THE EFFECT OF CENTRIFUGAL PUMP AND ROLLER PUMP ON BLOOD COMPONENTS DURING CARDIOPULMONARY BYPASS

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Centrifugal pumps are non-occlusive pumps that offer centrifugal blood pumping using the method known as the constrained force vortex principle. In this prospective study, there were two groups, each group including 10 patients undergoing coronary artery bypass grafting (CABG) surgery. In group I, extracorporeal circulation (ECC) was established with a centrifugal pump (CP), and in group II, with a conventional roller pump (RP). In both groups, the patients were selectively assigned to have similar characteristics in terms of clinical, hemodynamic, and angiographic data.

CP was compared to RP in terms of their hemolytic effect during ECC: plasma free hemoglobin, hematocrit, platelet count, leukocyte count, haptoglobin, lactic dehydrogenase level, postoperative chest drainage, postoperative blood transfusion level were investigated. These parameters revealed that there was significant hemolysis and trauma to the blood components in RP group compared to CP group ($p<0.05$, $p<0.01$, respectively).

Key words: Open hearth surgery, extracorporeal circulation, roller pump, centrifugal pump

A non-pulsatile blood pump, first used clinically in 1975, was originally described in 1968 (1,2). This pump employs a method of centrifugal pumping known as the constrained force vortex principle. Advantages of this pump over conventional roller pump (RP) have been described: centrifugal pump (CP) ensures an automatic modification of pumping volume in response to variations of peripheral vascular resistance and returning

blood volume; it handles blood more atraumatically, and does not generate particulate microemboli due to spallation of tubing (3-12).

Moreover, CP can not displace large volumes of gas, a safety feature in prevention of gross air embolism during cardiopulmonary bypass (CPB) (1,2,13-16). Centrifugal pumps are recommended suggested especially in technically difficult and prolonged extracorporeal circulation (ECC) procedures, re-operations, multiple valve replacements, coronary artery bypass grafting (CABG) with low ejection fraction, in thoracic aneurysm surgery, and in cases requiring left ventricle assistance (17,18).

MATERIALS AND METHOD

Between February and April 1997, 20 open heart procedures were included in the study. There were two groups in the prospective study, each group consisted of 10 patients undergoing CABG surgery. In group I, ECC was established with a CP (Medtronic, Biomedicus, Biopump, NJ. USA), and in group II, the circuit was established with a conventional RP (DeBakey, Baylor, Texas, USA). The clinical characteristics of the two groups are presented in Table 1. The patients of the two selectively assigned groups were considered to be similar in terms of clinical, hemodynamic and angiographic data.

Table 1. Clinical characteristics of the centrifugal and roller pump groups.

	CP (n=10)	RP (n=10)
Age	54±3	58±5
Sex	Female(1/10)	Female(2/10)
Coronary angiography		
2 VD	4	1
3 VD	6	6
4 VD	-	3
LMCAD	1	1
Previous AMI	-	-
Hypertension	2	3
DM	-	-
β-blocker treatment	-	-
Ca antagonist treatment	-	-

VD: vessel disease, LMCAD: left main coronary artery disease, AMI: acute myocardial infarction, DM: diabetes mellitus

Table 2. Hemodynamic characteristics during perfusion.

	CP (n=10)	RP (n=10)
Body surface area (m^2)	160±0.16	167±0.11
Perfusion duration (min)	61.4±10.7	64.0±11.4
Flow rate (l/min)	4.5±2.5	4±1.5
Perfusion index (l/min/m^2)	2.4±0.5	2.52±0.4
Aortic clamp period (min)	45.7±8.3	47.4±8.6
Perfusion pressure (mmHg)	79±11	74±10
Urine output index (ml/hr/m^2)	140±80	159±95

All of the patients were under the age of seventy and none had previous acute myocardial infarction or diabetes mellitus.

CPB was performed by standard bypass techniques. Table 2 presents hemodynamic characteristics of perfusion in both groups. Myocardial preservation was performed with St Thomas' cold crystalloid cardioplegic solution (10 ml/kg) and topical hypothermia. Moderate hypothermia up to 26°C was applied. The dilution rate was primarily set at 20%.

The left internal mammary artery (LIMA) was used as the bypass graft for the left anterior descending (LAD) coronary artery. The circumflex and right coronary artery was bypassed with the saphenous vein grafts.

Ten patients in whom CP was used were compared to another 10 patients in whom RP was used, with respect to plasma free hemoglobin (PFH), hematocrit (Htc), platelet count, leukocyte count, haptoglobin, lactic dehydrogenase level (LDH), and postoperative chest drainage and postoperative blood transfusion.

Precorporeal circulation levels served as controls, and PFH, Htc, platelet count, leukocyte count, haptoglobin and lactic dehydrogenase levels were measured 30 min after the onset of ECC, at the postoperative 1st and 24th hours. Postoperatively, mediastinal

Table 3. Changes with respect to PFH, Htc, platelet count, leukocyte count, haptoglobin, lactic dehydrogenase levels in the two groups.

	Preoperative	Postoperative			
	Perfusion		(30th min)	1st hour	24th hour
PFH	RP	5.7±4.7	36.8±15.8	69.7±23.5	5.3±4.1
(mg/dl)	CP	6.1±4.9	24.6±9.8**	55.5±21.9**	3.8±2.8**
Hct	RP	40.2±1.7	20.2±0.5	30.3±0.8	34.6±0.7
(%)	CP	43.1±1.2	24.0±0.9*	36.6±0.8*	39.7±1.0
Plt	RP	278.1±23.5	70.1±6.6	147.4±19.9	144.8±10.1
(x1000)	CP	266.7±23.9	95.6±13.1**	177.5±18.3**	170.2±11.9**
Leu(mm^3	RP	6.8±0.4	4.1±0.3	14.7±1.9	15.1±1.7
x100)	CP	7.1±0.4	4.3±0.4	13.8±1.1	14.9±1.2
Haptoglb	RP	109.8±8.8	44.2±9.0	44.7±7.6	50.6±4.6
(mg/dl)	CP	116.8±11.9	73.6±8.1**	77.6±8.8**	118.4±9.3**
LDH	RP	276±17	368±30	487±45	501±26
(IU)	CP	279±21	344±40*	426±34*	442±30*

PFH: plasma free hemoglobin, Htc: hematocrit, Plt: Platelet, Leu: leukocyte, Haptoglb: haptoglobin, LDH: lactic dehydrogenase.
*$p < 0.05$ significant, **$p < 0.01$ highly significant

drainage and blood transfusion levels were monitored for 24 hours since both of these parameters can be accepted as relatively good indices of overall hemostasis.

Hypothesized differences between the groups were analyzed and expressed as mean± standard error of mean, a double-paired Student's t test was performed to evaluate differences between the groups according to blood pump type. $p<0.05$ was considered statistically significant, $p<0.01$ was highly significant.

RESULTS

There was no operative or hospital mortality. All of the patients were discharged from the hospital. Long-term follow-up period varied between ten and twelve months, and all of the patients were symptom free.

During ECC there was no significant hemodynamic difference between the CP and RP groups (Table 2); duration of ECC [61.4±10.7 (CP) vs 64.0±11.4 min (RP)] and aortic cross-clamp time [45.7±8.3 (CP) vs 47.4±8.6 min (RP)] were similar.

Perfusion indices [2.40±0.50 (CP) vs 2.52±0.40 l/min/m2 (RP)] and flow rates [4.5±2.5 (CP) vs 4.0±1.5 l/min (RP)] of the two groups were also similar.

In cases where systemic vascular resistance (SVR) increased, sodium nitroprusside was administered to maintain physiological flow rates without changing the rotation frequency. In RP group, adjustments of rotation frequency had to be made manually.

Hemodynamically, the two study groups were not significantly different from each other. There were, however, significant differences when the two pumps were compared in terms of the effects on blood components.

Table 3 presents changes with respect to PFH, Htc, platelet count, leukocyte count, haptoglobin, lactic dehydrogenase levels before, during, and after ECC in both groups. Following the onset of perfusion, PFH gradually increased, and reached its maximum

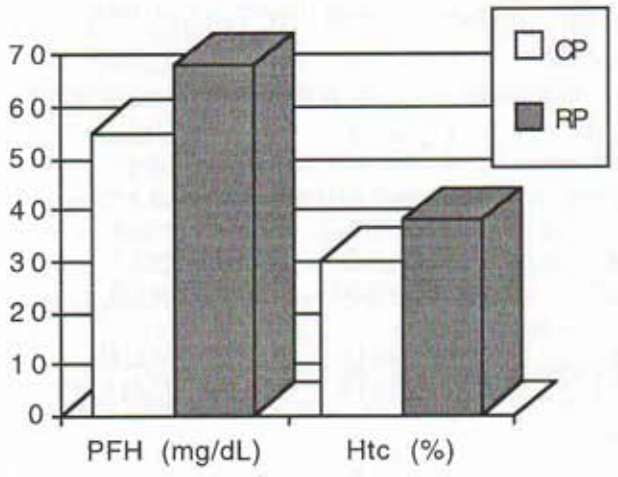

Figure 1. PFH and Htc levels in patients who have undergone CPB (postoperative 1st hour).

level in the post operative 1st hour (Table 3, Figure 1). The increment in PFH levels was significant in both groups after the onset of perfusion and remained at that level until the postoperative 1st hour ($p<0.01$). PFH recovered to the preoperative levels twenty four hours after the operation.

Hematocrit levels differed significantly between the two groups after the 30th minute of perfusion until the postoperative 1st hour ($p<0.05$). Further values of Htc were excluded from the study because of the variance in amount of blood transfusion. Table 3 and Figure 1 present the trends in Hct percentage. Although there was a statistically significant difference between the two groups, we do not consider this difference as important, since in every patient the amount of fluid added to the priming volume differs and hematocrit results are relative. In our opinion, Htc is not a reliable index of hemolysis in open-heart surgery.

Platelet count decreased after the initiation of ECC in both groups (Table 3). There was a significant decrease in platelet count in perfusion values and also between the CP and RP study groups ($p < 0.01$). The significant difference between the two groups appeared 30 min after the perfusion. Platelet count increased postoperatively but never reached the preoperative levels.

Postoperative chest drainage over 24 hours as a reflection of hematologic competence varied in both groups. Mean drainage and transfusion levels in group I and group II were 646±104 ml vs 460±25, ml and 735.7±75ml vs 571±48 ml, respectively ($p<0.05$).

As significant markers of hemolysis, haptoglobin and LDH levels in group I and group II were shown in Table 3 and Figure 2. The levels of haptoglobin and LDH revealed better preservation of hemoglobin in CP group ($p<0,05$). Leukocyte levels were shown in Table 3. In both groups, after the initiation of CPB, the leukocyte count showed a little decrease due to hemodilution and then started to rise significantly. There was no statistical difference between the two groups.

DISCUSSION

Various pumps have been invented in the research history of ECC and currently a roller pump, which was first introduced by Cappelleti (19), is the pump of choice. Although there is a wide experience with this pump, it still has many problems with respect to its potential damaging effect on blood components, durability, and safety (20). As a substitute for RP, CP was introduced and gained wide popularity in clinical and

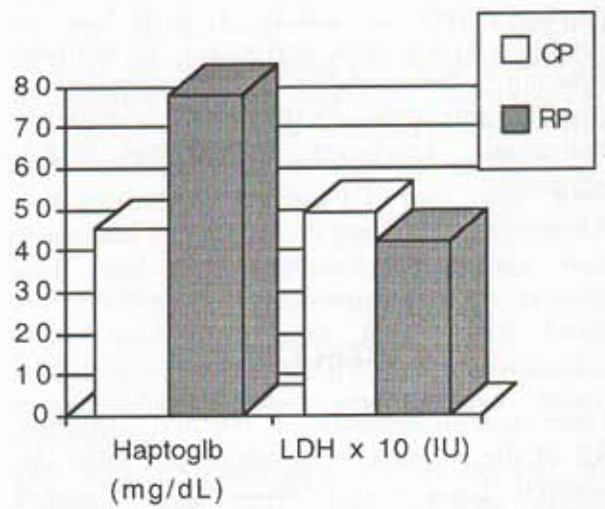

Figure 2. Haptoglobin and LDH levels in patients who have undergone CPB (postoperative 1st hour)

experimental ECC research (1,4,7,21,22).
Currently, CPs are the alternatives for short-term to intermediate application in heart-lung machines or in left ventricular assist devices (23).
CPs are toroidal pumps that operate on the constrained vortex principle. During CPB, blood is driven through the arterial line and returned to the patient by centrifugal forces or, in other words, by transferring kinetic energy in the direction of blood flow. "Kinetic pumps" (CPs) have the advantage of producing relatively high volumes at low pressures, whereas positive volume displacement pumps provide relatively low volumes at high pressures (2). Kinetic heart pumping possesses a high efficiency over a wide range of rotational speeds and flows. In other words, CPs have a hemodynamic feature in them that they alter flow rate in response to variations of preload and afterload. This pressure-flow rate response is similar to that of the heart (4,5). Recent studies demonstrated that centrifugal pumps could safely and automatically modify flow rate without changing the frequency of rotation. In these studies, it was stated that in sudden rises of systemic vascular resistance (SVR), CP can lower its flow rate without causing an abnormal increase in blood pressure even when its operation is kept at the same frequency of rotation, yet there is a possibility that the pump may fail to maintain the needed perfusion flow (6-9).
The same is true, however, with RP under the same conditions, flow rate must be lowered by reducing the frequency of rotation, so as to prevent an abnormal rise of arterial pressure. If a sufficient perfusion rate is not obtainable with the use of vasodilators, flow rate can be increased. If there is a sharp decrease in SVR, it should be solved by increasing the frequency of rotation in order to increase the perfusion rate in case RP is used, while flow rate may be increased without the necessity of changing the frequency of rotation in CP (7).
In the present study, none of the patients had preoperative systemic or pulmonary hypertension nor did the patients use beta blockers or other long-acting systemic vasodilators. None of the patients were diabetic. The only advantage observed in CP group was that in cases of systemic hypertension when flow rate fell under physiological perfusion indices, the pump gave an alarm indicating a need to decrease SVR.
Significant changes in hemostasis and degree of hemolysis are due to the usage of ECC during cardiac surgery. When ECC is utilized for a long-term cardiac and/or respiratory support, the duration of bypass may range from several hours to days. Plasma free hemoglobin (PFH) can be used as an index of pump-associated hemolysis. Several authors and manufacturers referred to the superior blood-handling capability of CPs when compared with RPs (8-12). Recent studies have demonstrated that PFH increases 7-10 times in RPs in comparison to CPs (10,11,24). It has been shown that RPs are more traumatic to red blood cells than CPs, suggesting that a RP is less desirable for long-term circulatory assistance from a hemolysis point of view (10,22,24,25). Recently, clinical and experimental studies have not demonstrated any significant difference among available CPs (9,23).
Beside these effects on hemoglobin, CP decreases the amount of so-called sublethal damage of erythrocytes which occurs after the first 24 hours of ECC by hemolysis of the destructed erythrocytes in the reticuloendothelial system (26,27).
In the present study, PFH levels of both groups gradually increased following the onset of perfusion and reached its maximum level at the post operative 1st hour. From then on, PFH levels decreased throughout the postoperative period. The increments in PFH levels were significant in both groups after the onset of perfusion and remained high in the postoperative first night ($p < 0.01$). PFH recovered to its preoperative levels by 24 hours after the operation.
Htc level differed significantly between the two groups after the 30th minute of perfusion ($p < 0.05$). Although there was a statistically significant difference between the two groups, we did not regard this result as important, since variation in priming might affect the results. In our opinion, Htc is not a reliable

index of hemolysis in open heart surgery.

Plasma level of LDH, an intracellular enzyme, was increased in parallel with the erythrocyte hemolysis (9,10,22,24,25). This increase in plasma level of LDH was lower in the CP group and the results significantly differed between the two groups ($p < 0.05$).

Haptoglobin, which is synthesized in the liver, normally appears in plasma in its free form. During hemolysis, it is bound to free hemoglobin with high affinity and its plasma level decreases rapidly (9,10,22,24,25). As a good marker of hemolysis, plasma haptoglobin levels were better preserved in CP group, while the difference between the CP and RP groups were significant ($p<0,01$).

Many investigators have reported platelet activation during ECC. It has been stated that all patients undergoing CPB displayed a platelet function defect.

Either platelet activation or platelet function defects can be responsible for the acute events in the hemostatic system. Especially, mechanical trauma and complex immunologic and cellular reactions might cause thromboembolism or non-surgical bleeding during the clinical use of CPB. There are many parameters measuring platelet activation/damage. Platelet count, PF release, thromboxane index, and β–thromboglobulin are some of these (28-31). Takeda (22) has shown that with the onset of ECC, platelet count decreases significantly in RP group compared to pre-ECC and CP group levels. Müller et al. (28) reported that the material used in blood pumps is much more important than the design of the pump. They stated that only roughly traumatizing designs involve the danger of relevant platelet release, as long as used plastic does not cause platelet activation (28).

Platelet count decreased after the initiation of ECC in both groups. There was a statistically significant decrease in platelet count at the 30th minute versus pre-ECC ($p < 0.01$) and in RP versus CP ($p < 0.05$). This difference continued and the levels did not recover to the preoperative levels.

It was reported that postoperative chest drainage was a relatively good index of overall hemostasis considering all the other parameters, such as surgical procedure, type of oxygenator priming mixture, temperature, and the amount of cardiotomy suction use. There was significantly less postoperative drainage in the CP patients compared to the RP group ($p < 0.05$). In parallel with the decreased blood trauma and drainage, transfusion requirement was significantly decreased in CP group ($p<0,05$).

Microemboli generated during ECC can be classified into three types: gaseous, biological, non-biological (spallation). RPs have the hazard of spallation of plastic tubing and macro/micro air embolism. Due to the design of CPs, spallation and air embolism are virtually not possible (1,2,13-16). Although it was not investigated in the present study, microembolism takes an important role in postoperative neuro-behavioural disturbances. These adverse effects were minimized with the use of CP (32-35).

In conclusion, centrifugal pumps are toroidal pumps that operate on the constrained vortex principle. Kinetic pumps have the advantage of producing relatively high volumes at low pressures. Kinetic heart pumping possesses a high efficiency over a wide range of rotational speeds and flows. In other words, CPs have a hemodynamic feature in them that they alter flow rate in response to variations of preload and afterload. Centrifugal blood pumping handles blood elements more atraumatically and does not generate particulate microemboli due to spallation of the tubing set. Prevention of gross air embolism is another safety measure of CPs.

When the patients in the two groups undergoing ECC were compared, CP was found to be significantly superior with respect to hematologic parameters. These results suggest that CPs can be used easily and safely in open heart surgery.

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