Adult cardiac surgery outcomes: role of the pump type

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Abstract

**Objective:** This study was carried out to evaluate whether the type of pump used for cardiopulmonary bypass (CPB; roller vs. centrifugal) can affect mortality or the neurological outcomes of adult cardiac surgery patients. **Methods:** Between 1994 and June 1999, 4000 consecutive patients underwent coronary and/or valve surgery at our hospital; of these, 2213 (55.3%) underwent surgery with centrifugal pump use, while 1787 (44.7%) were operated on with a roller pump. The effect of the type of the pump and of 36 preoperative and intraoperative risk factors for perioperative death, permanent neurological deficit and coma were assessed using univariate and multivariate analyses. **Results:** The overall in-hospital mortality rate was 2.2% (88/4000), permanent neurological deficit occurred in 2.0% (81/4000) of patients, and coma in 1.3% (52/4000). There was no difference in hospital mortality between patients operated with the use of centrifugal pumps and those operated with roller pumps (50/2213 (2.3%) vs. 38/1787 (2.1%); \( P = 0.86 \)). On the other hand, patients who underwent surgery with centrifugal pumps had lower permanent neurological deficit (34/2213, (1.5%) vs. 47/1787 (2.6%); \( P = 0.020 \)) and coma (20/2213 (0.9%) vs. 32/1787 (1.8%); \( P = 0.020 \)) rates than patients operated with roller pumps. Multivariate analysis showed CPB time, previous TIA and age as risk factors for permanent neurological deficit, while centrifugal pump use emerged as protective. **Conclusions:** Centrifugal pump use is associated with a reduced rate of major neurological complications in adult cardiac surgery, although this is not paralleled by a decrease in in-hospital mortality. © 2000 Elsevier Science B.V. All rights reserved.

**Keywords:** Roller pump; Centrifugal pump; Mortality; Neurological outcome

1. Introduction

Neurological injury is one of the most debilitating complications after adult cardiac surgery performed using cardiopulmonary bypass (CPB). Despite a continuous trend towards a decline in overall mortality in adult cardiac surgery, an increase in the average age of patients undergoing cardiac surgery has resulted in a substantial increase in serious adverse neurological events, and in the proportion of related in-hospital deaths[1,2].

Previous studies have assessed the effect of CPB on neurological outcomes in adult patients undergoing cardiac surgery[3–10]; however, little information exists on whether the type of the pump used for CPB (roller vs. centrifugal) can affect the neurological outcomes of adult patients undergoing cardiac surgery.

The aim of this study was to evaluate risk factors for perioperative mortality and adverse neurological outcomes, with special emphasis on the role of using a roller or centrifugal pump for perfusion.

2. Patients and methods

We have retrospectively reviewed the charts of 4000 consecutive patients who, during the period of January 1994–June 1999, underwent coronary and/or valve surgery with the use of CPB at our hospital. Patients who had additional procedures performed (LV aneurysmectomy, carotid endarterectomy, ascending aorta replacement) were excluded from the study.

2.1. Surgical procedure

On the morning of surgery, patients received their usual dose of antianginal drugs, and 2–5 mg morphine and 1 mg atropine as premedication. All patients received a standard moderate dose of fentanyl and benzodiazepine anesthesia,
which was induced by the administration of sodium thiopental (3 mg/kg), fentanyl (0.75 μg/kg), succinylcholine (1 mg/kg), diazepam (10 mg) and pancuronium bromide (0.1 mg/kg). After endotracheal intubation, patients were ventilated to normocapnia with an oxygen and air mixture. Boluses of fentanyl (with or without droperidol), diazepam and pancuronium bromide were given when necessary. Cefuroxime (2 g) was given intravenously for infection prophylaxis. A radial artery catheter and a flow-directed pulmonary artery catheter were inserted for hemodynamic measurements. The extracorporeal circuit consisted of a roller pump (CAPS HLM; Stockert Instruments, Munich, Germany) or a centrifugal pump (Biomedicus BioPump; Medtronic, Milan, Italy), hollow fiber oxygenator with integrated heat exchanger, arterial filter, cardiotomy reservoir and polyvinyl tubing system. In all cases, an 'open' system was used for perfusion.

The type of pump was chosen based on a consensus between the surgeon and anesthesiologist, with preference given to the centrifugal pump for CPB times which were expected to be longer (>100 min).

No heparin bonding was used in the perfusion tubing or oxygenator. The extracorporeal circuit was primed with 1500 ml electrolyte solution and 5000 IU bovine lung heparin (Liquemin; Roche, Italy).

After systemic heparinization (300 U/kg), CPB was initiated with cannulas placed in the ascending aorta and right atrium. The activated clotting time was kept at >400 s with additional heparin.

The pump flow was non-pulsatile in all operations. The flow rate was maintained at 2.4 l/min per m² during cooling and rewarming phases, and at 2.0 l/min per m² during stable hypothermia. The mean arterial pressure (MAP) during CPB was maintained between 60 and 90 mmHg, with CPB flows set as previously described, and vasoactive drugs were used to maintain the MAP in the desired range: if the MAP increased above the desired range, and was unresponsive to fentanyl or diazepam, sodium nitroprusside was started, but if the MAP fell below the desired range, norepinephrine, boluses or continuous infusion were added. Patients were cooled to 28–30°C. CPB flows and pressures were downloaded from the monitor and recorded every 5 min during perfusion. Any significant modification of the perfusion pattern during 5 min time intervals was also recorded by the perfusionist.

For myocardial protection, patients received a first dose (1000 cc) of cool (4°C) antegrade and retrograde high-potassium cold crystalloid cardioplegia (St. Thomas Hospital Cardioplegic solution containing 110 mmol/l NaCl, 16 mmol/l KCl, 16 mmol/l MgCl₂, 1.2 mmol/l CaCl₂ and 10 mmol/l NaHCO₃) just after aortic cross-clamping, which was repeated (250 ml retrograde) at every 20 min of the aortic cross-clamp time. Disturbances in the acid–base balance were appropriately treated, and the acid–base equilibrium was maintained by the alpha-STAT method. The hemotocrit during CPB was maintained at 18–25%.

After termination of CPB, heparin was antagonized with protamine sulfate at a 1:1 ratio (3 mg/kg). If necessary, inotropic support was given when patients were weaned from CPB. Autologous blood and residual volume from the extracorporeal circuit were infused into the patient when volume supplementation was necessary.

### Table 1
Preoperative variables of the study population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at intervention (years)</td>
<td>64 (57–70)</td>
</tr>
<tr>
<td>Preoperative weight (kg)</td>
<td>76 (64–80)</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.8 (1.7–1.9)</td>
</tr>
<tr>
<td>Male sex</td>
<td>2885/4000 (72)</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>2142/4000 (54)</td>
</tr>
<tr>
<td>History of smoking</td>
<td>1610/4000 (40)</td>
</tr>
<tr>
<td>Previous myocardial infarction</td>
<td>1685/4000 (42)</td>
</tr>
<tr>
<td>Previous cardiac surgery</td>
<td>288/4000 (7.2)</td>
</tr>
<tr>
<td>Previous vascular surgery</td>
<td>152/4000 (3.8)</td>
</tr>
<tr>
<td>Insulin-dependent diabetes mellitus</td>
<td>103/4000 (2.6)</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>414/4000 (10)</td>
</tr>
<tr>
<td>History of asthma</td>
<td>66/4000 (1.7)</td>
</tr>
<tr>
<td>History of COPD</td>
<td>344/4000 (8.6)</td>
</tr>
<tr>
<td>History of heart failure</td>
<td>535/4000 (13)</td>
</tr>
<tr>
<td>Previous TIA</td>
<td>271/4000 (6.8)</td>
</tr>
<tr>
<td>Previous RIND</td>
<td>43/4000 (1.1)</td>
</tr>
<tr>
<td>Previous stroke</td>
<td>147/4000 (3.7)</td>
</tr>
<tr>
<td>Previous neurological events</td>
<td>448/4000 (11)</td>
</tr>
<tr>
<td>Blood hematocrit (%)</td>
<td>39 (36–42)</td>
</tr>
<tr>
<td>Blood creatinine level (mg/dl)</td>
<td>1.1 (0.9–1.2)</td>
</tr>
<tr>
<td>Blood creatinine level (&gt;2 mg/dl)</td>
<td>57/4000 (1.4)</td>
</tr>
<tr>
<td>Sinus rhythm at preoperative EKG</td>
<td>338/4000 (85)</td>
</tr>
</tbody>
</table>

* Numbers in parentheses represent either percentage values or 25th and 75th percentiles.

### Table 2
Operative variables of the study population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of surgery</td>
<td>2704/4000 (68)</td>
</tr>
<tr>
<td>CABG</td>
<td>477/4000 (12)</td>
</tr>
<tr>
<td>AVR</td>
<td>416/4000 (10)</td>
</tr>
<tr>
<td>MVR</td>
<td>220/4000 (5.5)</td>
</tr>
<tr>
<td>DVR</td>
<td>183/4000 (4.5)</td>
</tr>
<tr>
<td>CABG + VR</td>
<td>2213/4000 (55)</td>
</tr>
<tr>
<td>Use of centrifugal pump for CPB</td>
<td>79 (61–101)</td>
</tr>
<tr>
<td>Aortic cross-clamp time (min)</td>
<td>109 (88–136)</td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>17/4000 (0.4)</td>
</tr>
<tr>
<td>Need to perform a circulatory arrest (&gt;5 min)</td>
<td>2.3 (2.1–2.4)</td>
</tr>
<tr>
<td>CPB flow during the cooling phase (l/min per m²)</td>
<td>70 (60–80)</td>
</tr>
<tr>
<td>Blood pressure during the cooling phase (mmHg)</td>
<td>2 (1.8–2.2)</td>
</tr>
<tr>
<td>CPB flow during the stable hypothermia phase (l/min per m²)</td>
<td>75 (65–85)</td>
</tr>
<tr>
<td>Blood pressure during the stable hypothermia phase (mmHg)</td>
<td>23 (2.2–2.4)</td>
</tr>
<tr>
<td>CPB flow during the rewarming phase (l/min per m²)</td>
<td>70 (65–80)</td>
</tr>
<tr>
<td>Blood pressure during the rewarming phase (mmHg)</td>
<td>29.2 (27.6–30.0)</td>
</tr>
<tr>
<td>Minimum esophageal temperature reached (°C)</td>
<td>30.6 (29.6–31.5)</td>
</tr>
<tr>
<td>Minimum rectal temperature reached (°C)</td>
<td>2.2 (2.1–2.3)</td>
</tr>
<tr>
<td>CPB flow during the entire bypass time (l/min per m²)</td>
<td>73 (67–79)</td>
</tr>
</tbody>
</table>

* Numbers in parentheses represent either percentage values or 25th and 75th percentiles.
After surgery, patients were admitted to the intensive care unit (ICU) and treated according to a standardized protocol. The MAP was kept at 70±90 mmHg, heart rate at 70±90 beats/min, and the cardiac index was maintained at greater than 2.0 l/min per m². Inotropic support was administered when necessary. Patients were ventilated to normocapnia, and an arterial oxygen tension of 80 mmHg with continuous positive-pressure ventilation until extubation was maintained according to the ICU regimen. Basic fluid administration consisted of 0.9% NaCl and polygelatine. Packed erythrocytes were infused when the hematocrit was <20% during CPB and <24% in the ICU. When their cardio-

<table>
<thead>
<tr>
<th>Variable</th>
<th>Centrifugal pump</th>
<th>Roller pump</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at intervention (years)</td>
<td>64 (57–70)</td>
<td>64 (56–70)</td>
<td>0.25</td>
</tr>
<tr>
<td>Preoperative weight (kg)</td>
<td>72 (64–80)</td>
<td>71 (64–80)</td>
<td>0.086</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.8 (1.7–1.9)</td>
<td>1.8 (1.7–1.9)</td>
<td>0.25</td>
</tr>
<tr>
<td>Male sex</td>
<td>73 (16/2213)</td>
<td>71 (1271/1877)</td>
<td>0.21</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>53 (11/2213)</td>
<td>54 (966/1877)</td>
<td>0.58</td>
</tr>
<tr>
<td>History of smoking</td>
<td>41 (9/2213)</td>
<td>39 (695/1877)</td>
<td>0.12</td>
</tr>
<tr>
<td>Previous myocardial infarction</td>
<td>45 (984/2213)</td>
<td>39 (701/1877)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous cardiac infarction</td>
<td>8.6 (190/2213)</td>
<td>5.5 (98/1877)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous vascular surgery</td>
<td>3.7 (81/2213)</td>
<td>4.0 (71/1877)</td>
<td>0.66</td>
</tr>
<tr>
<td>Insulin-dependent diabetes mellitus</td>
<td>3.1 (68/2213)</td>
<td>2.0 (35/1877)</td>
<td>0.035</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>11 (239/2213)</td>
<td>9.8 (175/1877)</td>
<td>0.32</td>
</tr>
<tr>
<td>History of asthma</td>
<td>1.7 (37/2213)</td>
<td>1.6 (29/1877)</td>
<td>0.99</td>
</tr>
<tr>
<td>History of COPD</td>
<td>8.2 (181/2213)</td>
<td>9.1 (163/1877)</td>
<td>0.31</td>
</tr>
<tr>
<td>History of heart failure</td>
<td>12 (275/2213)</td>
<td>15 (260/1877)</td>
<td>0.056</td>
</tr>
<tr>
<td>Previous TIA</td>
<td>7.7 (170/2213)</td>
<td>5.7 (101/1877)</td>
<td>0.013</td>
</tr>
<tr>
<td>Previous RIND</td>
<td>1.1 (25/2213)</td>
<td>1.0 (18/1877)</td>
<td>0.82</td>
</tr>
<tr>
<td>Previous stroke</td>
<td>4.2 (94/2213)</td>
<td>3.0 (53/1877)</td>
<td>0.040</td>
</tr>
<tr>
<td>Previous neurological events</td>
<td>13 (285/2213)</td>
<td>9.1 (163/1877)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood hematocrit (%)</td>
<td>40 (36–43)</td>
<td>39 (35–42)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood creatinine level (mg/dl)</td>
<td>1.1 (0.9–1.2)</td>
<td>1.1 (0.9–1.2)</td>
<td>0.23</td>
</tr>
<tr>
<td>Blood creatinine level (&gt;2 mg/dl)</td>
<td>1.5 (33/2213)</td>
<td>1.3 (24/1877)</td>
<td>0.78</td>
</tr>
<tr>
<td>Sinus rhythm at preoperative EKG</td>
<td>84 (1859/2213)</td>
<td>85 (1521/1877)</td>
<td>0.35</td>
</tr>
</tbody>
</table>

a Centrifugal vs. roller.
b Figures represent either percentage values followed by the proportion in parentheses or median followed by 25th and 75th percentile in parentheses.

Table 3
Preoperative variables of the study population by the type of pump

Table 4
Operative variables of the study population by the type of pump

<table>
<thead>
<tr>
<th>Variable</th>
<th>Centrifugal pump</th>
<th>Roller pump</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of surgery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CABGb</td>
<td>68 (1513/2213)</td>
<td>67 (1191/1877)</td>
<td>0.30</td>
</tr>
<tr>
<td>AVRb</td>
<td>12 (264/2213)</td>
<td>12 (213/1877)</td>
<td></td>
</tr>
<tr>
<td>MVrb</td>
<td>11 (232/2213)</td>
<td>10 (184/1877)</td>
<td></td>
</tr>
<tr>
<td>DVRb</td>
<td>5 (107/2213)</td>
<td>6 (113/1877)</td>
<td></td>
</tr>
<tr>
<td>CABG + VRb</td>
<td>4 (97/2213)</td>
<td>5 (86/1877)</td>
<td></td>
</tr>
<tr>
<td>Aortic cross-clamp time (min)</td>
<td>81 (62–1049)</td>
<td>76 (60–98)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>112 (90–140)</td>
<td>106 (85–131)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Need to perform a circulatory arrest (&gt;5 min)b</td>
<td>0.7 (16/2213)</td>
<td>0.4 (7/1877)</td>
<td>0.24</td>
</tr>
<tr>
<td>CPB flow during the cooling phase (l/min)</td>
<td>2.3 (2.2–2.4)</td>
<td>2.3 (2.2–2.4)</td>
<td></td>
</tr>
<tr>
<td>Blood pressure during the cooling phase (mmHg)</td>
<td>75 (65–80)</td>
<td>70 (60–75)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CPB flow during the stable hypothermia phase (l/min per m²)</td>
<td>2.0 (1.8–2.1)</td>
<td>2.0 (1.8–2.2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood pressure during the stable hypothermia phase (mmHg)</td>
<td>80 (70–85)</td>
<td>70 (60–80)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CPB flow during the rewarming phase (l/min per m²)</td>
<td>2.3 (2.2–2.4)</td>
<td>2.3 (2.2–2.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood pressure during the rewarming phase (mmHg)</td>
<td>75 (65–80)</td>
<td>70 (65–75)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Minimum esophageal temperature reached (°C)</td>
<td>29.5 (28.5–30.1)</td>
<td>28.3 (27.1–29.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Minimum rectal temperature reached (°C)</td>
<td>30.8 (30.0–31.6)</td>
<td>30.4 (29.3–31.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CPB flow during the entire bypass time (l/min per m²)</td>
<td>2.2 (2.0–2.3)</td>
<td>2.2 (2.1–2.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood pressure during the entire bypass time (mmHg)</td>
<td>75 (69–82)</td>
<td>70 (63–77)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

a Centrifugal vs. roller.
b Figures represent either percentage values followed by the proportion in parentheses or median followed by 25th and 75th percentile in parentheses.
respiratory condition had stabilized, patients were transported to the ward for further recovery.

2.2. Statistical analysis

The data are presented as medians (25 and 75% percentiles in brackets) for continuous variables or percentages for categorical variables. A commercial statistical package (SPSS for Windows Version 8.0; SPSS, Inc., Chicago, IL) was used for data analysis.

Thirty-seven preoperative and operative variables, including the type of pump employed for CPB (roller vs. centrifugal; Tables 1 and 2) were assessed for their possible effect on the occurrence of the following outcomes, which were defined as follows:

In-hospital mortality: any death occurring within 30 days after surgery, or anytime before discharge of the patient from the hospital;
Permanent neurological deficit: a central neurological deficit persisting >72 h;
Coma: unresponsiveness >24 h in the absence of sedation.

All continuous variables were first tested individually (univariate sense) with the non-parametric Mann–Whitney test, while categorical variables were explored by the Chi-square (Yates’ continuity correction) or the Fisher’s exact test when indicated.

The factors which were at least marginally significant \( (P \leq 0.2) \) by univariate analysis were included into a multivariable forward stepwise logistic regression model. The multivariate odds ratio (OR) for each independent variable in the final regression models and 95% confidence intervals were also computed. The \( P \) value for entry of a covariate into the model was set at a significance level 0.05, while the \( P \) value for the removal of a covariate was fixed at the 0.1 significance level. Every multivariable model was tested for reliability with the Hosmer–Lemeshow statistic [11].

3. Results

3.1. Patient population

The preoperative and operative clinical features of the patient population are reported in Tables 1 and 2, respectively. Briefly, the median age was 65, 72% of the patients were male, 3.7% had had a previous stroke, 7.2% were

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR</th>
<th>95% CI</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPB time (min)</td>
<td>1.015</td>
<td>1.011–1.394</td>
<td>0.0001</td>
</tr>
<tr>
<td>Previous cardiac surgery</td>
<td>1.7</td>
<td>1.2–2.3</td>
<td>0.0026</td>
</tr>
<tr>
<td>Blood creatinine level &gt;2 mg/dl</td>
<td>2.0</td>
<td>1.1–3.6</td>
<td>0.0189</td>
</tr>
<tr>
<td>Blood hematocrit (%)</td>
<td>0.94</td>
<td>0.88–0.99</td>
<td>0.0215</td>
</tr>
</tbody>
</table>

\( \chi^2(8) = 7.01; P = 0.54. \)
redos, 13% had a history of heart failure, 68% underwent coronary artery bypass grafting, 55% underwent surgery with the use of a centrifugal pump, and the median CPB time was 110 min.

The clinical variables of patients who underwent surgery using centrifugal or roller pumps are reported in Tables 3 and 4. Regarding preoperative variables, the two groups of patients were similar in age, body surface area, gender, history of hypertension, preoperative pulmonary, and renal status; on the other hand, patients who underwent surgery with the use of a centrifugal pump had a higher incidence of previous myocardial infarction, insulin-dependent diabetes mellitus, were more frequently redos, and had a higher incidence of previous transitory ischemic attack (TIAs), strokes, and overall neurological events. The analysis of the operative variables showed similar frequencies in the different types of surgery, as well as in the need to perform a circulatory arrest, while aortic cross-clamp and CPB times were, as expected, longer in cases using a centrifugal pump. Finally, there were statistically significant differences in perfusion pressures, flows and temperatures between roller and centrifugal pumps: pump flows were slightly lower in cases of centrifugal pump use, while pressures and temperatures were slightly higher; however, in no case did the differences between the two groups in CPB-related variables exceed a 10% variation, and this was reported as less than 5% in most of the comparisons.

### 3.2. In-hospital mortality

The overall in-hospital mortality rate of this series of patients was 2.2% (88/4000); there was no difference between hospital mortalities based on the type of pump, those being 2.3 (50/2213) and 2.1% (38/1787) for patients who were operated on using centrifugal and roller pumps, respectively ($P = 0.860$). The univariate risk factors for in-hospital death are reported in Table 5; and the multivariate risk factors for in-hospital death were longer CPB times, previous cardiac surgery, blood creatinine levels > 2 mg/dl, and lower blood hematocrit levels (Table 6).

The interactions among in-hospital mortality, neurological events, and type of pump are shown in Table 7.
of a centrifugal pump for CPB emerged as a protective factor (Table 9).

### 3.4. Analysis of the risk factors for the occurrence of perioperative coma

The significant or marginally significant univariate risk factors for perioperative coma are reported in Table 10. Regarding the type of pump used for perfusion, patients who underwent surgery with a centrifugal pump had a perioperative coma rate of 0.9% (20/2213), while the incidence of coma in patients who were operated using a roller pump was 1.8% (32/1787; \( P = 0.020 \)). Multivariable logistic regression analysis identified longer CPB times, previous vascular surgery and increasing age as independent risk factors for the occurrence of perioperative coma, while centrifugal pump use resulted as protective (Table 11).

### 4. Discussion

The continuous improvement of techniques in adult cardiac surgery has substantially reduced the morbidity and mortality in cardiac operations requiring CPB. Despite these advances, however, adverse neurological and neuro-behavioral outcomes continue to occur, at perhaps an increased frequency, due to the progressive aging of the population of patients undergoing cardiac surgery [1,2].

To date, several studies assessed the effect of CPB-related variables on neurological outcomes in adult patients undergoing cardiac surgery; in particular, it could be demonstrated that longer CPB times [4,5] and severity of ascending aorta atherosclerosis [4,8] were strong predictors

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### Table 9

Results of multivariate logistic regression for perioperative permanent neurological deficit

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR</th>
<th>95% CI</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPB time (min)</td>
<td>1.007</td>
<td>1.004–1.010</td>
<td>0.0001</td>
</tr>
<tr>
<td>Previous TIA</td>
<td>2.5</td>
<td>1.5–4.4</td>
<td>0.0067</td>
</tr>
<tr>
<td>Age at intervention (years)</td>
<td>1.038</td>
<td>1.014–1.062</td>
<td>0.0116</td>
</tr>
<tr>
<td>Use of centrifugal pump for CPB</td>
<td>0.57</td>
<td>0.38–0.87</td>
<td>0.0363</td>
</tr>
</tbody>
</table>

\( ^a \) Hosmer-Lemeshow goodness-of-fit-test, \( \chi^2(8) = 8.86; P = 0.35 \).

### Table 10

Significant or borderline univariate risk factors for perioperative coma

<table>
<thead>
<tr>
<th>Variable</th>
<th>Perioperative coma vs. no perioperative coma</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at intervention (years)</td>
<td>69 (64–72) vs. 64 (57–70)</td>
<td>0.001</td>
</tr>
<tr>
<td>Preoperative weight (kg)</td>
<td>68 (60–72) vs. 72 (64–80)</td>
<td>0.001</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.7 (1.6–1.8) vs. 1.8 (1.7–1.9)</td>
<td>0.001</td>
</tr>
<tr>
<td>Previous cardiac surgery(^a)</td>
<td>15 (8/52) vs. 7.1 (280/3948)</td>
<td>0.043</td>
</tr>
<tr>
<td>Previous vascular surgery(^a)</td>
<td>13 (7/52) vs. 3.7 (145/3948)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Peripheral vascular disease(^a)</td>
<td>21 (11/52) vs. 10 (403/3948)</td>
<td>0.019</td>
</tr>
<tr>
<td>Previous RIND(^a)</td>
<td>5.8 (3/52) vs. 1.0 (43/3948)</td>
<td>0.009</td>
</tr>
<tr>
<td>Previous stroke(^a)</td>
<td>12 (6/52) vs. 3.6 (141/3948)</td>
<td>0.008</td>
</tr>
<tr>
<td>Blood hematocrit (%)</td>
<td>35 (33–39) vs. 39 (36–42)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Blood creatinine level (mg/dl)</td>
<td>1.2 (1.0–1.5) vs. 1.1 (0.9–1.2)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Sinus rhythm at preoperative EKG(^a)</td>
<td>63 (33/52) vs. 85 (3347/3948)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Use of centrifugal pump for CPB(^a)</td>
<td>38 (20/52) vs. 56 (2193/3948)</td>
<td>0.020</td>
</tr>
<tr>
<td>Aortic cross-clamp time (min)</td>
<td>91 (76–126) vs. 79 (61–100)</td>
<td>0.005</td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>148 (111–181) vs. 109 (88–135)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Need to perform a circulatory arrest &gt;5 min(^a)</td>
<td>5.8 (3/52) vs. 0.4 (14/3948)</td>
<td>0.013</td>
</tr>
<tr>
<td>Blood pressure during the stable hypothermia phase (mmHg)</td>
<td>70 (60–80) vs. 75 (65–85)</td>
<td>0.030</td>
</tr>
<tr>
<td>Blood pressure during the rewarming phase (mmHg)</td>
<td>70 (65–75) vs. 70 (65–80)</td>
<td>0.024</td>
</tr>
<tr>
<td>Minimum esophageal temperature reached (°C)</td>
<td>28.2 (27.0–29.3) vs. 29.2 (27.6–30.0)</td>
<td>0.002</td>
</tr>
<tr>
<td>Minimum rectal temperature reached (°C)</td>
<td>30.0 (28.4–31.1) vs. 30.6 (29.6–31.5)</td>
<td>0.005</td>
</tr>
</tbody>
</table>

\( ^a \) Figures outside either parentheses represent percentage values or median followed by 25th and 75th percentiles in parentheses.
of perioperative neurological complications, while lack of arterial line filtration [9,12] and pH-stat acid–base management [10] could also increase the occurrence of postoperative central nervous system dysfunction. On the other hand, the possible effects of other CPB variables are still being debated, and the roles of temperature management (normothermic vs. moderately hypothermic perfusion), mean arterial pressure levels during CPB and type of perfusion (pulsatile vs. non-pulsatile) in affecting neurological complication rates have not yet been completely defined [13].

Centrifugal pumps have been widely used as the main pump in adult cardiac surgery, and are considered by some authors to be superior to the traditionally used roller pumps because of less blood trauma [14], reduced activation of the coagulation cascade [15] and improved biocompatibility [16], even if some of the studies could not document any significant benefits in terms of hemolysis [17], platelet damage [18] or immune response [19]; in addition, some recent evidence could document an increased inflammatory response to CPB in cases using centrifugal pumps [20,21].

There is less information, however, on the effect of the use of this kind of pump on clinical endpoints, and the effects on neurological function are not well established yet; even if centrifugal pumps have been shown to generate fewer microemboli than roller pumps [22], it was recently demonstrated that, for CPB times of less than 90 min, centrifugal pumps did not decrease serum S100B release, a marker for cerebral injury, compared with roller pumps [23]. In addition, only one paper, by Klein and colleagues, has previously evaluated the effect of centrifugal and roller pumps used for CPB on many different clinical outcomes, documenting a reduced rate of neurological complications when a centrifugal pump was used for perfusion; but no additional information was given about the criteria used to define neurological complications in this paper [24].

The aim of our study was then to retrospectively review the data concerning adult patients who underwent coronary and/or valve surgery at our hospital during a 5.5-year period (1994–June 1999); during that period, in fact, both types of pump (roller and centrifugal) were used at our hospital at the same time by the same team of surgeons, anesthesiologists and perfusionists. Our study could show that factors related both to the preoperative clinical status of the patients and to operative and CPB features can affect the occurrence of major neurological complications; age at intervention, previous vascular surgery, previous neurological episodes, as well as longer CPB times were risk factors for adverse neurological outcomes of adult cardiac surgery patients, as previously described [13].

In addition, our study documented that the use of a centrifugal pump can reduce the rates of the two most feared neurological complications of routine adult cardiac surgery performed with the use of CPB; univariate and multivariate analyses documented its protective effect, for the occurrence of both perioperative permanent neurological deficit and perioperative coma, reducing the risk reduction for the considered events by approximately half (multivariable ORs of 0.57 and 0.46 for perioperative permanent neurological deficit and perioperative coma, respectively).

Interestingly, the protective effect of centrifugal pump use could be documented even if there was a clear selection bias between the two pump types in our patient population, and centrifugal pumps were preferred, as previously stated, for cases with longer perfusion times. Also, the subgroup analysis comparing preoperative and operative variables by the type of pump could confirm that patients operated with centrifugal pumps, aside from the expected longer aortic cross-clamp and CPB times, also had an increased risk profile for the considered events, being more frequently redos, insulin-dependent diabetics, and having a higher rate of pre-existing neurological events; in fact, all of these three factors were previously documented as risk factors for unfavorable neurological outcome [2].

The hypothesis to explain the protective effect of the centrifugal pumps used for CPB is, that with centrifugal pumps, the embolic load to the brain is lower [22], as was previously demonstrated with ultrasonic microbubble detection in the arterial CPB line [25].

On the other hand, the potential neurological benefit of the use of a centrifugal pump for perfusion was not paralleled by a decrease in in-hospital mortality; this finding has no clear explanation to us, and further investigations will be needed to clarify this point.

In conclusion, this study, with the limits of a retrospective, non-randomized study, suggests that centrifugal pump use during routine adult cardiac surgery reduced perioperative permanent neurological deficit and coma rates. Prospective, multi-institutional, randomized studies will be needed to better define the possible protective effects of centrifugal pumps on neurological outcomes of adult cardiac surgery.

References


