Effect of pulsatile perfusion during cardiopulmonary bypass in terms of radial artery sphygmosgram

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OBJECTIVE: To investigate a quantitative method for using radial artery pulse waveforms to assess the effect of pulsatile flow during cardiopulmonary bypass (CPB).

METHODS: A total of 34 adults with heart disease who underwent open-heart surgery between April 2010 and January 2011 were randomized into a pulsatile perfusion group (n=17) and a non-pulsatile perfusion group (n=17). Radial arterial pulse waveforms of pulsatile and non-pulsatile perfusion patients were observed and compared before and during CPB.

RESULTS: No pulse waveform could be detected at patients’ radial artery in both groups when the aorta was cross-clamped. Pulse waveforms could be detected at pulsatile perfusion patients’ radial artery, but could not be detected at non-pulsatile perfusion patients’ radial artery during CPB. Additionally, patients’ pulse waveforms during pulsatile perfusion were lower than those before the operation.

CONCLUSION: Our findings indicate that radial artery sphygmosgram can be used as a valid indicator to evaluate the effectiveness of pulsatile perfusion during CPB.

INTRODUCTION
Numerous experimental and clinical publications have reported that pulsatile flow could significantly improve the blood flow of such vital organs as the brain, heart, liver, pancreas, kidney, and gastrointestinal system; reduce systemic inflammatory response; and decrease the incidence of postoperative deaths in pediatric patients. However, to date there has been no common definition or criteria established for pulsatile flow, resulting in ongoing disagreement and uncertainty in the field. As techniques in detecting and analyzing pulse waveforms of the radial artery over the past few decades, new methods of determining radial artery pressure flow have been established; such advances may prove helpful in measuring pulsatile flow during cardiopulmonary bypass (CPB) procedures. In this study, we...
sought to investigate a quantitative method for pulsatile flow with radial artery pulse waveforms during CPB: pulsatile perfusion versus nonpulsatile perfusion.

**MATERIALS AND METHODS**

**Patients**

We conducted a study from April 2010 to January 2011 on 34 adult patients (including 2 cases of congenital heart disease, 28 cases of rheumatic valvular heart disease and 4 cases of coronary atherosclerotic disease) who underwent open-heart surgeries at the Shanghai Chest Hospital Affiliated with Shanghai Jiaotong University. Studied surgical cases comprised 2 cases of congenital heart disease, 28 cases of rheumatic valvular heart disease, and 4 cases of coronary atherosclerotic disease. Patients were prospectively randomized into a pulsatile perfusion group (n=17) and a non-pulsatile perfusion group (n=17) using computer-generated numbering. The randomized treatment assignments were sealed in opaque envelopes and were opened individually for each patient.

All patients provided written informed consent prior to study participation. Participation in the study did not affect the standard of care provided to patients. The study was approved by Shanghai University of Traditional Chinese Medicine’s clinical medical ethics committee.

**CPB Technique**

The CPB circuit used in this study included a Stockert S5 blood pump (Sorin Group, Munich, Germany); a Trillium Affinity-541T hollow-fiber membrane oxygenator (Medtronic, Inc., Minneapolis, MN, USA); an arterial filter (Ningbo Fly Medical Healthcare Co., Ltd., Ningbo, China); and a 24F arterial cannula (Shanghai Xiangsheng Medical Apparatus Factory, Shanghai, China).

In the pulsatile perfusion group, pulsatile flow was produced with the fixed pulse rate of 75 beats per minute (bpm) by changing the rotational rate of the roller pump and setting the baseflow (20%-30% of the equivalent continuous flow), start time (20%-30% of the interval), and stop time (70%-80% of the interval), until two or three upward wave groups could be detected at patients’ radial artery (see the pump setting diagram shown in Figure 1). Pulsatile perfusion was applied continuously during the aortic cross-clamping period until aortic cross-clamping was released and heartbeat resumed. In the non-pulsatile perfusion group, non-pulsatile blood flow obtained with a standard CPB circuit was 2.2-2.41 (m²)⁻¹·min⁻¹. CPB was performed at a tepid temperature (nasopharyngeal temperature: 34°C).

**Sphygmograms**

In recent years, the DDMX-100 sphygmograph [Shanghai University of Traditional Chinese Medicine (TCM) Science and Technology Co., Ltd., Shanghai, China] was developed and patented in China (No. 200520038993.8). The sphygmogram apparatus comprises a pulse sensor (see the schematic diagram of the structure shown in Figure 2), a signal amplifier, an A/D converter, a recorder, and other accessories. The radial artery pulse wave signals can be detected by applying the sensor probe to the radial artery; these signals are then amplified by the signal amplifier and transmitted to the recorder. There they are drawn into pulse curve, that is, the radial artery pulse waveform or sphygmogram. Sphygmograms can be processed and analyzed with Pulse Condition Processing Program Version 3.0 (Shanghai University of TCM Science and Technology Co., Ltd., Shanghai, China). In our study, patients lay in the supine position with the left upper arm extended. The probe was placed on the radial artery (Figure 3 for the specific location used to detect radial artery pulse waves), and the pressure knob was ro-
tated after velcro was affixed until pulse waves appeared at their highest peak; the pulse wave graph was then captured and recorded with the sphygmograph. Arterial pulse waves of the upper body of humans generally comprise two or three upward wave groups, and the arterial pulse waves of the lower body generally comprise two upward waves; thus, radial artery pulse waves generally comprise two or three upward wave groups (including percussion wave, tidal wave, and dicrotic wave) and one or two intervals (also called notches) between each wave crest. In the sphygmogram (see Figure 4 for sphygmogram physiological parameters), the h1 value primarily reflects the ejection function of the left ventricle. The sphygmogram’s h3 value primarily reflects arterial tension. The h4 value primarily reflects peripheral vascular resistance, and the h5 value primarily denotes arterial compliance.

RESULTS

Radial arterial pulse waveforms could be detected in all of the 34 patients before CPB (a representative sphygmogram is shown in Figure 5), but no pulse waveforms could be detected at any of the 34 patients’ radial artery after aortic cross-clamping (representative sphygmogram is shown in Figure 6). In the pulsatile perfusion group, pulse waveforms could be detected at all patients’ radial artery during pulsatile perfusion; however, the upward waves of the sphygmogram during pulsatile perfusion were lower than those from before the operation (a representative sphygmogram is shown in Figure 7). In the non-pulsatile perfusion group, no pulse waveform could be detected at patients’ radial artery during CPB (a representative sphygmogram is shown in Figure 8).

DISCUSSION

By optimizing the experimental designs, we established two different modes of perfusion (different types of pulsatility). We found that pulse waveforms could be detected with a sphygmogram apparatus at each pa-
tient’s radial artery during pulsatile perfusion procedures. This finding means that a pulsatile pump can generate more pulsatile energy, and that hemodynamic energy can be delivered to the patients and be effectively transmitted; however, a non-pulsatile pump does not generate pulsatile flow. It also suggests that radial arterial pulse waveforms can not only reflect the delivering conditions of hemodynamic energy of pulsatile perfusion during CPB, but also be used as a quantification method for defining pulsatile perfusion.

We discovered that pulse waveforms can be detected at pulsatile perfusion patients’ radial artery before and during pulsatile perfusion; however, the upward waves of patients’ pulse waveforms during pulsatile perfusion are lower than those taken before the operation. With regard to a potential cause of this phenomenon, we speculate that it might be related to the differences between the hemodynamic energy generated by the heart and by the pulsatile pump, or it might be related to some energy having been absorbed by the components of the extracorporeal circuit during pulsatile perfusion procedures.

Previous studies confirmed that the sphygromogram h1 value primarily reflects the ejection function of the left ventricle and aortic compliance, and that h1 will rise when the ejection function of the left ventricle strengthens or aortic compliance increases, and vice versa. The h3 value primarily reflects arterial tension, and h3 will rise when arterial tension increases, and vice versa, or even disappears. The h4 value primarily shows the state of the blood volume at the beginning of diastole, and h4 will rise when arterial blood volume increases at the beginning of diastole resulting from increased peripheral resistance; h5 will reduce when circulating blood volume or peripheral resistance decreases. The h5 value primarily denotes arterial compliance, as a reduction in such compliance will cause h5 to fall or become flat. The t1 value corresponds to the time of rapid ejection of the left ventricle; the t4 value approximately corresponds to the time of the systolic phase; and the t5 value approximately corresponds to the time of the diastolic phase. The t value corresponds to the time of the cardiac cycle or sphygmos cycle. The w value corresponds to the time required for the maintenance of high arterial pressure.

In addition to the physiological parameters noted above, ratios such as those of h3/h1, h4/h1, h5/h1, w/t, t1/t may reflect specific heart conditions of heart, arterial systems, and blood flow more precisely and sensitively. Taking these details into consideration, we thus believe that the morphologies (shapes and sizes) of pulse waveforms can be used as a valid indicator of the effects of pulsatile perfusion during CPB.

Sphygmography can be used as a quantitative method to observe the delivering effects of hemodynamic energy during pulsatile perfusion, and sphygmographic morphologies can be used as an indicator to evaluate the effectiveness of pulsatile perfusion during CPB.

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REFERENCES


