Myocardial Preservation: Controlled Reperfusion

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Reperfusion injury after reestablishing coronary flow by releasing the aortic cross clamp after cardiac surgery with cardioplegic arrest causes myocardial damage and even death. Attenuation of this reperfusion response by controlling the biochemical and physical environment can avoid morbidity and mortality. Use of a warm reperfusate with addition of drugs that are known to decrease reperfusion injury with manipulation of coronary vascular resistance and the physical parameters of the reperfusion environment helps the heart to reestablish coronary perfusion while decreasing the harm produced by the period of ischemia that occurs during cardiac surgery with intermittent cardioplegic arrest.

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Reperfusion injury refers to the paradoxical increase in injury that occurs after restoration of normal blood flow to an organ that is subjected to a significant period of ischemia. In the heart this can range from reperfusion arrhythmias, myocardial stunning, no reflow phenomenon, lethal ischemic contracture (stone heart), and myocardial necrosis (Fig. 1).

Controlled reperfusion refers to the process of attenuation of reperfusion injury by controlling the composition of the reperfusate and the milieu under which the reperfusion is done.

We have used a method of controlled reperfusion by using warm hemic reperfusate with adenosine, esmolol, lignocaine, and nitroglycerin[1-8] administered at a controlled pressure with alteration of coronary vascular resistance to alter the reperfusion milieu and thus attenuate reperfusion injury.

CARDIOPLEGIA PROTOCOL

We use a modified blood cardioplegia solution that is made by using St Thomas I solution mixed in blood with 6 U of insulin per liter of cardioplegia solution given in a 4:1 blood-to-cardioplegia ratio (Fig. 2). Insulin allows large amounts of cardioplegia solution to be given without having high potassium concentrations at the end of the case. Warm induction of cardioplegia is done in special circumstances (described later) and not as a routine. Cardioplegia solution is given antegradely and retrogradely every 20 minutes. In portions of the surgery where an absolutely dry field is not required, cold normokalemic blood is continuously perfused through the coronary sinus and vented out through the aortic root, and additional cardioplegia solution is given if there is any electromechanical activity. The perfusionist is instructed to start retrograde continuous cold normokalemic blood within 10 minutes of delivery of cardioplegia solution (which allows the surgeon to do the initial assessment of intracardiac anatomy and required surgery) and is only interrupted at the surgeon's request. We tailor the systemic temperature according to the needs of the case. Patients with expected cross-clamp times $<$180 minutes, all isolated coronary artery bypass grafting (CABG) done on pump if done with cardioplegic arrest, and patients with hepatic dysfunction are operated at 32°C. Longer cases or cases with significant collateral flow causing flooding of the operative field (and rewarming the heart) and hearts with severe concentric hypertrophy are operated at 28°C or lower. Patients requiring circulatory arrest are operated at 16°C-18°C.

Controlled Reperfusion

Once the major portion of the case is over and it is determined that interruption of cardioplegia for expo-

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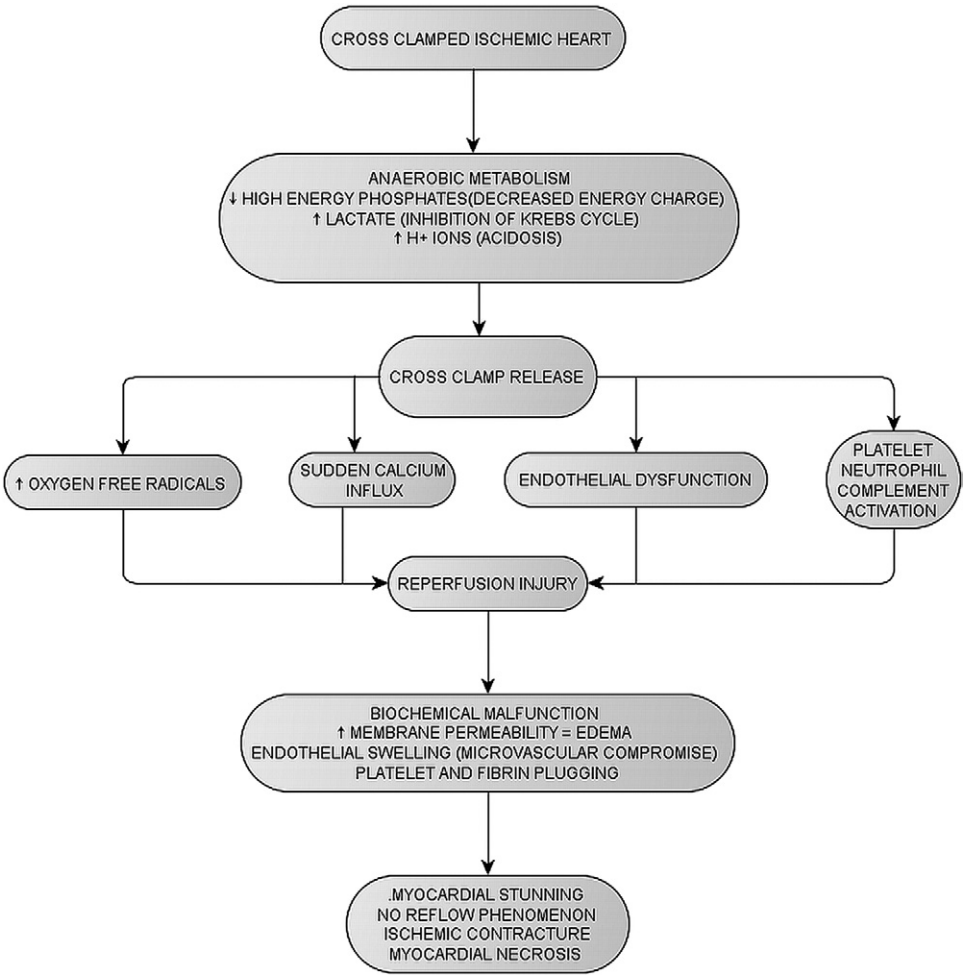

Figure 1. Flow chart of the cascading events that occur because of reperfusion injury that leads to myocardial damage.

sure is not necessary, continuous warm cardioplegia solution (32°C-37°C) is started. Emphasis is given at this stage to check on both the flow (a minimum of 350 mL/min in adult hearts and at least 1 mL/g of estimated left ventricle (LV) mass in children) and that the retrograde cardioplegia perfusion pressure is <40 mm Hg and preferably <35 mm Hg. Boluses of nitroglycerin (50 μg) and adenosine (6 mg) are given through the retrograde cardioplegia line by the perfusionist every minute until the pressure falls below 35 mm Hg (antegrade cardioplegia is given if a retrograde catheter cannot be placed and the target pressure is 40-60 mm Hg at the root or 100 mm Hg at the pump head). One mg/kg of lidocaine is given as a bolus through the cardioplegia line to ensure membrane stability.[7-9] Once the perfusion parameters are achieved, warm normokalemic perfusion is started. By the time the cardiotomies are closed, the heart should be beating in sinus rhythm or a slow junctional rhythm. Any ventricular fibrillation is deemed a state of membrane instability, and the heart is made asystolic with warm cardioplegia with boluses of lignocaine, adenosine, and esmolol.

Metabolic Monitoring of Adequacy of Cardioplegia and Reperfusion

This is done in all patients who were in preoperative cardiogenic shock, prolonged cases, or cases in which there is a clinical suspicion of inadequate myocardial protection (eg, severely hypertrophied hearts or any difficulty in delivering cardioplegia). Serial monitoring of the coronary sinus lactate and coronary sinus oxygen saturation ($S_{cs}O_2$) allows assessment of the adequacy of resuscitation of the heart.[10-12] Samples of the effluent are drawn from the coronary sinus during antegrade cardioplegia and via the aortic root during retroplegia.

The normal $S_{cs}O_2$ is 47.7% $\pm$ 8.6% and with continuous warm cardioplegia rises to 85%-90% and in the cold arrested continuously perfused heart is above 90%. Serial samples are drawn at 3- to 5-minute inter-