JECT. 2001;33:4–9
The Journal of The American Society of ExtraCorporeal Technology

Original Articles

Centrifugal Pump and Reduction of Neurological Risk in Adult Cardiac Surgery

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Presented at AmSECT 38th International Conference, Reno, NV, April 12–16, 2000.

Abstract: This study was performed to assess if the kind of pump used for CPB (roller vs. centrifugal) can influence neurological outcomes of adult cardiac surgery patients. Between 1994 and 1998, 3438 patients underwent coronary and/or valve surgery at our hospital; of these, 1805 (52.5%) underwent surgery with the use of a centrifugal pump, and 1633 (47.5%) were operated with a roller pump. The effect of the type of the pump and of common preoperative and intraoperative risk factors for five different neurological outcomes (permanent neurological deficit, coma, delirium, transient neurological deficit, overall neurological complications) were assessed with univariate and multivariate analyses in the whole patients population, in patients ≥ 75 years old and in patients with histories of previous neurological events. Centrifugal pump use was the only protective factor for perioperative permanent neurological deficit in multivariable models developed for the whole patient population and for patients ≥ 75 years old. In addition, it resulted as the only protective factor for perioperative coma occurrence in multivariable models developed for patients ≥ 75 years old, and for patients with histories of previous neurological events. The use of the centrifugal pump provided a risk reduction for the considered events ranging from 23 to 84%. Centrifugal pump use can be helpful in reducing the occurrence of some of the most feared neurological complications of adult cardiac surgery patients. *JECT. 2001;33:4–9*

Neurological injury is the most feared complication after adult cardiac surgery. Recently, the increase of the average age of patients undergoing cardiac surgery has resulted in a substantial increase of serious adverse neurological events and of the proportion of related in-hospital deaths (1, 2).

Previous papers have already evaluated the effect of cardiopulmonary bypass (CPB) on neurological outcomes in adult patients undergoing cardiac surgery, reaching sometimes conflicting results (3–10); however, there is little information about the possible role of the type of pump used for CPB on neurological outcomes of adult patients undergoing cardiac surgery.

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Received 15 April 2000; revised 17 June 2000.

MATERIALS AND METHODS

We retrospectively reviewed the charts of 3438 patients who, during the period January 1994–December 1998, underwent coronary and/or valve surgery with the use of CPB at our hospital. Patients who had additional procedures (left ventricular aneurysmectomy, carotid endarterectomy, ascending aorta replacement) scheduled or subsequently performed in the same operative session were excluded from the study. The median age of this patient population was 64; 91.2% of patients were equal to or less than 75 years old; 72% of the patients were males; 13.2% had history of heart failure; 7.3% were resternotomies; 10.2% had history of peripheral vascular disease. Concerning the neurological status of the patient population, previous transient ischemia attack (TIA), reversible ischemic neurological deficit (RIND), and stroke had occurred in 7.2, 1.0, and 3.3% of patients, respectively, for a total of 11.2% of patients with histories of previous neurological events.

Concerning operative variables, 67.4% underwent coronary artery bypass graft, 28.1% single or multiple valve replacement or repair, 4.5% coronary bypass plus valve replacement; 52.5% underwent surgery with the use of a centrifugal pump, and 47.5% had the procedure performed with a roller pump. Median CPB and aortic cross-clamp times were 109 and 79 minutes, respectively.

Surgical Procedure

Management of patients during and after operation was substantially the same. All patients received standard moderate dose fentanyl and benzodiazepine anesthesia; after endotracheal intubation, patients were ventilated to normocapnia with oxygen and air mixture. The extracorporeal circuit consisted of a roller pump (CAPS heart lung machine, 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. The type of pump chosen was based on surgeon and anesthesiologist consensus, with preference given to centrifugal pump for longer (> 100 min) expected CPB times.

No heparin bonding was used in 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 IU/kg), CPB was initiated with cannulas placed in the ascending aorta and right atrium. Pump flow was nonpulsatile in all operations. The flow rate was maintained at 2.4 L/min/m^2 during cooling and rewarming phases and at 2.0 L/min/m^2 during stable hypothermia. 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 MAP in the desired range. Patients were cooled to 28–30°C. Disturbances in the acid base balance were appropriately treated, and acid base equilibrium was maintained by the alpha-STAT method. The hematocrit during CPB was maintained between 18–25%.

Statistical Analysis

Data are presented as median (continuous variables) or percentage (categorical variables). Analysis of our data was carried out in two different steps.

Step 1. Statistical Analysis: The first step of our study was to explore if the type of pump employed for CPB (roller vs. centrifugal) could affect any of the following neurological complications of our patient population.

1. *Permanent neurological deficit*: a central neurological deficit persisting > 72 hours;
2. *Coma*: unresponsiveness > 24 h in absence of sedation;
3. *Delirium*: mental disturbance marked by illusions, confusion, cerebral excitement, and having a comparatively short course;
4. *Transient neurological deficit*: a central neurological deficit that is totally resolved within 24 hours;
5. *Overall neurological complications*: the sum of the previous four neurological complications.

The effect of the type of the pump was studied on:

1. the whole patients population ($N = 3438$, 100%);
2. patients ≥ 75 years old ($N = 3135$, 91.2% of the patient population); and
3. patients with history of previous neurological events ($N = 385$, 11.2% of the patient population).

Step 2. Statistical Analysis: Should a significant, or possibly ($p \leq .2$) significant, difference be detected in the five endpoints by the type of pump, further analysis was carried out by assessing the effect of both preoperative and operative (including CPB data) variables (Table 1) on the same endpoint, employing both univariate and multivariate analyses to correct for possible biases related to the retrospective analysis.

For that reason, preoperative and operative variables considered as possible risk factors for adverse neurological outcomes (Table 1) were analyzed. All continuous variables were first tested individually (univariate) with the nonparametric Mann–Whitney test; whereas, categorical variables were explored by the chi-square or the Fisher's exact test when indicated. Covariates found to be significant ($p < .05$) or possibly significant ($p \leq .2$) were then entered into a multivariable forward stepwise logistic regression model. The multivariable Odds Ratio (OR) for each independent variable in the final regression models were also computed. The p-value for the entry in the model of a covariate was set at significance level .05; whereas, the p-value for removal of a covariate was fixed at .1 significance level. Three different multivariable models were developed for the neurological outcomes where univariate analysis had previously shown a possibly effect of the type of the pump; the first one evaluated all patients in the study; whereas, the second and the third one assessed the risk factors for patients less than 75 years old and for patients with history of previous neurological events, respectively.

RESULTS

The overall in-hospital mortality rate of this series of patients was 2.2% (76/3438); permanent neurological deficit occurred in 2.0% (68/3438) of patients, coma in 1.3% (44/3438), delirium in 2.6% (91/3438), transient neurological deficit in 0.3% (10/3438), for an overall neurological

Table 1. Preoperative and intraoperative variables analyzed in step 2 statistical analysis.

Preoperative variables
1. Gender;
2. Body surface area (m^2);
3. Age at intervention (yrs);
4. Preoperative weight (kgs);
5. Previous cardiac surgery;
6. Cerebrovascular disease;
7. Previous TIA;
8. Previous RIND;
9. Previous stroke;
10. History of hypertension;
11. History of smoke;
12. Previous myocardial infarction;
13. Previous vascular surgery;
14. Insulin-dependent diabetes mellitus;
15. Peripheral vascular disease;
16. History of asthma;
17. History of COPD;
18. History of heart failure;
19. Blood hematocrit (%);
20. Blood creatinine level (mg/dl)
21. Blood creatinine level >2 mg/dl;
22. Sinus rhythm at preoperative EKG;

Operative and CPB variables
1. Surgeon (n° 1–6);
2. Type of surgery (CABG = 1; AVR = 2; MVR = 3; DVR = 4; CABG + VR = 5);
3. Aortic crossclamp time (min);
4. Cardiopulmonary bypass time (min);
5. Type of pump used for cardiopulmonary bypass (roller = 1; centrifugal = 2);
6. Need to perform a circulatory arrest >5 min;
7. Median CPB flow during the cooling phase ($1/min/m^2$);
8. Median blood pressure during the cooling phase (mmHg);
9. Median CPB flow during the stable hypothermia phase ($l/min/m^2$);
10. Median blood pressure during the stable hypothermia phase (mmHg);
11. Median CPB flow during the rewarming phase ($l/min/m^2$);
12. Median blood pressure during the rewarming phase (mmHg);
13. Minimum oesophageal temperature reached (°C);
14. Minimum rectal temperature reached (°C);
15. Median CPB flow during the entire bypass time ($1/min/m^2$);
16. Median blood pressure during the entire bypass time (mmHg).

complications rate of 5.1% (177/3438). Some patients showed more than one neurological problem; for that reason, overall neurological complication rate is lower than the sum of the other four complications collected in this study. The in-hospital mortality rate for patients who developed a neurological complication was 15.8% (28/177); whereas, for the patients free from this kind of complications, it was 1.5% (48/3261, $p < .001$).

Step 1. Statistical Analysis: There were no differences in hospital mortality based on the type of the pump, being 2.3% (41/1805) and 2.1% (35/1633) in patients who were operated with the use of a centrifugal or of a roller pump, respectively ($p = .692$).

Concerning the possible relations between the occurrence of postoperative neurological complications and the type of pump used for CPB, in the whole patient population (Table 2A) and in patients ≤ 75 years old (Table 2B), there was a possibly ($p \leq .2$) significant difference in permanent neurological deficit and postoperative coma rates, being relatively lower in patients who underwent surgery with the use of centrifugal pump; whereas, there were no significant differences in the incidence of postoperative delirium, transient neurological deficit, and overall neurological complications. In patients with history of previous neurological events (Table 2C) there was a significant difference in postoperative coma rates, being lower in patients who underwent surgery with the use of a centrifugal pump (1.0 vs. 4.5%, $p = .05$); whereas, no differences could be detected in other neurological outcomes.

Step 2. Statistical Analysis: Because it could be demonstrated that a possible effect of the type of pump used for CPB on the perioperative permanent neurological deficit and coma rates, further statistical analyses were carried out for these two complications, assessing both univariate and multivariate predictors of such complications.

Risk Factors for Perioperative Permanent Neurological Deficit

The significant or borderline significant univariate risk factors for perioperative permanent neurological deficit in the whole patient population were increasing age at intervention, previous vascular surgery, cerebrovascular disease, peripheral vascular disease, previous TIA, lower preoperative blood hematocrit, higher preoperative blood creatinine level, a blood creatinine level > 2mg/dl, nonsinus rhythm at preoperative ECG, the use of roller pump for CPB, longer aortic crossclamp and cardiopulmonary bypass times, the need to perform a circulatory arrest > 5 min, and lower minimum esophageal and rectal temperature reached (°C).

Multivariable logistic regression analysis identified longer cardiopulmonary bypass times, previous TIAs, and increasing age as multivariate risk factors in the whole patient population for perioperative permanent neurological deficit, and the use of a centrifugal pump for CPB emerged as the only significant protective factor (Table 3A). The risk model developed for patients < 75 years of age showed that longer cardiopulmonary bypass times, previous vascular surgery, the need to perform a circulatory arrest > 5-min duration, and increasing age as multivariate risk factors for perioperative permanent neurological deficit; whereas, the use of a centrifugal pump for CPB was, again, the only significant protective factor (Table 3B). When this kind of analysis was carried out in patients with history of previous neurological events, only lower levels of hypothermia emerged as risk factors (Table 3C).

Analysis of the Risk Factors for the Occurrence of Perioperative Coma

The significant or borderline significant univariate risk factors for perioperative coma in the whole patient popu-

Table 2A. Effect of the type of the pump on neurological outcomes of the whole patient population (n = 3438).

Neurological complication	Roller pump	Centrifugal pump	p
Permanent neurological deficit	39/1633 (2.4%)	29/1805 (1.6%)	0.127
Coma	26/1633 (1.6%)	18/1805 (1.0%)	0.116
Delirium	39/1633 (2.4%)	52/1805 (2.9%)	0.423
Transient neurological deficit	5/1633 (0.3%)	5/1805 (0.3%)	0.874
Overall neurological complications	85/1633 (5.2%)	92/1805 (5.1%)	0.838

Table 2B. Effect of the type of the pump on neurological outcomes of patients ≤75 years old (n = 3135).

Permanent neurological deficit	37/1492 (2.5%)	25/1643 (1.5%)	0.054
Coma	24/1492 (1.6%)	14/1643 (0.9%)	0.053
Delirium	35/1492 (2.3%)	42/1643 (2.6%)	0.704
Transient neurological deficit	5/1492 (0.3%)	5/1643 (0.3%)	0.879
Overall neurological complications	78/1492 (5.2%)	75/1643 (4.6%)	0.389

Table 2C. Effect of the type of the pump on neurological outcomes of patients with history of previous neurological events (n = 385).

Permanent neurological deficit	7/179 (3.9%)	7/206 (3.4%)	0.789
Coma	8/179 (4.5%)	2/206 (1.0%)	0.050
Delirium	0/179	2/206 (1.0%)	0.501
Transient neurological deficit	1/179 (0.6%)	1/206 (0.5%)	0.879
Overall neurological complications	16/179 (8.9%)	12/206 (5.8%)	0.401

Some patients may show more than one of the neurological complications; for that reason the sum of the coma, permanent neurological deficit, delirium and transient neurological deficit rates may not give the exact rate of the overall neurological complications.

lation were increasing age, lower preoperative weight and body surface area, previous cardiac surgery, previous vascular surgery, peripheral vascular disease, previous RIND, previous stroke, lower blood hematocrit, higher blood creatinine level (mg/dL), non-sinus rhythm at preoperative ECG, the use of a roller pump for CPB, longer aortic crossclamp and cardiopulmonary bypass times, the need to perform a circulatory arrest > 5 min, lower blood pressure levels during the stable hypothermia and the rewarming phase, lower minimum esophageal and rectal temperatures reached (°C).

Multivariate logistic regression analysis identified longer cardiopulmonary bypass times, previous vascular surgery, higher blood creatinine levels, lower preoperative weight, increasing age, the need to perform a circulatory arrest > 5 min, previous RIND, and lower average blood pressures during the stable hypothermia phase as independent predictors of perioperative coma in the whole patient population (Table 4A).

The risk model developed for patients under 75 years old showed longer cardiopulmonary bypass times, previous vascular surgery, previous RIND, the need to perform a circulatory arrest > 5 min, increasing age, as independent risk factors of perioperative coma, while the use of a centrifugal pump for CPB emerged as protective (Table 4B).

The analysis of risk factors for coma in patients with histories of previous neurological events could show increasing CPB time and preoperative creatinine levels as risk factors, while centrifugal pump use emerged as a strong protective factor (Table 4C).

DISCUSSION

Recent years have shown a substantial reduction in morbidity and mortality rates of adult cardiac procedures requiring CPB. The only complications that continue to occur at almost the same frequency are neurological and neurobehavioral ones; this can be attributable to the progressive aging of the population of patients undergoing cardiac surgery and also to the continuously worsening risk profile of the same patients (1, 2).

Table 3A. Results of multivariate logistic regression for perioperative permanent neurological deficit in the whole patient population (n = 3438).

Variable	p	Odds Ratio
Cardiopulmonary bypass time (min)	<0.001	1.01
Previous TIA	0.009	1.57
Age at intervention (yrs)	0.011	1.04
Use of centrifugal pump for CPB	0.042	0.77

Table 3B. Results of multivariate logistic regression for perioperative permanent neurological deficit in patients ≤75 years (n = 3135).

Cardiopulmonary bypass time (min)	<0.001	1.01
Previous vascular surgery	0.001	2.23
Need to perform a circulatory arrest >5 min	0.003	3.64
Use of a centrifugal pump for CPB	0.012	0.62
Age at intervention (yrs)	0.013	1.06

Table 3C. Results of multivariate logistic regression for perioperative permanent neurological deficit in patients with history of previous neurological events (n = 385).

Minimum rectal temperature reached (°C)	0.009	0.64

Table 4A. Results of multivariate logistic regression for perioperative coma in the whole patient population (n = 3438).

Variable	p	Odds Ratio
Cardiopulmonary bypass time (min)	<0.001	1.01
Previous vascular surgery	0.001	2.22
Blood creatinine level (mg/dl)	0.015	1.36
Preoperative weight (kgs)	0.018	0.97
Age at intervention (yrs)	0.021	1.05
Need to perform a circulatory arrest >5 min	0.026	2.87
Previous RIND	0.035	2.30
Average blood pressure during the stable hypothermia phase (mmHg)	0.037	0.97

Table 4B. Results of multivariate logistic regression for perioperative coma in patients ≤75 years (n = 3135).

Cardiopulmonary bypass time (min)	<0.001	1.01
Previous vascular surgery	<0.001	2.38
Previous RIND	0.008	2.89
Need to perform a circulatory arrest >5 min	0.009	3.43
Use of a centrifugal pump for CPB	0.010	0.60
Age at intervention (yrs)	0.015	1.06

Table 4C. Results of multivariate logistic regression for perioperative coma in patients with history of previous neurological events (n = 385).

Cardiopulmonary bypass time (min)	<0.001	1.02
Blood creatinine level (mg/dl)	0.006	2.47
Use of a centrifugal pump for CPB	0.022	0.16

Many previous studies have addressed their efforts to study the effect of CPB-related variables on neurological outcomes in adult patients undergoing cardiac surgery; if longer CPB times and ascending aorta atherosclerosis are widely accepted risk factors for perioperative neurological complications, the role of temperature management (normothermic vs. moderately hypothermic perfusion), mean arterial pressure levels during CPB, type of perfusion (pulsatile vs. nonpulsatile and acid base management is still debated (11).

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 improved biocompatibility (12), reduced blood trauma (13), and activation of the coagulation cascade (14). There is lesser and controversial information, however, on the effect of the use of this kind of pump on neurological function: centrifugal pumps have been shown to generate fewer microemboli than roller pumps (15–17), but a recent paper showed that, for CPB times under 90 minutes, centrifugal pumps did not decrease serum S100β release, a marker for cerebral injury, with respect to roller pumps (18). Information is also lacking about clinical neurological endpoints.

Our study, with the limits of a retrospective nonrandomized study, but with the advantage of a very large patient population operated at a single institution, showed that centrifugal pumps can provide some reduction on the incidence of two of the most feared neurological complications of routine adult cardiac surgery performed with the use of CPB; centrifugal pump was the only protective factor at multivariate analysis for the occurrence of perioperative permanent neurological deficit, both on the whole patients population and in patients under 75 years old; in addition, it was the only protective factor for the occurrence of coma in patients under 75 years old and in patients with histories of previous neurological problems. In these models, it provided a risk reduction for the considered events ranging from 23 to 84% (odds ratios ranging from 0.16 to 0.77).

The protective effect of use of centrifugal pumps for CPB on the most feared neurological complications of adult coronary and/or valve surgery was not, to our knowledge, previously described.

The main 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 (15–17), because it was previously demonstrated with ultrasonic microbubble detection in the arterial CPB line (19), and this may effectively exert a protective effect in terms of the occurrence of perfusion-related neurological complications.

An alternative hypothesis is that, when a roller pump is used, the risk of whole body, and thus brain hypoperfusion, can be higher. A preliminary study from our group could document that patients perfused with roller pumps received perfusion flows 15 to 25% lower with respect to pump flow set on the pump console; whereas, this did not happen when a centrifugal pump was used, and this was attributable to the use and opening of the pump a–v shunts (i.e., arterial filter or blood sampling shunt). This difference in delivered flow could be ascribed to the different ways to set and measure perfusion flows with these two types of pumps: in fact, roller pumps usually do not incorporate a flowmeter on the CPB arterial line, and perfusionists can only set pump flow on the pump console without knowing if this would be the actual flow delivered to the patient. On the other hand, with centrifugal pumps, blood flow settings are done with the aid of a magnetic flowmeter on the arterial line, and the effect of the a–v shunts is directly corrected by adjusting pump speed depending upon flowmeter readings (20).

In conclusion, this study shows that centrifugal pump use during routine adult cardiac surgery reduced some of the most feared neurological complications. Prospective, multi-institution randomized studies will be needed to define better the possible protective effects of centrifugal pumps on neurological outcomes of adult cardiac surgery.

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