The Heart Surgery Forum®

EDITORIAL

Combining Coronary Revascularization and Valvular Surgery on a Beating Heart: An Analysis

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BACKGROUND

It is important from the outset to define the term "beating heart surgery" (BHS) because it has been used to describe a range of surgical procedures. Although "beating heart surgery" literally means surgery performed when the heart is beating, until recently the term was used almost exclusively to describe surgery on the beating heart performed without cardiopulmonary bypass ("off-pump" surgery). However, we believe that BHS should be used to describe all types of surgery in which cardioplegia is not used, whether performed on-pump or off-pump. One should also consider whether BHS is an appropriate term to describe cardiac surgery performed while the heart is fibrillating. Obviously, during fibrillation the heart is beating, but it is not pumping blood. We suggest that "beating heart surgery" should be used for all types of cardiac surgery in which the heart is beating (not fibrillating) in the same type of rhythm (sinus, atrial fibrillation, pacemaker rhythm) as before the operation. BHS should be considered an appropriate term to describe either on-pump or off-pump surgery in which retrograde coronary sinus perfusion is used.

It is well known that at least two factors contribute to postoperative cardiac mortality and morbidity: the use (and duration) of cardiopulmonary bypass and cardioplegic arrest. The development of cardioplegia during the last 20 years and the use of blood cardioplegia worldwide during the last 10 years has resulted in a shift from pure crystalloid mixtures to more natural solutions. However, despite the increased knowledge about myocardial metabolism, the arrested heart technique cannot be made a purely "natural" one. The development of off-pump surgery during this period as a less intrusive alternative may have been driven by a number of considerations, such as the desire to reduce the length of the skin incision, to avoid cardiopulmonary bypass, or to avoid the use of cardioplegia. Today it may be said that the off-pump technique, which is actually a variety of techniques used to obtain the most benefit for the patient, is a flexible approach intended to match the operation to the patient rather than the patient to the operation. With this goal of flexibility in mind, we believe that on-pump BHS is also justifiable, especially in patients with impaired left ventricular function. Matching the operation to the patient means selecting the technique or combination of techniques that is most suitable for the indications presented by the patient.

Appropriate BHS procedures might include pure coronary artery bypass grafting (CABG) cases, pure valvular cases, and combined (valvular-CABG) cases. We have previously described the use of BHS with retrograde coronary sinus perfusion in two groups of patients with good results [Gersak 2000]. In the beginning we used this technique for patients with poor left ventricular function, but further experience with greater numbers of patients has convinced us that the technique can also be used for "normal" patients. We also suggest the use of on-pump CABG for patients who have severely impaired ventricular function because we believe that the cardiac muscle should be preserved as much as possible. Furthermore, in some combined cases with impaired ventricular function, we use initial off-pump CABG followed by BHS for the valve component of the operation. However, it is questionable to use off-pump surgery for CABG in combined cases if the ventricular function is impaired and we already know that CPB will be required for the valve operation. Perhaps CABG should be performed on-pump with the heart beating but allowed to rest using a temporary left and right ventricular assist device. On the other hand, if off-pump CABG is used first, and then CPB is started for the BHS valve operation, CPB time could be significantly lowered. The combined surgical techniques we have used are discussed below.

SURGICAL TECHNIQUES

Valve Procedures with CABG

The first step is to initiate the normal CPB connection (double J-cannula and bicaval cannulation, as for cardiac

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transplantation). All distal anastomoses of the diseased coronary arteries are then performed on the beating heart, using regional stabilization if necessary. CPB is not started until all of the distal anastomoses are completed.

For patients with severely impaired ventricular function, it is important to cannulate for CPB at the beginning so that CPB can be started at any time if the surgeon wishes to perform the CABG on-pump. At our facility we use on-pump CABG for patients who have impaired left ventricular function and enlarged hearts—the operation can be performed much faster this way and the CPB time is not significantly longer.

At our facility we usually perform the LIMA to LAD anastomosis first, followed by the graft to the left circumflex (LCX) region, with the graft to the right coronary artery (RCA) done last. However, if we use on-pump CABG on the beating heart, it is not necessary to perform the LIMA to LAD anastomosis first because the heart is actually resting, in which case the graft to the LCX region can be performed first.

There is one more advantage to using on-pump CABG for patients with impaired left ventricular function. The graft to the RCA region can sometimes be a major stress in off-pump CABG for these patients, and starting CPB at this point can reduce the potential for complications resulting from the off-pump procedure.

After each of the venous distal anastomoses is completed, the grafts are connected with the oxygenated blood perfusion line as a means for the arterialized blood to enter the coronary circulation. Pressure and flow rate in these grafts must be monitored with caution. Mean pressures over 60 mm Hg should be avoided. When all of the distal anastomoses have been performed, a vent is placed in the aorta and CPB is started.

It is important to emphasize the difference between "pure off-pump" CABG in combined cases and anastomoses-only off-pump. In "pure off-pump", the surgeon sutures the proximal anastomoses to the aorta while off-pump using partial cross-clamping. In the other, only the distal anastomoses are performed off-pump (or on-pump) and the proximal anastomoses are perfused and sutured to the aorta at any time while the aorta is totally cross-clamped and coronary sinus perfusion is working. We would like to emphasize that in using the latter technique we cross-clamp the ascending aorta just once, thus reducing the risk of embolization. In high-risk combined cases this is especially important, because the ascending aorta is normally highly calcified.

Pure Valve Procedures

When CPB has been started, the patient is placed in Trendelenburg position for the installation of the vent into the left ventricle through the right superior pulmonary vein (for the aortic valve). When this vent is in place, the patient is restored to the horizontal position.

The Mitral Valve

For a mitral valve procedure, total CPB is first obtained and the right atrium (RA) is emptied. The RA is dissected as much as possible from the left atrium (LA) between the interatrial sulcus. Then a cut is made 1 cm from and parallel to the atrioventricular sulcus, opening the RA and exposing the coronary sinus (CS) opening. From outside the RA, a 4/0 polypropylene purse suture is made around the CS ostium and a retrograde cannula is inserted, a tourniquet applied, and a catheter is connected with the retrograde oxygenated blood perfusion line.

Both vents (aortic and left ventricular) maximally drain the heart while simultaneously the aorta is clamped and the retrograde CS perfusion is started at a rate of approximately 300 ml/min., resulting in mean retrograde pressure of about 50-60 mm Hg [Gersak 2000].

The incision parallel to the interatrial septum is made in the LA, exposing the LA and providing good visualization of the interatrial septum from both sides. If this is not enough to obtain a good vision of the mitral valve, a vertical cut is then made, starting from the mid-part of the RA to the septum toward and through the fossa ovalis. This cut is similar to the incision described in an earlier article [Gersak 2000], but the present incision is angled 45 degrees in the direction of the CS, preserving the CS and retrograde perfusion. Hooks are then easily applied, giving excellent exposure of the mitral valve. The procedure on the mitral valve is then performed, and if the mitral valve repair is made, the testing on the beating heart is done. The left ventricle is filled with saline, the aortic pressure is registered through the aortic vent, and the necessary corrections for the mitral valve are finalized. The aortic vent is then opened, the heart is completely emptied, and the vent is inserted in the left ventricle through the mitral valve or, if necessary through, the apex. At this point, if the mitral valve repair or replacement was done, the aortic valve replacement (AVR) will be done next. The excision of the left auricle is performed with two layered 4/0 continuous sutures if the LA is enlarged or if the patient is in atrial fibrillation (AF). A continuous 3/0 polypropylene suture, starting at the fossa ovalis, is used to close the interatrial septum. The left atrium is sutured from the cranial portion toward the end of the atrial cut, reducing the LA. Next the RA is closed, and if the patient is in AF, the right auricle is removed, closing with two layered 4/0 continuous sutures.

The Aortic Valve

For an isolated aortic valve procedure, either single or double venous cannulation may be used, depending on experience. The retrograde coronary sinus catheter is placed as described above for the mitral valve operation when double cannulation is used. If a single venous cannula is used, the coronary sinus catheter is also secured with a transatrial 3-0 polypropylene suture near the junction of the inferior vena cava and the right atrium. We use this suture to prevent coronary sinus catheter displacement during the operation.

The aorta is opened 1 cm above the right coronary artery ostium in an L-fashion, and the incision is extended to the middle of the non-coronary sinus. This type of incision is important because the right ventricle otherwise blocks the view of the aortic valve. The operation proceeds from this point as an ordinary aortic valve procedure. We always use pledgeted mattress sutures, so that the pledgets are always on the ventricular side. Because the right coronary artery region is sometimes difficult to suture, we developed the following system for suturing: first we place all three commissural sutures, then we proceed clockwise, forehand up, from the left non-coronary commissure to the left right-coronary commissure, with the last suture backhand up. Then we suture backhand up counterclockwise from the non-coronary–right-coronary commissure toward the left right-coronary commissure, and counterclockwise forehand up from the left non-coronary commissure to the non-coronary–right-coronary commissure.

Completion of the Surgery

If a CABG procedure was also performed, the aorta is still clamped when the proximal anastomoses are performed in sequence. The retrograde perfusion also is not stopped, and the CABG grafts which are not sutured to the aorta still receive oxygenated blood antegrade. At this point, the proximal portions of the grafts are clamped with bulldog clamps, the heart is de-aired through the aortic vent (the procedure is quick, because the left ventricle is not fully empty), the retrograde perfusion is stopped, and the aorta is declamped. The grafts are then released from the bulldog clamps after de-airing with the insulin needle. The anastomotic sites are examined for bleeding, and the retrograde sinus catheter is removed.

CPB is shut off after systemic pressures indicate that normal cardiac performance has been restored, and the cannulas are then removed in standard fashion.

DISCUSSION

Advantages of Beating Heart Surgery

The principal advantages of BHS are:

(1) Myocardial muscle is perfused, and the heart is not doing any work.
(2) There is no reperfusion injury.
(3) Ablation of atrial fibrillation is possible—reducing aortic cross-clamp time, which is prolonged with the arrested heart technique, and enabling testing of the ablation effect.
(4) Blood runs retrograde into the sinusoids. In cardiosclerosis, as well as in experimental ischemia and hypoxia, we see a paradox at work in the myocardium: the inflow diminishes while the backflow increases. In reality the expansion of the venous channel compensates for the deficiency of the arterial vascularization of the blood supply, bringing nutrients to the myocardium by retrograde blood flow.
(5) CPB duration is shorter.
(6) Aortic cross-clamp time is shorter—in fact, when the aorta is cross-clamped the myocardium is not ischemic, because the heart is perfused retrograde.
(7) Testing of the mitral valve repair can be done under the real physiologic condition of a contracting left ventricle.
(8) Duration of CPB and aortic cross-clamp time is shorter in combined operations.

Observations on Surgery-Related Phenomena

Ischemia-Reperfusion Injury

Off-pump CABG reduces the invasiveness of surgery but jeopardizes the anastomoses because of cardiac motion and the need to hurry to reduce the time of local ischemia. Short periods of ischemia, on the other hand, reduce reperfusion injuries that appear later due to reoxygenation shock: ischemic tissue is reperfused after the surgery. Reperfusion injury plays a major role in many clinical conditions, including shock and coronary artery occlusion disease. In addition, no-reflow phenomenon, stunning, or hibernating myocardium often occurs when reperfusion is introduced. Arrhythmia also frequently accompanies disturbance of the heart function during reperfusion.

Changes in cells appear in organelles and in whole cells due to alteration of membrane permeability to water and electrolytes. Key substances formed during reperfusion are oxygen free radicals, which cause tissue injury and influx of calcium ions into the cells. Many mediators (adenosine, ET, AT, iNOS, bradykinin) are released due to myocardial ischemia. In vascular endothelium, a critical step in injury is leukocyte adhesion, which leads to increased microvascular permeability and thrombosis. Crucial endothelial regulation is controlled by nitric oxide (NO), which may trigger short- and long-term effects that can be either beneficial or deleterious. In the cardiovascular system, the major targets of NO activity are guanylyl cyclase, heme proteins, protein thiols, iron-non-heme complexes, and superoxide anions. A beneficial effect is the induction of iNOS by endogenous vasoconstrictor agonists, which provides cardiac protection against ischemia-reperfusion injury [Stoclet 1999].

Protection against reperfusion injury can be achieved by oxygen free radical scavengers—antioxidant enzymes, like superoxide dismutase and catalase, which are also upregulated by ischemia—and this can lead to a lesser production of oxygen-derived free radicals during reperfusion. Calcium antagonists, acting as free radical scavengers, stabilizers of membranes, and calcium entry blockers, appear at present to be the most frequently used anti-ischemic agents. In addition to calcium antagonists, blood volume expanders consisting of colloid solutions and/or electrolyte solutions can be efficiently used.

Generally, improved microcirculation and vasorelaxation are the primary protection mechanisms for ischemia-reperfusion injury.

Preconditioning

Many research findings support the beneficial clinical effects of ischemic preconditioning. Evidence that preconditioning may offer patients protection against irreversible myocyte injury comes first from experiments on isolated heart models. In these experiments, minor ischemia seemed to be beneficial. Preconditioning is considered to be the most efficient anti-ischemic intervention, but its beneficial effects are often short-lived since they may be lost in a reperfusion period that lasts for a few hours. Preconditioning the heart with a few minutes of ischemia increases its resistance to subsequent longer ischemic periods, which results in many benefits. Among the most important benefits are reduction of reperfusion injuries, diminished arrhythmia, prevention of myocardial stunning and post-ischemic contractile dysfunction, marked limitation and decrease of infarct size, and reduction in endothelial injury.

Myocardial function during reperfusion can be improved by pharmacological, ischemic, or heat stress-induced preconditioning. This response might be related to the expression of stress proteins or heat shock proteins. To protect the myocardium against reperfusion injuries, preconditioning with brief ischemic periods prior to a more prolonged one can be used. Since protection is receptor mediated, the preconditioning process is triggered by several endogenic agonists that are released from stressed ischemic cells. The response can be evoked by infusion of the same endogenic substances—adenosine, catecholamines, angiotensin, endothelin, bradykinin—most of them acting mainly on receptors, coupled to protein kinase C. An end effector responsible for preconditioning the cells is not known yet. It has also been shown that over-expression of heat stress proteins facilitates protein synthesis and makes myocytes more resistant to ischemia. It is believed that newly formed proteins and denatured ones are repaired and stabilized by the heat stress proteins.

Protection of the myocardium by preconditioning with short ischemic periods, by selective mitochondrial ATP-sensitive potassium channel activation, and by drugs acting on alpha-adrenergic receptors has been confirmed. The exact mechanisms of preconditioning that induce delayed protection are unknown. Ischemic induction of preconditioning processes such as the expression of protective proteins suggests that pharmacological stimulation mimics the endogenous protective pathway. This insight could lead to the development of new pharmacological interventions to induce delayed myocardial protection in clinical procedures such as angioplasty, coronary bypass surgery, or even surgery in patients at high risk of infarction.

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