Original Article

The Design and Application of a Pediatric Centrifugal Pump

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Keywords: centrifugal pump, pediatric cardiac surgery, congential heart defect, cardiopulmonary bypass

Presented at the American Society of Extra-Corporeal Technology 35th International Conference, April 3-6, 1997, Phoenix, Arizona.

ABSTRACT

This centrifugal pump (CP) includes two parts: the blood pump and the driving apparatus. They are connected by six twin magnetic disc plates and driven by a magnetic DC motor (120W). The blood pump had six leaves deadlocked between two plastic discs. Six leaves were set at 30° angles, separately. In the lower chamber of the CP, there was an inlay magnetic disc, which is connected with the disc leaves by an axis. This axis was sealed by silicon rubber and a ceramic ring. The priming volume of the blood chamber was 34 ml.

In vitro testing showed that the free hemoglobin caused by the CP was much less than that caused by a roller pump after 180 min. The effect of this CP on blood cell damage was also studied in an animal model. Six goats were placed on cardiopulmonary bypass for 180 min. Perfusion flow rates were maintained between 1.5 and 2.5 L/min. The plasma free hemoglobin was lower in the CP group (6.04 mg/dL) than in the roller pump group (32.25 mg/dL), $p < 0.01$.

The CP has been used in ten pediatric patients undergoing cardiopulmonary bypass surgery. The patients' ages were from three to five years, and body weights were from 15 to 20 kg. Perfusion flow rates were maintained between 1.8 and 2.5 L/min, and bypass times were from 30 to 50 min. The rotation speeds were from 2000 to 2500 rpm. All the patients recovered smoothly, and no hemoglobinuria occurred.

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INTRODUCTION

The centrifugal pump (CP) has been used in assisted circulation and cardiopulmonary bypass (CPB) for decades (1, 2). In recent years, it has attracted more attention from pediatric surgeons because of its low prime volume and less damaging effects on blood cells (3, 4). Here we report our design* for a CP and the results of laboratory and clinical testing.

MATERIALS AND METHODS

The CP consists of two parts: the blood pump and the driving apparatus. Both are connected by six twin magnetic disc plates and driven by an oblate DC motor (120W).

Blood pump: The blood chamber of the pump is made of acrylic resins. In the chamber, there are six plastic leaves which are deadlocked between two plastic discs. The leaves are set at 30° angles. In the center of the upper disc, there is a 20 mm diameter hole (blood inlet). In the lower chamber of the blood pump, there is an inlay magnetic disc which is connected to the disc leaves by an axis. This axis is sealed by silicon rubber and a ceramic ring to prevent blood leakage. The priming volume of the chamber is 34 ml.

Driving apparatus: The pump is driven by an oblate DC motor, 120W, 3600 rpm. The motor axis is connected to another inlay magnetic disc. When this magnetic disk connects with the disc of the blood pump, the pump can move with the rotation of the motor. Blood is driven into the pump through the top hole and out of it through the side hole by centrifugal force. The perfusion flow rate is displayed by an electromagnetic flow meter, and the motor speed is controlled by voltage of the motor. The outlet pressure of the pump is between 0-600 mmHg, and the maximum flow rate is 8 L/min. The pump connector's diameter is 3/8 inch.

*Centrifugal pump made by the laboratory of Pediatric Thoracic and Cardiovascular Surgery, Xin Hua Hospital, Shanghai, China.

LABORATORY AND CLINICAL TESTS

IN VITRO TEST

The centrifugal pump and a roller pump were compared for blood cell trauma under the same conditions, including perfusion pressure, flow rate, blood temperature, and hematocrit (20%). Four different flow rates from 1 to 4 L/min were selected for the test, which lasted three hours at each flow rate. Blood samples were obtained at 30 minute intervals and plasma free hemoglobin was measured.

Fresh blood was obtained, anticoaguated by ACD, and diluted with ringer's solution (a hematocrit of 20%; 500 ml diluted blood was selected for each test). The blood temperature was controlled at 23°C. Another 2000 units of heparin was added at the beginning of the test.

ANIMAL TEST

Six goats, weighing from 30 to 50 kg, were the subjects of the animal test. After anesthesia, the chest was opened and routine CPB was conducted. The same type of hollow fiber oxy-

Table 1: Plasma free hemoglobin at different perfusion flows and perfusion times between centrifugal pump and roller pump in the in vitro test

Pressure	100 mgHg		100 mmHg		150 mmHg		150 mmHg	
Perfusion Flow	1 L/min		2 L/min		3 L/min		4 L/min	
Pump	RP	CP	RP	CP	RP	CP	RP	CP
TIME (min)	HEMOGLOBIN (mg%)							
0	11.6	11.0	10.2	9.9	10.4	10.2	9.5	10.8
30	15.2	18.8	33.4	15.2	37.6	25.7	38.6	33.4
60	21.6	24.8	51.2	21.6	65.3	33.4	83.1	38.8
90	30.6	28.4	67.7	28.6	85.3	46.2	133.3	50.4
120	37.2	38.4	84.7	34.0	119.5	50.0	191.2	57.5
150	41.0	40.2	101.3	46.0	141.3	62.9	215.2	66.1
180	44.6	40.4	115.7	51.2	151.4	71.5	280.9	68.5

Table 2: Plasma free hemoglobin at different perfusion flows and perfusion times between centrifugal pump and roller pump in the animal test

Pump	HCT	Flow	Pressure	Plasma free hemoglobin (mg/dl)						
	%	L	mmHg	0	30	60	90	120	150	180
CP	20	1.50	180	0	0.01	1.79	1.39	2.80	4.01	4.21
CP	10	2.50	185	0	0.40	2.82	2.62	3.12	3.12	3.92
CP	13	2.20	180	0	2.9	4.3	7.7	11.7	11.7	10.0
RP	15	2.44	440	0	0.1	7.4	8.7	28.0	15.1	20.2
RP	16	2.25	330	0	0.4	9.9	15.5	26.0	32.0	39.6
RP	16	2.0	270	0	4.13	7.84	17.54	20.44	22.54	36.94

genators were used for each test. Three tests each were conducted for the centrifugal pump (Group 1) and roller pump (Group 2). The flow rates were controlled between 1.5 and 2.5 L/min. Blood samples were drawn at 30, 60, 90, 120, and 150 minutes of bypass for plasma free hemoglobin management.

PRIMARY CLINICAL DATA

This centrifugal pump was used in 10 pediatric patients with congenital heart defects undergoing CPB surgery. The patients' ages were from three to five years, and their weights were from 10 to 20 kg. The perfusion flow rates were maintained at from 1.83 to 2.5 L/min, and bypass times were from 30 to 50 min. The rotation speeds of the pump were from 2000 to 2500 rpm.

RESULTS

In the in vitro test, there were no significant differences in plasma free hemoglobin between the two types of pump at any intervals when a 1 L/min flow rate was used. However, at the flow rate of 2 L/min or above, the blood trauma of the CP was much less than that of the roller pump (paired t test $p < 0.01$) (Table 1).

In the animal test, after 180 minutes on bypass, the plasma free hemoglobin increased by $6.04 \pm 6.06\%$ in the CP group, whereas in Group 2, it increased by $32.24 \pm 32.25\%$ (paired t test $p < 0.01$) (Table 2). From the results, we can see less blood trauma in animals using the centrifugal pump than using the roller pump. But the difference after a short bypass time (less than 30 minutes) was not significant.

In clinical testing, the CP was used with ten pediatric patients. All patients recovered well and no hemoglobinuria occurred.

DISCUSSION

Our testing showed less blood trauma in the CP, however this advantage is not significant when the CPB time is short (5, 6). If CPB is needed for a long time or as an assist pump for postoperative heart failure, use of the centrifugal pump is obviously more advantageous than use of the roller pump (7).

There is a 1.5 to 2 mm rift between the leaves and the shell of the blood chamber in the CP. The rotating speed must be high to maintain forward blood flow. If the rotating speed is low, the perfusion flow will be backward; thus, the CP is not suitable for infants. The arterial line must be clamped as soon as the CP stops (8).

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