

Clinical effectiveness and requirements of pulsatile flow perfusion with a centrifugal pump.



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PULSATILE PERFUSION DURING CPB

Cardiopulmonary bypass has been successfully applied during open-heart surgery for more than half of century for treating patients suffering from various types of heart diseases¹. However, patients who have experienced cardiopulmonary bypass are still vulnerable to postoperative complications and organ dysfunction as a result of poor organ perfusion²⁻⁴. For optimal organ perfusion during cardiopulmonary bypass, the pulsatile perfusion flow is considered more physiological than the non-pulsatile flow⁵⁻⁸. For more than three decades, several types of pulsatile pumps have been introduced and undergone extensive evaluations either in animal experiments or in cardiac surgical patients. These pumps include the modified roller pump head that allows rapid acceleration and deceleration^{9,10}, the pulsatile assist device or pulsator to add pulsation on the arterial line^{11,12}, the intra-aortic balloon pump or pulsatile catheter pump to produce pulsatility to the flow from within the aorta^{13,14}, and the centrifugal pump to make periodical acceleration of the pump speed^{15,16}

PULSATILE PERFUSION DURING CPB WITH A CENTRIFUGAL PUMP

Centrifugal pump is a relatively new type of pump used as the main perfusion pump in the cardiopulmonary bypass circuit in replacing the conventional roller pump^{17,18}. In our clinical study, we aimed to evaluate the clinical effectiveness of the pulsatile flow generated by the Rotaflow centrifugal pump with regard to its contribution to the hemodynamic energy identified by the energy equivalent pressure and the surplus hemodynamic energy^{8,19,20}. Patients undergoing cardiopulmonary

bypass for elective coronary artery bypass grafting in the University Medical Centre Groningen were prospectively included in this study. Patients were randomly allocated to a pulsatile perfusion group (n=16) or a non-pulsatile perfusion group (n=16). Anesthesia was induced with sufentanil, midazolam, and propofol. The cardiopulmonary bypass circuit included a centrifugal pump as a main perfusion pump (RotaFlow, Maquet Cardiopulmonary, Hirrlingen, Germany) and a membrane oxygenator (Quadrox, Maquet Cardiopulmonary, Hirrlingen, Germany). The perfusion flow was maintained at 2,4L/min per square meter of body surface area and the circuit was primed with 1000 ml Ringers-lactate, 500 ml Haes 200/0.5 10% and 50 mg heparin. St. Thomas crystalloid cardioplegia solution was used for myocardial protection. During CPB, the nasopharyngeal temperature was lowered to 32°C and the mean arterial pressure was maintained between 60 and 90 mmHg. In the pulsatile perfusion group, pulsatile flow was generated by accelerating the speed of centrifugal pump at a rate 60 cycles per minute, whereas in the non-pulsatile perfusion group the mode of centrifugal pump was set as a continuous flow. Pulsatile flow was started at the beginning of aortic cross-clamping until the declamping of aorta.

RESULTS

Results demonstrated that the systemic blood pressure was significantly higher in the pulsatile group (p<0.01) than that in the non-pulsatile group during the period of aortic cross-clamping, while the diastolic blood pressure was similar between the two groups. Accordingly, there was a significantly higher pulse pressure

in the pulsatile group ($p < 0.01$). The mean arterial pressure did not differ between the two groups. The energy equivalent pressure was a fraction higher in the pulsatile group than that in the non-pulsatile group during aortic cross-clamping under hypothermia (73 ± 11 mmHg versus 65 ± 10 mmHg, $p = 0.058$). Compared with the mean arterial pressure, the energy equivalent pressure was 1.8% to 2.3% more in the pulsatile group during the period of cross-clamping, whereas in the control group there was virtually no any difference between the mean arterial pressure and the energy equivalent pressure. The surplus hemodynamic energy produced by the centrifugal pump in the pulsatile group was between 1510 to 2325 ergs/cm³ during aortic cross-clamping. Within the extracorporeal circuit, much higher SHE was detected either after the oxygenator or in the vicinity of the aortic cannula than that was detected in the radial artery of patients, showing a significant drop of hemodynamic energy ($p < 0.01$).

EFFECTIVENESS AND REQUIREMENTS

Numerous experiments have shown that the pulsatile mode of perfusion is associated with a better microcirculation, greater lymph flow, higher oxygen consumption, and lower lactate level than the non-pulsatile mode of perfusion. However, the clinical effectiveness of pulsatile flow is far from satisfactory because there is lack of standards in quantifying the hemodynamic energy generated by the pulsatile pumps. Compared with our experiments using the intra-aortic pulsatile catheter pump¹⁴, our clinical results with the centrifugal pump seems much less effective with regard to the pulsatility. As a result, the pulsatile centrifugal pump used in the clinic produced much less energy equivalent pressure and surplus hemodynamic energy. This difference is not really surprising because it is well-known that if the pulsatile pump is located in the cardiopulmonary circuit, the produced pulsatility will be counteracted by the

resistance of oxygenator²¹ and the size of the aortic cannula²².

FUTURE PERSPECTIVE

In the future, the clinical requirements on pulsatile perfusion pump may rely on the development of new membrane oxygenator with low resistance and the aortic cannula with minimal damping effect. Ultimately, the pulsatile perfusion should be beneficial for patients who are expected to have a prolonged duration of cardiopulmonary bypass, for patients who have had senile arteriosclerosis with high pulse pressure, and for patients who have a high operation risk for postoperative organ dysfunction.

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