Continuous Warm Blood Cardioplegia

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The goal in cardiac procedures is to have a safe operating time while minimizing the ischemic period that causes damage to the heart. Different methods and combinations of arrest and myocardial protection are currently being used throughout the country. The heart can be arrested electromechanically, chemically, or physically. This article will introduce STs to a new method using warm blood cardioplegia.

Hypothermic Blood Cardioplegia

The most common method of myocardial protection is hypothermia. When cardiopulmonary bypass is initiated, the heart becomes empty. Placing a clamp across the ascending aorta, an infusion of cold (5°C) cardioplegia (mixture of blood and chemicals) is used to arrest the heart. This is also used as an energy source. The cardioplegia solution is used to put the heart in a kind of "suspended animation," allowing surgical procedures to be performed while the muscle is not working.

At this point in the procedure, a phrenic insulating pad may be placed behind the heart to protect the phrenic nerve from damage, and an ice "slush" or ice cold saline fluid is poured onto the heart. A metal needle tip probe may be inserted into the myocardium to monitor temperature. Also, the systemic temperature of the patient may drift to 32°C or may be actively cooled to 30°C.

When the heart is completely still, optimal amounts of cardioplegia have been infused, and the desired coolness of temperature has been reached, the surgical procedure is performed.

Whether the procedure is coronary artery bypass or valve replacement, it is necessary to infuse more cardioplegia solution and pour slush about every 10 minutes. This intermittent cold blood cardioplegia provides a state of hypothermic ischemic arrest.

Hypothermia is used to prolong the safe period of ischemic arrest during cardiac surgery by reducing the heart's oxygen demands. Due to this effect, hypothermia has been the fundamental component of most methods of myocardial protection. However, hypothermia has a number of side effects including its detrimental effects on enzyme function, energy generation, and cell membranes.

The precise composition of the optimal cardioplegia solution remains somewhat controversial.[1] However, it is widely acknowledged that hypothermia, introduced into clinical medicine in the early 1950s,[2] is the single most important component of myocardial protection.[3-8] This approach is based on a large amount of data indicating that myocardial hypothermia significantly diminishes cardiac metabolism.[8-10] Hence, during ischemic cardiac arrest (ie, anaerobic arrest), oxygen 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,[11] membrane stability,[12] calcium sequestration,[13] glucose utilization,[14] ATP generation and utilization,[15] and tissue oxygen uptake,[16] as well as on pH[17] and osmotic homeostasis.[18] Since current hypothermic techniques involve ischemic arrest, the heart has to be reperfused following the procedure. This can lead to "reperfusion injury."[19]

Cardiac surgery has become safer due to many improvements in surgical techniques, perfusion technology, and cardiac anesthesia. However, the major advancement over the past 15 years has been in the field of myocardial protection. A new method of myocardial protection based on the concept of "warm aerobic arrest" has recently been described.[10]

Both animal and human data show that electromechanical work is the major determinant of myocardial oxygen consumption.[20,21] Therefore, if the heart is kept electromechanically arrested and continuously perfused with warm blood (ie, aerobic arrest), then the need for hypothermia is questionable.

This new approach being used during open heart surgery to aid in myocardial protection is known as warm continuous blood cardioplegia, normothermia, or aerobic arrest. This method is successfully achieved by using an antegrade cardioplegia cannula as well as a retrograde cardioplegia cannula.

Technique of Warm Blood Cardioplegia

After routine prep and draping of the patient, an incision is made from the sternal notch to xiphoid and a median sternotomy is carried out. After placement of the chest retractor, the pericardium is opened and suspended with stay sutures.

The surgeon asks the anesthesiologist to begin heparinization at this time. The ascending aorta is cannulated as well as the right atrium (the superior and inferior vena cava are cannulated at this time for mitral valve replacement). Full cardiopulmonary bypass is initiated. With the heart empty and beating, a cardioplegia cannula is introduced to the root of the aorta and secured with a stay suture and tourniquet. The cross clamp is applied and blood cardioplegia is infused into the aorta (Figure 1). Cardiac arrest is invariably achieved within 1 minute of infusion of cardioplegia solution.

Oxygenated blood is mixed in a 4:1 ratio with a Frems' cardioplegic solution (Frems' solution consists of 1,000 mL of dextrose in water, 100 Eq KCl, 18 mEq Mg SO_3, 12 mEq tromethamine, and 20 mL of CPD solution; osmolality=425 mOsm/L; pH=7.95), resulting in a high potassium blood cardioplegia mixture. The mixture is administered at 300 mL/min for a total of 1 L, and then switched to low potassium blood cardioplegia delivered at 100 mL/min. The blood cardioplegia is delivered continuously. The low potassium blood cardioplegia (consists of 1,000 mL of d5w, 25 mEq KCL, 18 Eq Mg SO_3, 12 mEq THAM, and 20 mL of CPD solution) is perfused throughout the procedure unless some electrical activity is noted, which necessitates the temporary return to the high potassium cardioplegic solution.

Retrograde Technique

When the retrograde cardioplegia technique is used, a retrograde cannula is inserted through the right atrium, into the coronary sinus, and held secure with a pursestring suture and lightly clinched down with a tourniquet (Figure 2). The coronary sinus lies posterior, between the left atrium and the left ventricle, left of the atrioventricular groove (A-V groove) into which the cardiac veins enter. The right extremity of the coronary sinus turns forward and upward to enter the right atrium (Figure 3). The cannula is inserted prior to the initiation of cardiopulmonary bypass.[22] Cardiac arrest is achieved with 500 mL of high potassium blood cardioplegia (containing the mixture previously described) given antegrade through the aortic root. Then at the sterile field, the perfusion is switched to retrograde and the remaining 500 mL is given while venting the aortic root. The perfusionists will then switch to low potassium blood cardioplegia and perfuse retrograde continuously during the case at a rate of 100 mL/min. This technique can be used for all valve and coronary bypass procedures.

Using the retrograde cardioplegia reverses the circulation in the heart, providing a continuous flow of blood in the arteries. Since the flow of blood is now from the veins to the arteries, the blood cardioplegia has nowhere to drain. An aortic vent site is helpful at this time. The vent is turned on to prevent the heart from becoming distended as well as to help with visualization. This can be awkward at times, and blood in the visual field is frustrat-

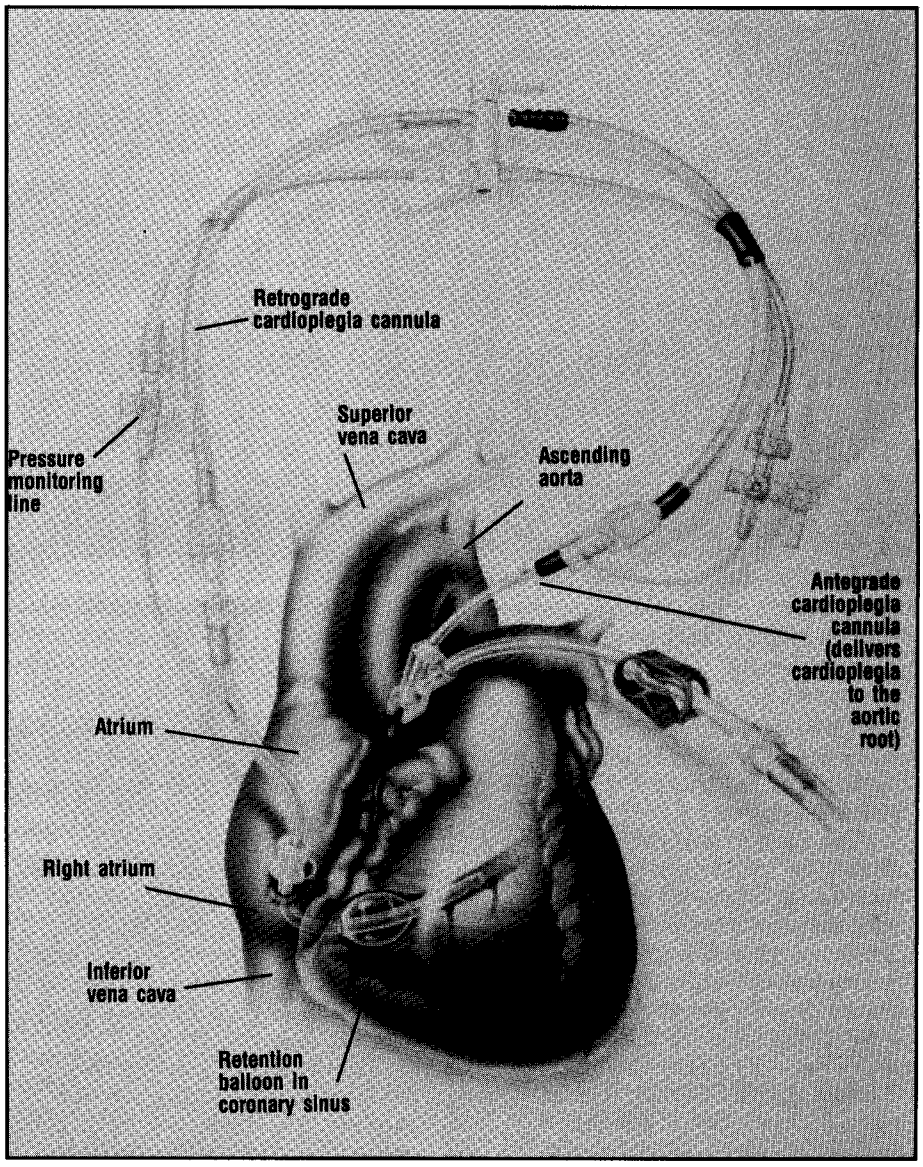

Figure 1. Retrograde cardioplegia cannula system to deliver normothermic continuous antegrade/retrograde cardioplegia. (Photo courtesy of Research Medical, Inc., Midvale, Utah.)

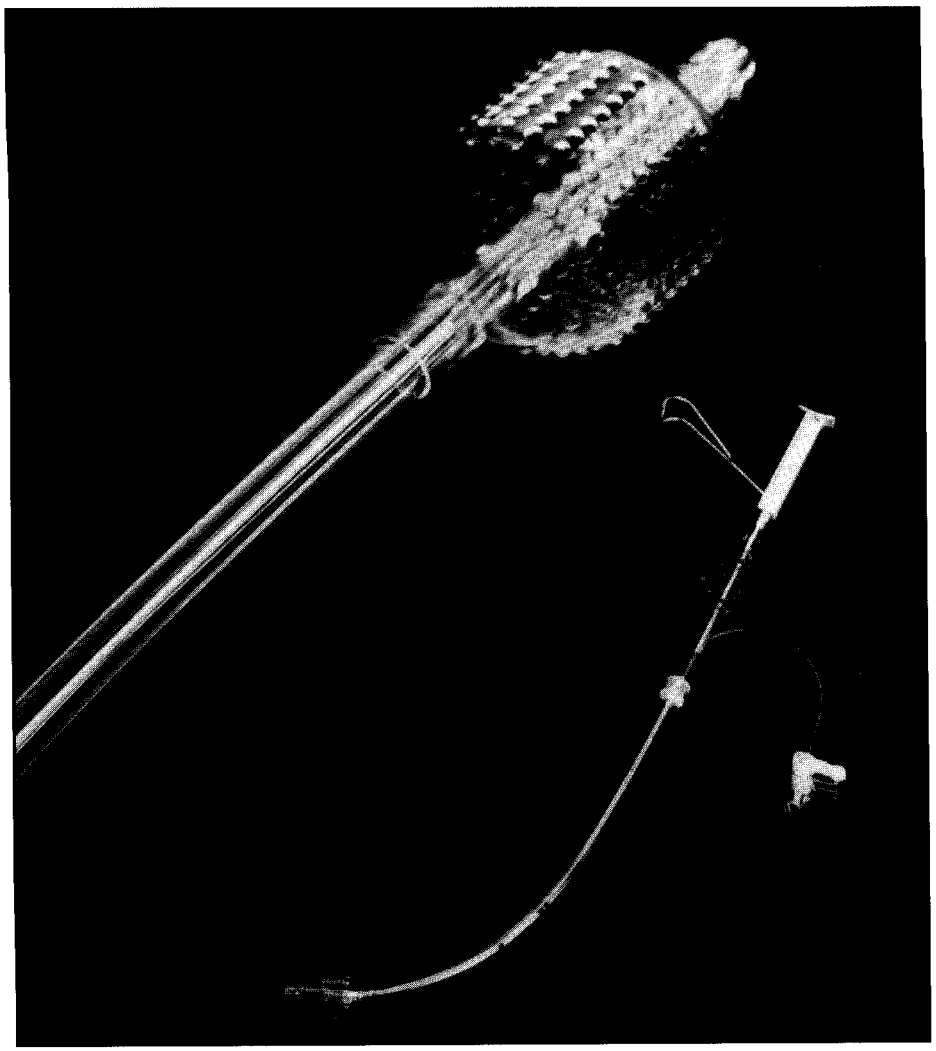

Figure 2. Retrograde cardioplegia cannula with balloon. (Photo courtesy of Research Medical, Inc., Midvale, Utah.)

ing. These problems can be easily overcome if the team members work together and communicate well with one another.

Visualization is a problem. Among the techniques for allowing the surgeon improved visualization is for the scrub person to apply a constant stream of warm saline, "warm squirt," while the surgeon is sewing distally. Another successful technique is to gently "blow" the blood away. By connecting the suction tubing to a CO_2 tank with a micro filter, cool air is emitted. A third technique includes using a small vessel occluder inserted into the vessel to help occlude the flow. If all else fails, the flow may be interrupted for up to 10 minutes.

The surgical technologist *must* be ready to assist in providing adequate visualization during distal anastomoses.

In coronary artery bypass surgery, the distal anastomoses are fashioned first according to the severity of the disease. The low potassium cardioplegia is perfused down each graft after completion of anastomoses through a multiport cardioplegia delivery set.

This technique can be easily adapted for use during valvular surgery. In patients having an aortotomy (aortic valve), the coronary sinus is perfused continuously throughout the procedure. During mitral valve surgery, the aortic root is perfused continuously with warm blood cardioplegia. The low potassium blood cardioplegia is infused continuously for all valvular procedures, and the pressure, measured at the cardioplegia delivery system, must not exceed 130 mm Hg. During coronary surgery, when cardioplegia is flowing only down saphenous vein grafts, less than 100 mL/min of cardioplegia is occasionally delivered down the vein grafts to avoid exceeding the pressure limit.

The primary scrub person's full attention is now essential for the entire time the cross clamp is on. Particularly close attention must be paid to the operative field. The cardioplegia is run continuously (there is no "down" time) between distal anastomoses. The surgeon will not stop to infuse the heart with cardioplegia or add slush; the procedure continues rapidly. It is necessary to aid in the visualization as well as to prevent the chest from overflowing since fluid may build up from copious irrigation or the flow may drain into the chest. The surgical team must be alert to pressure changes in the retrograde pressure monitor line. Pressure changes indicate cardioplegia flow in the coronary sinus may be obstructed. The cannula may be pressing against the wall of the coronary sinus, the stay sutures around the cannula may be too tight, or the cannula may be falling out of the coronary sinus. It may be necessary to readjust the placement of the retrograde cannula.

Complications

Available literature suggests that continuous warm blood cardioplegia may have lower complication rates than continuous cold cardioplegia. Studies have shown the operative mortality is also lower in warm blood cardioplegia, although this may not be statistically significant because of the small numbers involved in the studies.[19]

In the study by Lichtenstein et al.,[23] patients undergoing coronary artery bypass surgery using continuous cold blood cardioplegia were compared with a group receiving continuous warm blood cardioplegia. There was no significant difference in mortality between the

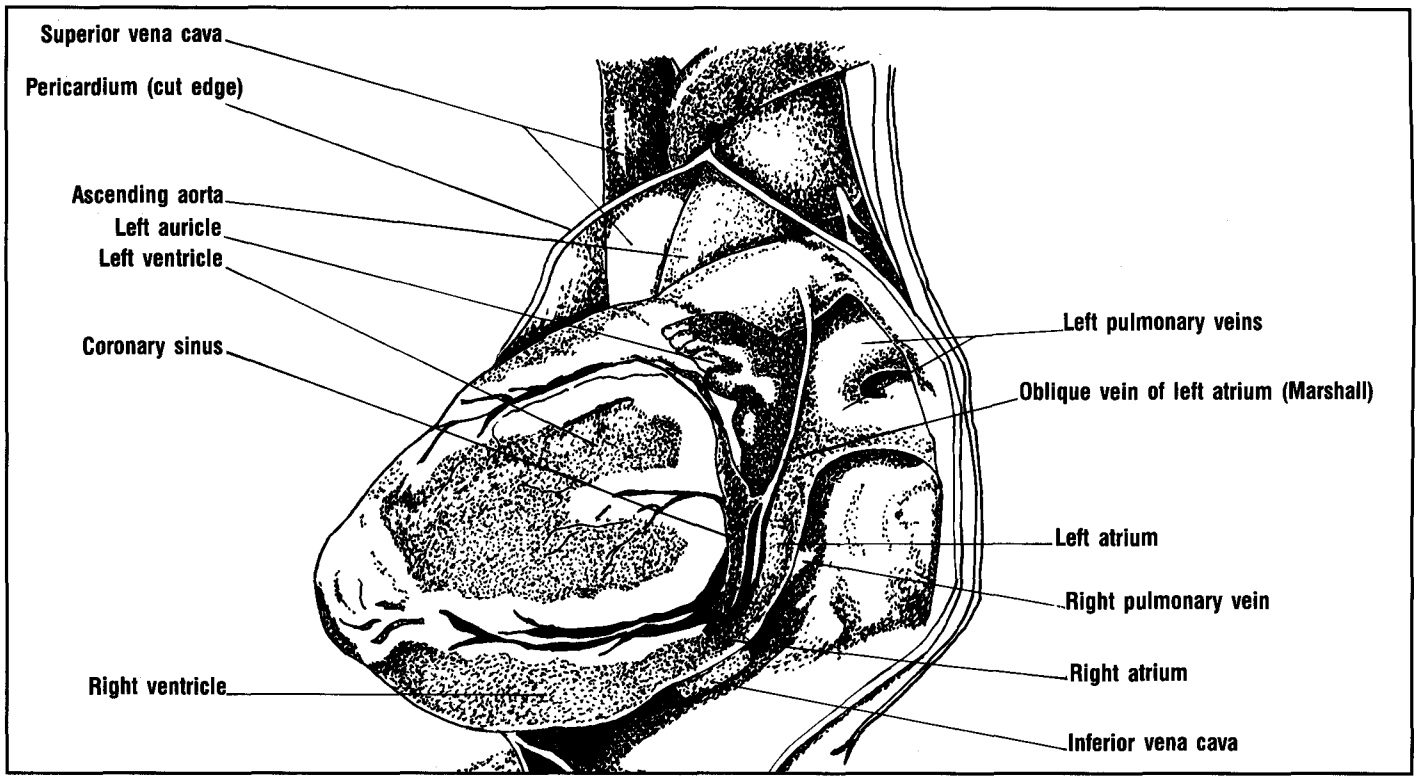

Figure 3. Heart drawn out of pericardial sac. (Adapted from Netter FH.[22])

groups (cold 2.1% versus warm 1.1%), but there were significant decreases in the usage of the intra-aortic balloon pumps, myocardial infarction, strokes, and re-operation for bleeding when the two approaches were compared by chi-squared analysis.[23] These improved clinical results were observed despite an increase in cross clamping time, but most importantly, nearly 100% of the patients returned to normal sinus rhythm without defibrillation.

While the present technique can at times be cumbersome (blood in the operative field is troublesome, particularly during coronary artery bypass surgery), this is a relatively minor problem to overcome given the potential advantage of greatly prolonged operative time that is possible with good myocardial preservation.[24] Furthermore, similar technical problems have been overcome by surgeons using intermittent ischemic or fibrillatory arrest.[25,26]

Advantages of Continuous Warm Blood Cardioplegia

Continuous warm blood cardioplegia has two major components: continuous blood cardioplegia and normothermic (warm) perfusion. Each of these components has been used individually in cardiac surgery,[27,28] but they had not been used together. It is this combination that makes the technique so effective since continuous cardioplegia, when performed under hypothermic conditions, has a number of disadvantages, as does normothermia when applied in an ischemic, contracting, or fibrillating myocardium. If electromechanical arrest can be achieved chemically as first suggested by Melrose,[29] and if ischemia can be eliminated by continuous perfusion with blood, the need for hypothermia becomes questionable.

This new technique for delivery of continuous, normothermic blood cardioplegia 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 benefit patients with poor ventricular function.

The secret to achieving optimal success with this technique lies in good communication skills among the perfusionists, surgical technologists, surgeon, and any other members of the operating room team. The perfusionist must pay close attention to the pressure of the retrograde cannula and communicate an increase or decrease in the monitor line. The surgical technologist may need to remind the team to turn on the vent during retrograde and to turn it off during antegrade perfusion, as well as pay extremely close attention to the operative field during distals. Of course the surgeon will communicate his/her frustration to all members of the surgical team if bloody flow makes it impossible to see.

Summary

The mainstay of myocardial protection at the present time is hypothermia. The initial goal of hypothermia was cerebral protection, but it became the single most important factor of myocardial protection. The concept of hypothermia has been ingrained in the modern approaches to heart surgery, but two of the

major effects of hypothermia have been ignored: many changes may occur on a cellular level that could result in significant cell damage, and hypothermia itself does not lead to a decrease in myocardial oxygen consumption. The major determinant of myocardial oxygen is electromechanical work—a beating heart. Diminished myocardial oxygen with hypothermia is actually due to a decrease in heart rate.

Hypothermia is used to prolong safe periods of ischemic arrest. Surprisingly, hypothermia actually increases myocardial oxygen consumption per beat, due to increased contractility.

Continuous warm blood cardioplegia is a controversial technique because of the lack of hypothermia. There are many concerns for patient selection criteria, as well as the effects on the brain. Studies from around the country are forthcoming and the scientific community awaits the results. Δ

Editor's note:
Nannette Hages, CST, was first introduced to continuous warm blood cardioplegia in 1989. The first known patient to undergo this procedure in the United States was operated on at that time. Upon moving to Florida a few years later, Nannette Hages, CST, was a member of the surgical team that performed the first known continuous warm blood cardioplegia in that state.

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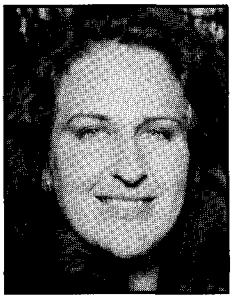

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