Studies on the Optimum Condition of Coronary Artery Perfusion under Hypothermia

Eiji Sekino, Sohei Suzuki, Susumu Ainai, Toshio Tsuge and Takeshi Momokawa

Department of Surgery (Prof. Y. Ishikawa), Hirosaki University School of Medicine, Hirosaki

Optimum conditions for coronary flow under hypothermia were experimentally investigated on dogs. The control of coronary perfusion by flow rate alone was occasionally accompanied by undesirable side-effects, and adequate perfusion pressure was found to be important in sustaining optimum coronary flow. The most favorable results were obtained at perfusion pressures of 90 mmHg at 30°C, 50 mmHg at 25°C and 40 mmHg at 20°C.

Recently, open-heart surgery has come to deal increasingly with heart lesions or diseases that necessarily require the aid of coronary artery perfusion during operation. In such heart surgery, hypothermic techniques are also valuable because they suppress oxygen requirement of the myocardium and facilitate quick recovery of myocardial activity.

Several reports have been published on coronary artery perfusion and have revealed that special considerations must be taken when it is performed under hypothermia.

In our previous studies on the coronary blood flow rate under hypothermia, the rate at different temperatures was discussed and we concluded that the rates calculated from the experimental data might be sufficient to prevent myocardial hypoxia under artificial coronary artery perfusion.

This paper is concerned with the optimum conditions of coronary artery perfusion to the hypothermic heart.

METHODS AND RESULTS

1) Simultaneous recording of pressure curves of the coronary artery and aorta, and coronary blood flow rate under hypothermia

Experimental dogs weighing 8.5 to 21 kg were kept in the third stage of anesthesia by intratracheal ether anesthesia and were cooled by immersing in a water tub. Two small polyethylene tubes were inserted into the aortic root and a branch of the coronary artery for simultaneous measurements and blood sam-
pling. Other tubes for blood sampling to estimate the cardiac output and coronary blood flow rate by Scheinberg's N₂O method were inserted into the coronary sinus through the right atrium. An electromagnetic blood flow meter probe was placed on the trunk of the left coronary artery and a needle type electric thermister probe was put into the left ventricular myocardium.

Fig. 1 shows pressure curves of the coronary artery and aorta. These curves were simultaneously recorded at each temperature. The dicrotic wave of the

Fig. 1. The pressure curves of the coronary artery (CP) and aorta (AP) which were simultaneously recorded under general hypothermia.
aortic pressure curve which was observed at 35°C became smaller in amplitude as hypothermia progressed and further diminished under deep hypothermia, but no dicrotic waves were found in the coronary artery pressure curves. The mean pressures of the coronary artery and aorta were almost not influenced by body temperature.

Table 1 shows calculated values of the cardiac output, coronary blood flow, etc., at body temperatures of 35, 30, 25 and 22°C.

<table>
<thead>
<tr>
<th>Esophageal temperature (°C)</th>
<th>Cardiac output (ml/kg/min)</th>
<th>Coronary blood flow (ml/100 g heart muscle/ min)</th>
<th>Cerebral blood flow (ml/100 g brain/min)</th>
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<tr>
<td>35</td>
<td>283</td>
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2) Observations on the correlation between myocardial temperature and coronary artery perfusion pressure or flow rate

Experimental animals were dogs weighing 8 to 17 kg; anesthesia and monitors were the same as in the preceding experiment. For the coronary perfusion, a Kay-Cross type oxygenator, a two-hand roller pump and a Brown-Harrison type heat exchanger were used and the aortic root technique was adopted. Two series of experiments were made; one was under the condition of a constant perfusion flow rate at varying myocardial temperature and the other was under a fixed myocardial temperature at varying perfusion flow rate.

Experiment 1

The perfusion was made with blood diluted to 30% by a low-molecular weight dextran solution and adjusted to the same temperature as the myocardial temperature. Then, the blood temperature was lowered and raised.

Experimental data were grouped into those of high flow rate perfusion (70–100 ml/100 g heart muscle/min), of moderate flow rate perfusion (40–60 ml/100 g heart muscle/min) and of low flow rate perfusion (20–40 ml/100 g heart muscle/min).

The aortic root pressure rose with decrease in myocardial temperature in all flow rate groups. With the low flow rate, sufficient perfusion pressure was not easily obtainable at the start of perfusion. With the moderate flow rate perfusion, the pressure was kept ideal when the myocardial temperature was in the range of 30 to 25°C.

However, with the high flow rate perfusion and with the moderate flow rate perfusion at temperatures below 25°C, the perfusion pressure continued to rise
with advancing myocardial hypothermia, bringing about myocardial stiffening or intramyocardial hemorrhage.

**Experiment 2**

In this experiment, myocardial temperature was controlled beforehand at 30, 25 and 20°C by total body perfusion before coronary artery perfusion was started. The coronary artery perfusion was performed with cooled blood adjusted to the same temperature as the myocardial temperature. Perfusion flow rate was changed from low to high and vice versa.

In the groups at 30 and 25°C, only slight rise in perfusion pressure was caused by an increase in flow rate, but in the 20°C group, the elevation of pressure was extreme. Individual data are shown in Tables 2 and 3, in which the perfusion pressure at the appearance of myocardial stiffening and the presence or absence of intramyocardial hemorrhage are shown.
Several reports\textsuperscript{9,10} are known on the change in the coronary blood flow rate in the course of progressive hypothermia. In our previous study,\textsuperscript{7} the rate of the coronary blood flow was given as 103 ml/100 g heart muscle/min at body temperature of 35, 30 and 25°C, and the rates decreased to 67.7% (71 ml/100 g heart muscle/min) and 47.9% (18 ml/100 g heart muscle/min), respectively.
Fig. 3. Changes of coronary artery pressure due to changes in perfusion flow rate in each myocardial temperature group.

Fig. 4. A case of coronary artery perfusion at 20°C. Extreme rise of perfusion pressure (CF) resulted from a decrease of coronary artery blood flow rate (CP).

We supposed that these rates of coronary blood flow at each temperature might be ideal in order to protect the myocardium from hypoxia and to maintain optimum cardiac activity.

Under mechanically enforced coronary artery perfusion, however, various differences in the circulatory parameters may be expected as compared with the normal circulation. The present studies were carried out to find the optimum condition of coronary artery perfusion with special reference to the hypothermic state.
We can conclude from the results from 1) that non-pulsatile or low amplitude pulsatile flow may be useful and adequate for coronary artery perfusion and, with coronary perfusion by the aortic root technique, the pressure of the aortic root may be an adequate guide in the estimation of perfusion pressure of the coronary artery.

The results from 2) demonstrated the correlation between perfusion flow rate or perfusion pressure and myocardial temperature. In coronary perfusion under hypothermia, perfusion flow rate should be decreased according to falling myocardial temperature. In deep myocardial hypothermia the perfusion pressure will rise steeply even at a flow rate which is tolerable in slight hypothermia, and lead to myocardial stiffening, intramyocardial hemorrhage and irreversible cardiac arrest.

The electromagnetic flow meter on the coronary artery indicates a deflection toward a lower rate under such conditions.

Analytical observations of experiments 1 and 2 in 2) give a rule concerning coronary artery perfusion under hypothermia. That is, the optimum perfusion pressure is between 60 to 90 mmHg at 30°C, 40 to 50 mmHg at 25°C and 30 to 40 mmHg at 20°C. Sometimes, however, no parallel relationship is observed between coronary artery perfusion flow rate and perfusion pressure at any myocardial temperature. This is presumably due to differences in cardiac vascular resistance, whether they may be related to individual difference or to the hypothermia procedure.

Optimum regulation of coronary artery perfusion especially under hypothermia is achieved more reasonably by the control of perfusion pressure than by that of flow rate.

References


