ORIGINAL ARTICLE

Continuous Warm Blood Cardioplegia: A New Technique for Myocardial Protection

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Abstract

Hypothermia is used to prolong the safe period of ischemic arrest by reducing the heart's oxygen demands. Due to this effect, hypothermia has been the fundamental component of most methods of myocardial protection during cardiac surgery. However, hypothermia has a number of unwanted side effects, such as detrimental effects on enzyme function, energy generation, and cell membranes. Since electromechanical arrest accounts for 90% of myocardial oxygen consumption, arresting the heart with chemical cardioplegia will reduce O_2 consumption dramatically. Therefore, if the resting (arrested) heart is continuously perfused with oxygenated blood cardioplegia, one can easily provide the remaining 10% of O_2 that it requires. Under these conditions, the need for hypothermia becomes questionable. In this paper, we describe the perfusionist's experience using the antegrade and retrograde technique of continuous warm blood cardioplegia.

Introduction

Great advances in surgical techniques, perfusion technology, and cardiac anesthesia have made heart surgery safer. However, the major advance over the past 15 years has been in the field of myocardial protection. A new method of myocardial protection has recently been described, which is based on the concept of "warm aerobic arrest" (1-4). This paper will describe our experience with this technique from the perfusionist's perspective.

Although the precise composition of the optimal cardioplegia solution remains somewhat controversial (5), it is widely acknowledged that hypothermia, introduced into clinical medicine in the early 1950's (6), is the single most important component of myocardial protection (7-12). This approach is based on a large body of evidence indicating that myocardial hypothermia significantly diminishes cardiac metabolism (12-14). Hence, during ischemic cardiac arrest, i.e., anaerobic arrest, O_2 consumption is decreased and postoperative cardiac impairment should be kept to a minimum.

Despite these benefits, hypothermia has several major disadvantages, such as its effects on enzyme function (15), membrane stability (16), calcium sequestration (17), glucose utilization (18), ATP generation and utilization (19), tissue O_2 uptake (20), as well as on pH (21) and osmotic homeostasis (22). Since current hypothermic techniques involve ischemic arrest, the heart has to be reperfused following the procedure. This can lead to "reperfusion injury" (23).

Electromechanical work is the major determinant of myocardial O_2 consumption (24, 25). Therefore, if the heart is kept electromechanically arrested and continuously perfused with warm blood during an operation, (i.e., aerobic arrest), then the need for hypothermia is questionable.

We have recently developed an approach which allows for aerobic arrest during open heart surgery (overcoming many of the disadvantages of ischemic hypothermia mentioned above) and provides a terminal aspartate glutamate enriched cardioplegia. Using this technique, the heart is maintained at 37°C with continuous warm blood cardioplegia, thus eliminating the period of ischemia/reperfusion, and completely avoiding the detrimental side-effects of hypothermia.

The Technique of Warm Blood Cardioplegia

After median sternotomy and heparinization, the ascending aorta was cannulated and a single atrial cannula was used. Cardiopulmonary bypass was instituted and the patients were systemically cooled to a rectal temperature of 35°C. With the heart empty and beating, high potassium blood cardioplegia at 37°C was infused into the root of the aorta via a cardioplegia cannula and the aorta was clamped. Cardiac arrest was invariably achieved within one minute of infusion of cardioplegia solution.

The Cardioplegia Solutions

Oxygenated blood was mixed in a 4:1 ratio with Fremes' cardioplegic solution (a) resulting in a high potassium blood cardioplegia mixture with hematocrit = 18%, and a potassium concentration = 23 mEq/l, and was delivered at 300 ml/min for

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a. High potassium Fremes' solution consists of 1,000 ml of 5% dextrose in water, 100 mlq of KCl, 18 mEq $MgSO_3$, 12 mEq tromethamine, and 20 ml of CPD solution; osmolality 425 mOsm/l; pl l, 7.95.

a total of 1 liter, and then switched to low potassium blood cardioplegia delivered at 100 ml/min. The blood cardioplegia was delivered continuously through a Bentley HE-100 (b) cardioplegia set. The low potassium blood cardioplegia, which was identical to the high potassium cardioplegia except for the potassium concentration (c), (yielding a mixture with (K^+)= 7 mEq/l) was perfused throughout the procedure, unless some electrical activity was noted, which necessitated temporary return to the high potassium cardioplegic solution. Then at the end of the procedure, just before the aortic cross-clamp is removed, 250 ml of aspartate-glutamate solution mixed 1:4 with blood (total volume = 1250 ml) was given as the "reperfusion" or third cardioplegic solution (d) at the rate of 250 ml/min.

Retrograde Technique

When the retrograde cardioplegia technique is used, a DLP™ retrograde cannula (e) is inserted through the right atrium, into the coronary sinus, prior to the initiation of cardiopulmonary bypass. Cardiac arrest is achieved with 500 ml of high potassium blood cardioplegia (as in footnote a) given antegrade through the aortic root. Then switch to retrograde perfusion is made and the remaining 500 ml is delivered while venting the aortic root. A switch to low potassium blood cardioplegia (as in footnote b)is then made and retrograde perfuse continuously during the operation at a rate of 100 ml/min (and keeping the coronary sinus pressure < 50 mmHg) is maintained. This technique can be used for all valve and coronary bypass procedures. If visualization is a problem, then flow can be interrupted for up to 10 minutes, if necessary, while completing an anastomosis.

Antegrade Technique

In coronary artery bypass surgery, the distal anastomoses were fashioned first according to the severity of the disease. Upon completion, potassium blood cardioplegia was then perfused down each graft through a DLP™ multi-port cardioplegia delivery set. When blood in the operating field made visualization difficult, a soft, flexible probe was used to occlude the artery and prevent blood from obscuring the view, or the arteriotomy was irrigated with room temperature saline. Alternatively, the root of the aorta could be vented while maintaining flow down specific grafts or the cardioplegia infusion could be interrupted in any of the grafts or even totally interrupted for periods of up to 10 minutes and then resumed.

This technique can be easily adapted for use during valvular surgery. In cases with an aortotomy, the coronary ostia are separately cannulated using soft cannulas, and cardioplegia can then be perfused continuously throughout the procedure. During mitral valve surgery the aortic root is perfused continuously with warm blood cardioplegia.

For all valvular procedures the low potassium blood cardioplegia is infused continuously at a rate of 100 ml/min during surgery, and the pressure measured at the cardioplegia delivery system does not exceed 130 mm Hg. During coronary artery surgery, occasionally when cardioplegia is flowing down only saphenous vein grafts, sometimes less than 100 ml/min of cardioplegia is delivered down the vein graft in order not to exceed the pressure limit.

Discussion

The literature suggests that continuous warm blood cardioplegia may have lower complications rates than continuous cold blood cardioplegia. The operative mortality was also lower, although this was not statistically significant, because of the small numbers involved (2, 3).

In the study by Lichtenstein et al. (4), patients undergoing coronary artery bypass surgery using continuous cold blood cardioplegia were compared to a group receiving continuous warm blood cardioplegia. There was no significant difference in mortality between the groups (cold 2.1% vs. warm 1.1%), and there were significant decreases in the usage of the intra-aortic balloon pump, myocardial infarction, strokes, and reoperation for bleeding when compared by chi-squared analysis (4). These better clinical results were observed despite an increase in cross-clamping time. More importantly, nearly 100% of the patients returned to normal sinus rhythm without defibrillation.

While this technique is somewhat more cumbersome, (blood in the operative fleld is troublesome, particularly during coronary bypass surgery) it is a relatively minor problem to overcome, given the potential advantage of prolonged operative time that is possible (1) with good myocardial preservation. Furthermore, similar technical problems have been overcome by surgeons using intermittent ischemic or fibrillatory arrest (27, 28).

Conclusion

This technique has two major components: continuous blood cardioplegia and normothermic perfusion. Each of these components has been used individually in cardiac surgery (29, 30), but not together. It is this combination that makes the technique so effective. Continuous cardioplegia when performed under hypothermic conditions has a number of disadvantages, as does normothermia. If electromechanical arrest can be achieved chemically as first suggested by Melrose (31), and if ischemia can be eliminated by continuous perfusion with blood, the need for hypothermia becomes questionable.

This new technique for the delivery of continuous, normothermic, blood cardioplegia with terminal substrate enhancement is relatively easy to perform, safe and effective. It represents a new approach to the problem of maintaining myocardial protection during cardiac surgery, and should provide benefit in difficult patients with poor ventricular function.

b. American Bentley, Inc., Irvine, CA.

c. Low potassium Fremes' solution consists of 1,000 ml of D5W, 25 mEq KCl, 18 mEq $MgSO_3$, 12 mEq THAM, and 20 ml of CPD solution.

d. 60 ml of THAM, 60 ml of CPD, 65 ml of aspartate-glutamate, 10 ml of D50W, and 50 ml. of D5W, to which 20 mg of Lidocaine is added. K^+ is added as needed to maintain arrest, up to a maximum of 8 mEq.

e. DLP, Inc., Grand Rapids, MI

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