NORMOTHERMIC MYOCARDIAL PRESERVATION

An Optimal Approach for Myocardial Protection during All Forms of Open-Heart Surgery

Richard M. Engelman, M.D., John A. Rousou, M.D.,
Joseph E. Flack III, M.D., David W. Deaton, M.D.,
A. Bernard Pleet, M.D., and Dipak K. Das, Ph.D. *

Baystate Medical Center
Springfield, Massachusetts

*The University of Connecticut School of Medicine
Farmington, Connecticut

INTRODUCTION

Dennis Melrose and his colleagues[1] in 1955 published the initial work in Lancet on "elective cardiac arrest" using potassium ion in the form of potassium citrate administered through the coronary arteries to effect "cardioplegic arrest." The authors, far in advance of their time, postulated that this approach could be used to permit cardiac procedures to be carried out in the arrested, quiescent heart, permitting reestablishment of normal cardiac function after correction of the intracardiac defect. This report was initially accepted and used in the clinical setting, albeit in a limited fashion since "open-heart surgery" was not widely utilized in the 1950's. It rapidly became apparent that significant myocardial necrosis was associated with this technique and the approach was abandoned. [2] In fact, it was not until a number of years later that the deficiencies of the Melrose approach were found to be the relatively high concentration of citrate which was toxic and not the technique of potassium cardioplegia itself. [3]

In the 1960's, the concept of myocardial preservation, predominantly for valve replacement, was that of continuous coronary perfusion, often with the fibrillating heart. [4,5] Studies[4,5] were written supporting this approach with relatively low mortality and with most surgeons accepting the method as that of "optimal preservation." In fact, numerous cannulae were developed[5,6] to provide a means of safe cannulation of the coronary ostia. Despite this, intimal hyperplasia and coronary stenoses remains a complication of direct coronary cannulation, [7] and continuous ventricular fibrillation has been shown to lead to subendocardial ischemia, particularly in association with left ventricular hypertrophy. [8]
To obviate problems noted in the fibrillating heart, induced myocardial ischemia was proposed as a method permitting operative procedures in a quiescent heart. [9] During induced myocardial ischemia, often at or near normothermia, a condition termed "stone heart" was noted which was associated with very severe hemorrhagic necrosis. [10] This generally fatal outcome was manifested by a firm, contracted heart unable to beat effectively during reperfusion. The pathophysiology of this injury was clearly shown to be a consequence of massive calcium influx into the cell during reperfusion. [10]

With the development and acceptance of ischemic arrest as a method for accomplishing a quiet, bloodless operative field, Shumway and associates[11] explored the use of deep cardiac hypothermia. This work derived from successful studies utilizing deep hypothermia for organ preservation, particularly kidneys, and the initial results at Stanford were outstanding. The rationale for cardiac hypothermia is based upon the marked decrease in myocardial oxygen demand with a decrease in myocardial temperature down to the range of 5-10°C. This is illustrated in Figure 1.

With the general acceptance of myocardial hypothermia in the late 1960's, the stage was set for a significant improvement in myocardial preservation in the 1970's. The rejuvenation of chemical cardioplegia occurred initially in Germany in 1970 with the development of a solution based on an intracellular milieu, abolishing a transcellular sodium gradient and interrupting sarcolemmal function. [12] Because of significant inconvenience attendant in the use of an intracellular infusate, and the variability of solution content and volumes required, this approach has never assumed general acceptance in the United States. [12]

At about the same time that Kalmar[13] and Bretschneider[14] were working on one approach to clinical cardioplegia, Gay and Ebert[15] in New York City were exploring the use of hyperkalemic, hypothermic crystalloid cardioplegia to accomplish both cardiac hypothermia and rapid cardioplegic arrest. Their goal was to use cardioplegia for inducing hypothermia and immediate arrest, not to provide nutrients to the myocardium. [15] The demands of this approach involved the use of potassium to produce asystole by diastolic arrest without necessitating systemic potassium overload. The most effective concentration of potassium was found to be from 20-35 mEq/L of potassium chloride. The crystalloid cardioplegic solution was routinely cooled to 4°C resulting in myocardial temperatures of 10-20°C from intermittent cardioplegic administration in an antegrade fashion. By manipulating potassium concentration in the extracellular fluid, the fast phase of membrane depolarization is interrupted and cardiac arrest ensues. Utilizing the approach proposed by Gay and Ebert and further perfected by St. Thomas' Hospital in London, [16] this cardioplegic formulation is extracellular-based containing a high sodium and high potassium concentration, leading to diastolic depolarization. The antegrade crystalloid cardioplegic administration of a cold solution with systemic hypothermia became generally accepted in the latter half of the 1970's as the best method of optimal preservation. It was immediately associated with extremely gratifying results, and became the standard for all aspects of cardiac surgery. Only hemodilution and disposable oxygenators have had such a positive effect on cardiac surgery in reducing morbidity and mortality.