PERFUSION PROBLEMS IN INFANTS

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For open heart surgery on an infant under 10 kilograms of body weight, we are currently employing the following method. With the initial application of surface cooling followed by perfusion cooling, the rectal temperature is brought down to 20 or 17 degrees Centigrade, and intermittent circulatory arrest is induced following the anoxic arrest of the heart by aortic cross-clamping. In order to obtain a quiet and bloodless operative field, caval blood is drained by gravity after the circulatory arrest is induced.

Since we have come a long way to settle on the current method, it seems to be worthwhile to outline our clinical and laboratory experiences in a chronological order.

After initial unsuccessful attempts at developing a dependable pump-oxygenator for clinical use, we started experiments on hypothermia advocated by Bigelow. The method involved cooling of the body without paying special attention to cooling of the brain. The results of our experiments with this were discouraging and no clinical application was made. We proved experimentally that the cerebral temperature by this method remained relatively high compared with the rectal temperature, and the cerebral oxygen consumption also remained high. Therefore, as a modification, the head in particular was subjected to cooling. Employing this method, we were able to prolong the period of the circulatory occlusion to the heart up to 35 minutes. So we started to apply this method clinically in 1954.

Since then we began to pay particular attention to the cerebral circulation. At that time Ozawa in Japan found in his experimental study that circulatory occlusion could be performed safely with infusion of oxygenated blood into the aorta to maintain the cerebral and the coronary circulation. We applied this method supplemented by hypothermia on 12 patients with one death.

To minimize hazards from high-flow perfusion in those days, efforts were made to find the least-possible flow rate in our laboratory. By applying an electromagnetic flow meter on the carotid artery, the allowable lower limit of the cerebral blood flow was determined. The method was utilized to find the minimum flow rate for the coronary circulation in dogs. It was learned that a dog weighing 8-10 kilograms, could tolerate the circulatory occlusion of 30 minutes' duration with infusion of oxygenated blood into the aorta at a rate of 300 milliliters per minute. This infusion rate corresponds to 1174 milliliters in an average man. In a hypothermic state, the infusion rate can be reduced further to 939 milliliters at 35 degrees Centigrade and to 704 milliliters at 30 degrees. Therefore, it was thought then that such a low-flow rate perfusion could be achieved simply by insufflating oxygen into venous blood. This idea led us to develop a kind of bubble oxygenator, a foam oxygenator to be exact, and it was first used clinically combined with our hypothermic method in April, 1956.

Although several different types of oxygenators have been developed in our laboratory, and we have switched from surface cooling to perfusion cooling, our basic principle of combined use of perfusion and hypothermia has remained unchanged throughout the period. Using this principle, we have performed approximately 4,800 cases of open heart surgery.

It was clearly demonstrated by our experiments and by others as well that circulatory occlusion could be further prolonged with the induction of deeper hypothermia. However, risks of ventricular fibrillation at lower temperature interfered with its clinical application.

In 1960, Okamura and his colleagues in Japan developed a method to induce deep hypothermia. His method included surface cooling down to 20 degrees Centigrade, deep ether anesthesia and administration of ganglion blocking agents. Using this method clinically, he showed that circulatory arrest as long as 60 minutes could be done in safety.

In 1963, Horiuchi in Japan advocated a combined method of deep hypothermia and coronary perfusion, proving the method to be safer in clinical practice than previous methods. At that time, we once resorted to hypothermia down below 20 degrees Centigrade by perfusion cooling. However, we felt that it was unnecessary and not always safe to induce deep hypothermia in adults or older children, and thus we adopted again moderate to mild hypothermia for this particular group of the patients.

Deep hypothermia, however, seemed to have a definite advantage for an infant weighing under 10 kilograms, since it was difficult to maintain a slim balance between infusion and venous drainage on a small infant. Perfusion cooling on a small infant is unfavourable, since it tends to induce a rapid fall in temperature creating a marked temperature gradient in various parts of the body and tends to cause vasoconstriction. For this reason, we applied surface cooling followed by perfusion cooling to achieve hypothermia down to 20 degrees Centigrade, and obtained a bloodless field with circulatory occlusion and an extremely low-flow rate perfusion in 1965.

In 1967, Higasa in Japan recommended a method in which perfusion rewarming was utilized after the induction of deep hypothermia by surface cooling. This modification seemed to be a good method for assuring a safer recovery from the deep hypothermic state, still taking full advantage of Okamura's technique in deep hypothermia.

Learning these experiences by others, we started to employ circulatory arrest during the intracardiac procedure at a rectal temperature of 20 degrees Centigrade. And moreover, we added exanguination up to 30 per cent of the blood volume by caval drainage by gravity during the period of circulatory arrest. This helped a great deal to facilitate the intracardiac procedure by creating a quiet and bloodless field.

Currently we utilize this method for infants under 10 kilograms of body weight and mild to moderate hypothermia with perfusion for ordinary cases. Our current method for infants is carried out as follows:

After administration of chlorpromazine in doses of 0.8 milligrams per kilogram of body weight, the infant is anesthetized with Fluothane and is cooled down to 30 degrees Centigrade by surface cooling. As the rectal temperature reaches 30 degrees Centigrade, we proceed to expose the heart for caval and aortic cannulations. By that time, the temperature usually drifts down further to 26 degrees Centigrade. Our oxygenator is mounted on a scale, so that it is possible to maintain precise balance between blood withdrawal and infusion. The priming volume for the infant-size is 700 milliliters. Using this type of pump-oxygenator, the infant is cooled down to 20 degrees Centigrade by perfusion cooling. After the aortic cross-clamping, the circulatory arrest is instituted. During the circulatory arrest, the rectal temperature tends to drift down to 17 degrees Centigrade. The caval cannulae are kept open for further blood withdrawal, and the heart goes into the anoxic arrest soon after the aortic cross-clamping. Thus a motionless and bloodless operative field is obtained, and the intracardiac procedures can be done with ease, as they are done on the gastrointestinal tract.

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The aortic clamp is released every 40 minutes and the whole body is perfused for a 2-minute-period.

During this period the intracardiac procedure is temporarily interrupted. Whenever possible, it is preferable to institute perfusion every 20 minutes for 2 minutes with the aortic clamp in place. This intermittent perfusion is a safeguard for the brain from anoxic damage. Occasionally excessive bronchial circulation may hinder the intracardiac procedure, but it ceases soon after the cessation of the perfusion. On resumption of whole body perfusion, the exact amount of drained blood from the caval route is slowly infused back into the infant, before pump-perfusion is reinstituted. For this purpose, our oxygenator mounted on a scale has a definite advantage over conventional ones.

Rewarming by perfusion is gradually undertaken upon completion of the intracardiac procedure by keeping the temperature difference between caval blood and blood for infusion within 5 degrees Centigrade and the surface rewarming takes over thereafter.

We applied this method on 22 infants. As shown on the slide, we lost 4 cases out of 22, since nearly all infants were critically ill.

Next, I would like to show you a few interesting cases.

This is a 2-month-old boy weighing 2,900 grams with tetralogy of Fallot. Frequent anoxic spells made it necessary for us to perform surgery on an emergency basis. However, severe hypoplasia of the pulmonary artery excluded the possibility of creating a systematic to pulmonary shunt. Therefore, radical correction was performed using perfusion and deep hypothermia.

A ventricular septal defect was patch-closed and the outflow-patch reconstruction was done to enlarge the pulmonary trunk. His recovery was uneventful and he is doing well up to the present.

The second case is a 4-month-old boy weighing 4 kilograms with total anomalous pulmonary venous connection with success.

The last case is a 9-month-old infant with transposition of the great arteries with an intake ventricular septum. Mustard's procedure was successfully performed on the infant.

In conclusion, although there are various points yet to be refined and improved, we are satisfied to some extent with our current method of combined perfusion and hypothermia.