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# Myocardial Protection During Open-Heart Surgery: Role of Cold Blood Cardioplegia

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**Abstract**

**Background:** Protection of an arrested heart during open heart surgery is the single important factor for a successful outcome. The clinical conduct of a cardiac operation is a compromise between ideal operative condition and ideal myocardial preservation.**Material and Methods:**The study was conducted in the department of cardiovascular and thoracic surgery, in a tertiary care hospital. All the patients irrespective of age, sex, diagnosis and operative cardiac procedure were operated under hypothermic cardiac arrest.**Results:**A total of 57 patients were operated, majority in third decade of life, with almost same sex distribution. Echocardiography was the investigation of choice. Repair of atrial septal defect was the common surgical procedure. All were operated under hypothermic cardiac arrest. P ost bypass period was uneventful.**Conclusion:**Hypothermic cardiac arrest is the gold standard for ideal myocardial protection during open heart surgery.

**Keywords:**Hypothermia, Blood Cardioplegia, Myocardial protection.

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## Introduction

During cardiac surgery myocardial damage is cumulative. Each patient may respond differently, unpredictably, and may or may not lead to immediate or delayed poor outcome. Cardiac surgery may induce myocardial ischemia which may be local or global. Though ischemia is the major factor inducing intraoperative myocardial damage, harmful mechanical and pharmacological factors must also be taken in to account. The hallmark of excellent results depends on myocardial protection, so all the interventions are undertaken in preoperative, intraoperative and postoperative period to optimize myocardial oxygen supply and demand. The earliest cardiac surgical procedures used venous inflow occlusion techniques, but with the development of Cardiopulmonary Bypass (CPB), hypothermia became the primary technique of tissue protection in general and myocardial protection in particular. The limitations of these techniques were overcome after the introduction of cardioplegia by St. Thomas group in 1975. Hypothermia has been prominently employed in myocardial protection technique since the beginning of open-heart surgery. For every 10-degree centigrade (C) of temperature reduction in biologic system, the metabolic rate of chemical process is reduced by a factor of two. Cardiac cooling may be accomplished with systemic cooling, iced saline irrigation, ice slush / cooling pads placed around the heart, or

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perfusion hypothermia. Though all of these are effective, studies have shown that the most effective way of cooling the heart is perfusion hypothermia, with the draw back that the heart is cooled in a heterogeneous manner. In view of this fact addition of a topical hypothermic technique greatly improves the homogeneity of myocardial cooling, for an ideal myocardial protection, and the concept had been given long back.[1,2] The first successful repair of an atrial septal defect (ASD), and other series of patients using surface cooling was reported in 1953,[3,4] and further successful results were obtained when hypothermia was combined with cardiopulmonary bypass (CPB).[5] A basic hypothesis underlying use of circulatory arrest for cardiac and aortic surgery is that there is a safe duration of this state, the length of which is inversely related to the temperature of the organism during the arrest period. A safe period of cardiac arrest is characterized by absence of detectable functional or structural organ derangements in the early and late post-operative period. Another hypothesis is that hypothermia, without itself producing damage, reduces metabolic activity to the extent that the available energy stores in the various organs maintain cell viability, throughout the ischemic period of circulatory arrest, and thus allow normal structure and function to return after re-perfusion is accomplished. The magnitude of reduction of oxygen consumption is hypothesized to be directly related to safe duration of circulatory arrest. Methods of decreasing myocardial metabolism during CPB, are myocardial hypothermia, and cardioplegic arrest. The goals of hypothermic cardioplegia / topical ice slush are, immediate and sustained electromechanical quiescence, rapid and sustained homogenous myocardial cooling, maintenance of therapeutic additives in effective concentrations and periodic washout of metabolic inhibitors. To know the outcome of patients undergoing open heart surgery, hypothermic cold cardioplegic solution, supplemented by ice slush over the heart has been used in the present study.

**Material and Methods**

The study has been conducted in the Department of Cardiovascular and Thoracic Surgery, on the patients undergoing open heart surgery. Patients including those referred from other departments, were evaluated with a detailed history, thorough general / systemic examination. All the patients had echocardiography evidence of cardiac pathology before admission in the department. As and when indicated transthoracic echocardiography (TTE) was repeated. Depending on the age, diagnosis and indications, other investigations such as transesophageal echocardiography (TEE), coronary angiography, were also done. Pre-operative investigations included, blood sugar, complete blood count, liver, kidney, lung, functions, coagulogram, all the cultures, evaluation of activity, skiagram chest, interdepartmental consultations / clearances. Preanesthetic consultation and informed consent was the routine in all. Patients were operated under general anesthesia. After induction of anesthesia and endotracheal intubation, invasive monitoring lines were placed and secured. Heart was approached through median sternotomy, systematic purse string sutures were given for Aortic, SVC / IVC, Vent and Cardioplegic cannulation, full heparinization was done by monitoring ACT levels. Bypass circuit / Cannula were deaired, systematic cannulation was done, CPB started, cross clamp applied, cardioplegia given and all the patients were operated under cardiopulmonary bypass.

Myocardial protection was done by using cold blood cardioplegia, in a ratio of 4:1, four parts of blood and one part of cardioplegic solution. The cardioplegia was made in plasmalyte-A, ingredients of the cardioplegic solutions used were as per the composition, specified in St. Thomas solution. Oxygenated blood was drawn from the pump oxygenator, and mixed with the potassium containing cardioplegic solution and passed through disposable cardioplegic cooling tubes, which are joined and passed through MYOthermXP, which has a temperature of 8-10 degree centigrade (C), from there the cardioplegia goes to the patient with a

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temperature of 12–13-degree C. After CPB was established with the perfusate at 32 degree C, the aortic root catheter was inserted through a previously placed purse-string stitch, attached to the cardioplegic line, and de-aired. The aorta was clamped as soon as the aortic root catheter was in place, and in any event before the heart has been cooled sufficiently, vent started and cardioplegia given. Heart was arrested with an induction dose of cold blood cardioplegia using antegrade or retrograde (if otherwise indicated) delivery. The induction dose was 20 ml per kg body weight or 150 ml. $min^{-1}$. $m^{-2}$ for 3 minutes in adults and in children with body surface area less then 1 m2 the infusion was given at the same flow rate but for 2 minutes only. External cooling of the heart was established while the cardioplegic solution was being administered, and was done by using thin layer of ice slush over the anterior surface of the heart, far away from the phrenic nerve, the fluid so produced by melting of the ice slush was immediately aspirated by using wall sucker. Far maintenance, cardioplegic solution was reinfused after every 25 minutes. The concentration of potassium was decreased in the reinfusion solution, and the dose was one fourth of the induction dose, if otherwise not indicated more. In patients with ASD, the temperature was maintained between 32-33 C, and in valve replacement and myxoma surgery the temperature was 28-31C. Retrograde cardioplegia was used in very few patients. After the surgical procedure cross clamp was removed, but the CPB was continued for some time or till the patient was hemodynamically stable. Spontaneous cardiac activity with acceptable vital signs was observed in majority after removal of cross clamp. After hemodynamic stability, at least organized cardiac rhythm and moderately elevated heart rate patients were gradually weaned and then taken off CPB. Intraoperative events related to cardioplegia were recorded. Systematic decannulation was done, complete hemostasis achieved, pacing wires secured, drainage tubes placed and wound closed in layers. Patients were shifted to ICU, most of them ventilated overnight. Intraoperative / post operative events, morbidity and mortality was recorded. After discharge patients were followed in out-patient department.

**Results**

53 patients were included in the study, with almost equal sex ratio and majority in third decade of life. ASD was the common diagnosis in 60.37% of patients, [Table1]. Most of the patients were in New York Heart Association Functional Class (NYHA) II, [Table2]. Direct closure of ASD was the common surgical procedure performed in 32.07%, [Table3]. Cold blood cardioplegia and local ice slush was used in all. Patients for ASD repair were operated in mild hypothermia 32-33 degree C, those with valve replacement, ventricular septal defects (VSD) and myxoma in moderate hypothermia 28–31-degree C. The main ionic ingredients / components of cardioplegic solutions are indicated in [Table4]. Cold cardioplegic infusion was given at a flow rate of 150 mL. $min^{-1}$. $m^{-2}$ for three minutes, delivering a dose of 750 to 1000 ml in adults. In children's the cardioplegia was infused at the same flow rate but for two minutes only. CPB time was 30-50 minutes in patients with ASD repair, and 90-130 minutes in mitral valve replacement, with a maximum of 190 minutes in one patient. Cross clamp time was 16-40 minutes in patients with ASD repair and 70-100 minutes in patients with mitral valve replacement, with a maximum of 150 minutes in one patient. There were two minor and one major CPB events. On CPB during MVR line pressure increased, aortic line filter busted, heart lung machine arterial line pressure sensor did not work. Pump was stopped, filter was replaced, reconnected to circuit, complete deairing was done, all this in 2 to 3 minutes, CPB was restarted. Surgery was completed, patient weaned of bypass successfully and patient discharged after 10 days. None of the events were related to hypothermic blood cardioplegia. Post-operative period was uneventful in majority and three patients died within one month after surgery.

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**Table 1: Distribution of patients as per diagnosis**

| Diagnosis | Number of patients | Percentage |
|---|---|---|
| ASD | 32 | 60.37 |
| Mitral Valve Disease | 10 | 18.86 |
| Atrial Myxoma | 5 | 9.83 |
| VSD | 4 | 7.54 |
| Aortic valve disease | 2 | 3.77 |

**Table 2: Distribution of patients as per NYHA functional class**

| Functional Class | Number of Patients | Percentage |
|---|---|---|
| I | 6 | 11.32 |
| II | 29 | 54.54 |
| III | 14 | 26.41 |
| IV | 4 | 7.54 |

**Table 3: Distribution of operative procedures**

| Operative procedure | Number of patients | Percentage |
|---|---|---|
| Direct repair of ASD | 17 | 32.07 |
| Patch closure of ASD | 15 | 28.30 |
| Mitral valve replacement | 10 | 18.86 |
| Excision of myxoma | 5 | 9.43 |
| Patch repair VSD | 3 | 5.66 |
| Aortic valve replacement | 2 | 3.77 |
| Direct repair VSD | 1 | 1.88 |

**Table 4: Composition of cardioplegic solution**

| Ionic component | Ionic composition (mmoL /L) |
|---|---|
| Potassium | 16 |
| Sodium | 110 |
| Chloride | 128 |
| Calcium | 2.4/1.2 |
| Magnesium | 32/16 |
| pH | 7.8 |
| $NaHCO_3$ | 10 |
| Osmolarity | 280 |

## Discussion

The word cardioplegia combines the Greek cardio meaning the “heart” and plegia “paralysis”. Technically this means arresting or stopping the heart so that surgical procedures can be done in a still and bloodless field, most commonly, however, the word cardioplegia refers to the solution used to bring about asystole of the heart, or heart paralysis. Cardioplegia solution is the means by which the ischemic myocardium is protected from cell death, this is achieved by reducing myocardial metabolism through a reduction in cardiac work load and by the use of hypothermia. Various components in cardioplegic solutions such as potassium induces rapid cardiac arrest before its metabolic stores are depleted, magnesium helps in preventing cellular potassium and magnesium loss. The ability to control a patient’s body temperature within a wide range is one of the most important therapeutic modalities available

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to the cardiac surgery team. The rationale for hypothermia during cardiac surgery is that the chemical reactions are slower at lower temperatures, so the rate of consumption of intracellular high energy phosphate stores will be slower at lower temperatures. The hypothermia is defined as mild, moderate, deep and profound with temperatures of 32-35, 26-31, 20-25 and <20 C for each category respectively. Though cold applications recommended for some illnesses in human being's dates back to 1650 BC, the evolution of hypothermia for cardiac surgery started in 1950,[1,2] in 1951 it was demonstrated that dogs perfused with cold blood tolerated and survived 15 minutes of total circulatory arrest.[6] In 1953 first successful ASD repair, and other successful clinical results were reported using surface cooling.[3,4] The successful repair of heart defects in humans using hypothermia combined with cardiopulmonary bypass was reported in 1958.[2] It has been established beyond any doubt that the effective way of cooling the heart is the perfusion hypothermia, not only to arrest the heart, but the oxygen consumption of a chemically arrested heart is approximately one fifth that of the empty, beating, and fibrillating heart at 37-degree C. The requirements of a perfusion hypothermia are cardioplegia, which should induce myocardial arrest, prevent interstitial and intracellular edema, prevent loss of cellular metabolites, maintain approximate acid base balance, provide metabolic substrate, and should be noncytotoxic. Cardioplegia mixed with blood has the potential advantages, since blood provides trace elements, proteins, and enzymes that may not be found in analogs of interstitial fluid.[7] Hypothermia is not without adverse effects, though relatively benign, is not entirely without its own morbidity, and include deleterious effect on platelet function and potentiation of citrate toxicity notable, with subsequent reduction in serum ionized calcium, leading to reversible coagulopathy and depression of myocardial contractility. When compared the results of cold blood cardioplegia and crystalloid cardioplegia are almost same in terms of spontaneous sinus rhythm, relative risks, mortality in 30 days, atrial fibrillation, or stroke.[8] Cold blood potassium cardioplegia has been used safely in cardiac surgery, though with different ingredients.[9] Cold blood cardioplegia reduces the increase in cardiac enzymes levels compared with cold crystalloid cardioplegia.[10] Way back in early fifties the coronary system was perfused with a solution of acetylcholine, and resuscitation of heart was obtained by perfusion of coronaries with oxygenated blood.[11] The observations of the present study though differ in type of surgical procedure, are in similarity to other studies, where myocardial protection using cold blood with potassium cardioplegia has been achieved with excellent results on patients undergoing coronary artery bypass surgery.[12] The markers of myocardial damage are significantly lower in patients randomized to cold blood cardioplegia compared with those receiving cold crystalloid cardioplegia, and similar observations have been made in other studies.[10] Our findings are at variance to the studies where, systemic normothermia with warm cardioplegia had been introduced to prevent the deleterious effects of hypothermia.[13] Though myocardial protection was initially achieved using crystalloid cardioplegic solutions,[14] there has been an increase in use of blood based cardioplegic solutions, after the concept was introduced and we are in agreement with this concept.[15] It has further been observed that the blood cardioplegic solutions formulated to be as similar as possible to a clinically well-established crystalloid cardioplegic solutions, significantly improves that rate of recovery even of the higher risk patients.[16] Comparison of present formulations to that of del Nido cardioplegia solutions has found equivalent results of a single dose del Nido cardioplegia, but delayed spontaneous restoration of cardiac activity.[17] Systemic reviews and meta-analysis have concluded that there is no significant difference in postoperative rate of mortality, between the use of warm and cold cardioplegia.[18] If needed cardioplegic solution must be reinfused after every 25 minutes and same has been recommended by others also.[19,20]

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## Conclusion

Hypothermic open-heart surgery can be performed in any cardiac center, ingredients are easily available, composition is not difficult, monitoring is possible, reinfusion is not a problem, myocardial protection is not bad and outcome is good.

## Limitations

The results of the cardioplegic solutions used in present study were not compared with any other solution. No complex intracardiac procedure was performed. None of the patients had preoperative ischemic insult to the heart. None of the patients had severe left ventricular dysfunction. There were neither any neonates nor childrens with any complex cyanotic heart diseases.

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