tr>
<tr>
<td>Peritoneal dialysis employed</td>
<td>8 (65)</td>
<td>11 (52)</td>
<td>5 (42)</td>
<td>0.389</td>
</tr>
</tbody>
</table>

a) TCA, total circulatory arrest; DAX, the descending aorta cross-clamped; NCA, non-circulatory arrest.  
b) Figures in parentheses represent percentage values.
4. Discussion

We have attempted, since 1978, reconstruction of the aortic arch concomitantly with intracardiac repair in infants with the obstructed aortic arch and associated cardiac malformations suitable for biventricular repair. Before 1990, such a single-staged approach was basically chosen in those with interruption of the aortic arch. Since 1991, in contrast, one stage repair has been applied also in infants with coarctation of the aorta, unless the patients were in a ductal shock. Our present investigation was retrospectively carried out in this cohort of patients. Due to the nature of its design, later surgical procedures could have provided better surgical results. For example, a simple method of sternal traction [10] might have decreased the incidence of sternal splintage in order to avoid compression of the heart by primary closure of the sternum. Postoperative inhalation of nitric oxide, which we began to utilize in patients with congenital heart disease in 1993, might also have had a positive influence on respiratory and circulatory circumstances immediately after the procedure. We should not emphasize too much, therefore, a positive impact of the non-circulatory arrest technique in the light of surgical outcomes.

It was encouraging, nonetheless, to find that the postoperative laboratory data were better when circulatory arrest was avoided. Ischemia of the lower body can be clearly minimized by continuous perfusion to the descending aorta. Postoperative levels of creatinine and enzymes in the serum most likely reflect ischemia or malperfusion of

---

**Fig. 2.** The amount of urine output during cardiopulmonary bypass, and the first and the second postoperative 12 h. Not surprisingly, the amount of urine output during cardiopulmonary bypass was significantly greater in the group of patients undergoing continuous perfusion to the descending aorta. TCA, total circulatory arrest; DAX, the descending aorta cross-clamped; NCA, non-circulatory arrest.

**Fig. 3.** Postoperative laboratory data in the intensive care unit. The maximal concentrations of urinary β-microglobulin, serous creatinine, creatine phosphokinase (CPK), and glutamic oxaloacetic transaminase (GOT) were lower in the non-circulatory arrest group than in the other groups. As for glutamic pyruvic transaminase (GPT), a difference was not obvious.
the major organs posed not only by impaired postoperative circulation, but also by artificial circulation during cardiopulmonary bypass. In addition, since no ischemia is to be employed for the major systemic organs, the blood temperature need not to be lower than 25°C. This could also be advantageous in order to minimize coagulation disorders after re-warming and coming off cardiopulmonary bypass.

To provide efficient use of continuous perfusion to the lower body, the surgeon would pay attention to the technical aspect that might mitigate against achievement of the operative procedure for reconstruction of the aorta. The second cannula placed to the descending aorta can produce difficulty in anastomosis between the aortic arch and the descending aorta. In our 12 patients, fortunately, cannulation into the distal part of the descending aorta was successfully achieved without major bleeding, and the descending aorta was readily anastomosned to the aortic arch. The cardiopulmonary bypass times, as well as the overall operative times, were not longer in the non-circulatory arrest group compared with the other groups. The reconstructed aortic arch proved eventually to be in good shape in all of the 12 patients in the intermediate term after the primary repair. No interventional procedures have been thus far needed for recurrent or residual obstruction of the aorta. Extensive dissection and mobilization of the descending aorta, which is undoubtedly essential for ideal anastomosis for aortic reconstruction, would also be of practical importance for safe and sophisticated management of cannulation. In addition, the second cannula into the descending aorta is preferably to be placed via the right to the ascending aorta in patients having the descending aorta coursing leftward of the vertebrae. With this orientation, the second cannula would not interfere with the surgical field at all during aortic anastomosis. As for during intracardiac maneuvers, the cannula does not annoy the surgeon, since it can be removed after completion of the aortic arch.

Another option is placement of the second cannula at the most distal portion of the descending aorta at the diaphragm level. When the pericardium is incised open at its posterior-inferior part, just leftward of the vertebrae, the descending aorta is present as expected. It may be possible for this option, although we have yet to attempt it, to be more easily achieved than the superior approach beyond the pulmonary arteries we chose. In reality, the surgeons at the Fukuo Children’s Hospital in Japan have employed this option in a series of patients with excellent results, and reported its efficacy at the academic meetings in Japan [11]. They have also applied this option to the Norwood procedure in neonates with hypoplastic left heart syndrome with great success [12]. The optional maneuver should be of surgical use particularly in such patients in whom extensive aortic reconstruction is needed.

In conclusion, maintenance of perfusion, not only to the upper body but also to the lower body, could be readily achieved when the obstructed aorta and associated cardiac malformations are to be repaired in a single-staged fashion. On the basis of our present findings, this alternative circulatory support during aortic reconstruction was efficient to minimize ischemic damage on the bodily organs, and considered less invasive than the employment of circulatory arrest.

References


Appendix A. Conference discussion

Dr A. Urban (St. Augustin, Germany): Do you use peritoneal dialysis in all of the patients or have you used it in all of the patients, or do you implant routinely a peritoneal dialysis catheter?

Dr Uemura: We routinely place a tube for peritoneal dialysis. For a better postoperative course, we usually use peritoneal drainage for a short
time. However, as I showed in the slide, peritoneal dialysis was not considered to be needed in a half of the patients because the amount of urine output was quite large.

Dr S. Sano (Okayama, Japan): I presented a paper of cerebral perfusion at the last EACTS conference in Glasgow. I think this technique is also very good. We do not apply lower body perfusion because our mean cross-clamp time during arch repair is only 15–16 min. I wonder whether enzymes, liver and kidney functions differ with a cross-clamp time of 15–16 and 30–40 min. We repair the coarctation and interrupted aortic arch with VSD at the rectal temperature of 30–32°C. I wonder whether you checked all the data, including liver and kidney function, etc. according to the temperature, cross-clamp time and circulatory arrest time of the lower body?

Dr Uemura: In our current series, the standard deviation of the data was relatively large. I think it reflected the difference of cross-clamping time or temperature. However, we could not determine precisely, this time, the differences made by such impacts on the enzymes or other parameters, because the number of patients with perfusion to the lower body remained small.

Dr G. Stellin (Padova, Italy): Your maneuvers in handling cardiopulmonary bypass to avoid circulatory arrest are indeed very ingenious. When the circulatory arrest is employed, we have the advantage of a bloodless field. In this way, aortic arch repair can be accomplished very effectively with a ‘safe’ arrest time, usually under 30 min. I wonder whether a further risk is introduced in cannulating the innominate artery and descending aorta while reconstructing the aortic arch? Did you have any complication in your patients related to this more complex approach?

Dr Uemura: We have never encountered such complications, and anastomosis between the aortic arch and the descending aorta was not very difficult at all, and cannulation into the descending aorta could be achieved very easily.

Dr Stellin: So why have you abandoned the circulatory arrest?

Dr Uemura: In our policy, continuous perfusion is advantageous, even for the upper body as Professor Sano described last year, and perfusion to the lower body was just an extension of such a policy. We should perfuse the lower body to avoid ischemic damage as much as possible. That’s why we place the cannulation into the descending aorta.

Dr Sano: I just want to add one comment. There are two reasons why we use cerebral perfusion. One is the neurological damage after circulatory arrest. Another reason is that if we will be able to repair coarctation plus VSD as some of usual VSD, the temperature during CPB is much warmer, postoperative management is much easier and the patient’s recovery is much quicker. This is why we repair the CoA and IAA with VSD at a temperature of 30–32°C with high flow bypass. I put a peritoneal dialysis catheter into all the neonates after repair, however, actual dialysis was done on only a few of these patients.

Dr Uemura: If you place the cannula also into the descending aorta, your patients would be much better.

Dr Sano: That’s why I asked you, if the cross-clamp time of the descending aorta is only 15 or 20 min, even with the short time, if the liver function or creatinines, etc. are different, then we need to use the descending aorta cannulation.