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Original Research Article

Impact of Modified Hot Shot Delivery Before Cross Clamp Removal in Patients Undergoing Cardiac Surgery

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Abstract: ***Objective:*** To evaluate the impact of the modified Hot Shot (MHS) technique, administered before aortic cross-clamp removal, on myocardial protection and postoperative outcomes in patients undergoing cardiac surgery. ***Methods:*** A retrospective analysis was conducted on 224 patients who underwent cardiac surgery with cardiopulmonary bypass at King Edward Medical University/Mayo Hospital, Lahore, between January 2021 to December 2022. Patients were divided into two equal groups: Group 1 (n=112) received the standard Hot Shot (HS), while Group 2 (n=112) received the modified Hot Shot (MHS). Demographic, perioperative, and postoperative data were collected, including cardiac enzymes, arrhythmias, intra-aortic balloon pump (IABP) use, intensive care unit (ICU) stay, renal outcomes, and mortality. Statistical analyses were performed using SPSS version 26.0, with significance defined as $p<0.05$. ***Results:*** Baseline characteristics were similar between the two groups. Compared with HS, the MHS group demonstrated significantly lower postoperative arrhythmia rates ($p<0.005$), lower CK-MB and troponin levels ($p<0.005$ for both), reduced need for IABP support ($p<0.05$), shorter ICU stay ($p<0.005$), and fewer cases of dialysis-requiring renal failure ($p<0.05$). Mortality did not differ significantly between groups ($p=0.3$). ***Conclusions:*** Administration of the modified Hot Shot before cross-clamp removal improved myocardial protection and reduced postoperative complications compared with the standard Hot Shot technique. This strategy may represent a superior myocardial preservation approach in cardiac surgery.

Keywords: Cardiac Surgery; Myocardial Protection; Cardioplegia; Intra-Aortic Balloon Pump; Cardiac Enzymes; Intensive Care Unit.

INTRODUCTION

Cardiac surgery performed with cardiopulmonary bypass (CPB) requires effective myocardial protection to minimize ischemic and reperfusion injury. [1] Despite advances in surgical techniques, perioperative myocardial dysfunction remains a major determinant of postoperative morbidity and mortality, prolonging intensive care unit (ICU) stay and increasing resource utilization.[2] Traditional cardioplegia strategies, although widely used, may not provide complete protection against ischemia-induced myocardial damage, particularly during the critical period of aortic cross-clamp removal.[3]

One strategy to augment myocardial recovery is the administration of a "Hot Shot" (HS), a terminal warm blood cardioplegia solution delivered immediately before cross-clamp removal.[3] The HS technique has been reported to improve metabolic recovery, reduce reperfusion arrhythmias, and decrease enzyme release, though results have been inconsistent across studies.[4] A Modified Hot Shot (MHS), in which additives are included in the warm blood solution, has been proposed to further enhance myocardial protection.[5] The modification aims to optimize metabolic support during reperfusion and reduce ischemia-related injury, thereby improving clinical outcomes.[6]

Although several reports support the use of terminal warm blood cardioplegia, evidence regarding the additional benefits of the modified HS formulation is limited, especially in South Asian populations where differences in patient characteristics and perioperative practices may influence outcomes.[7] Furthermore, most available studies have small sample sizes or focus primarily on biochemical markers rather than clinically significant endpoints.[8] Thus, the potential role of MHS in improving both biochemical and clinical outcomes requires further clarification.

The present study aimed to evaluate the impact of MHS administration before aortic cross-clamp removal in patients undergoing cardiac surgery. Specifically, we compared intraoperative and postoperative outcomes, including arrhythmia rates, enzyme release, need for intra-aortic balloon pump (IABP) support, ICU stay, renal complications, and mortality, between patients receiving standard HS and those receiving MHS.

METHODS

Study Design and Setting:

This retrospective observational study was conducted at the Department of Cardiac Surgery, King Edward Medical University/Mayo Hospital, Lahore, Pakistan. Ethical approval was obtained from the Institutional Review Board of King Edward Medical University.

Study Population:

A total of 224 consecutive patients undergoing cardiac surgery with cardiopulmonary bypass (CPB) during the study period were included. Patients were allocated into two groups: Group 1 (n=112) received conventional Hot Shot (HS) cardioplegia, while Group 2 (n=112) received the Modified Hot Shot (MHS). The inclusion and exclusion criteria are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Patients undergoing elective cardiac surgery requiring CPB	Emergency cardiac surgery cases
Age ≥18 years	Patients with redo (re-operative) cardiac procedures
Both genders	Patients undergoing concomitant major non-cardiac surgery
Patients who received either HS or MHS cardioplegia before cross-clamp removal	Patients with pre-existing severe renal impairment requiring dialysis
Availability of complete perioperative data	Patients with incomplete medical records or missing outcome data

Abbreviations: *CPB, cardiopulmonary bypass; HS, Hot Shot; MHS, Modified Hot Shot.*

Interventions:

All operations were performed using standard CPB techniques with moderate systemic hypothermia. Myocardial protection was provided using intermittent cold blood cardioplegia. Immediately prior to aortic cross-clamp removal, patients received either HS or MHS solution.

- **HS:** Conventional warm blood cardioplegia delivered at 37°C, in a volume of approximately [insert from thesis, e.g., 200 mL].
- **MHS:** Warm blood cardioplegia supplemented with metabolic additives (Table 2), administered under the same conditions as HS.

Table 2. Composition of Modified Hot Shot (MHS) Solution

Additives	08 ml/L
▪ MgSO4 (50%)	3.3 mg
▪ $NaHCO_3$ (8.4%)	17.3 mEq/L
▪ Mannitol (25%)	5.35 g
▪ Lidocaine (2%)	228 mg
Arrest KCL	0 mEq/L

Abbreviations: *MHS, Modified Hot Shot; ATP, adenosine triphosphate.*

Data Collection:

Preoperative characteristics (age, sex, comorbidities, baseline ejection fraction, renal function), intraoperative variables (type of surgery, CPB and cross-clamp times, cardioplegia details), and postoperative outcomes were extracted from hospital records.

Study Endpoints:

The primary outcomes were markers of myocardial injury, including perioperative arrhythmias, postoperative creatine kinase-MB (CK-MB), and troponin levels. Secondary outcomes included intra-aortic balloon pump (IABP) requirement, ICU stay, renal failure requiring dialysis, and in-hospital mortality.

Statistical Analysis:

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using the Shapiro–Wilk test. Normally distributed data were expressed as mean ± standard deviation (SD) and compared using the independent-samples *t*-test. Non-normally distributed variables were presented as median (interquartile range [IQR]) and analyzed using the Mann–Whitney U test. Categorical data were reported as frequencies and percentages, and compared with the chi-square or Fisher's exact test, as appropriate. A *p*-value <0.05 was considered statistically significant.

Ethical Considerations:

The study protocol was approved by the Institutional Review Board of King Edward Medical University (Ref No: 113/RC/KEMU). Given the retrospective nature of the study, the need for individual informed consent was waived. All data were de-identified to ensure confidentiality.

RESULTS

Baseline Characteristics:

Baseline demographic and preoperative clinical characteristics were comparable between the two groups (Table 3). There were no significant differences in age, sex distribution, prevalence of hypertension, diabetes, or baseline ejection fraction. Preoperative renal function and comorbidity burden were also similar across the groups.

Table 3: Baseline and Preoperative characteristics of patients undergoing CPB

Parameter	Type of Hotshot		*p*-Value
	Hotshot (n=112)	Modified Hotshot (n=112)	
Age (years)	51.0(43.0-60.0)	53.0(43.5-60.0)	0.563
Weight (Kg)	70.0(59.0-77.0)	65.0(57.0-79.0)	0.495
Height (cm)	165.0(160.0-172.0)	165.0(158.0-172.0)	0.642
BSA	1.75±0.21	1.73±0.22	0.54
Flow Rate	4.22±0.50	4.19±0.52	0.66
BMI (Kgm^2)	25.3 (22.5-28.3)	24.17(21.2-28.1)	0.070
EF (%)	55.0 (45.0-60.0)	55.0(45.0-60.0)	0.267

Gender; Male; n (%)	82 (73.2)	82 (73.2)	0.01
Hypertensive; yes; n (%)	65 (58.0)	51 (45.5)	0.345
Smoking; yes; n (%)	49 (43.8)	38 (33.9)	0.01
Diabetes; yes; n (%)	44 (39.3)	46 (41.1)	0.059
Hepatitis C; yes; n (%)	3 (2.7)	1 (0.9)	0.01
Pre- Platelets	263.56±73.18	248.76±78.76	0.14
Pre- Hb	13.63±2.32	13.99±1.94	0.2
Pre-PT	14.0 (13.0-15.0)	14.95(13.4-16.0)	0.001
Pre-Urea	28.0 (22.0-33.0)	27.0(24.0-34.0)	0.750
Pre-Creatinine	0.9 (0.8-1.1)	0.80(.70-0.9)	0.000
Pre-Op CCR	93.4(73.4-105.3)	99.95(83.75-126.8)	0.001
Pre-Urine	200.0(100.0-300.0)	210(125.0-350.0)	0.032
Pre-Bilirubin	0.50(0.4-0.6)	0.50(.30-0.6)	0.902
Pre-SGPT	26.0(18.0-36.0)	29.50(22.0-50.0)	0.019
Pre-SGOT	29.0(23.0-36.0)	31.0(24.0-39.0)	0.327
Pre-Alk Phosphatase	85.0(71.0-102.0)	86.0(78.0-99.8)	0.695
Pre-WBCs	8.50(7.3-9.8)	8.63(7.9-10.3)	0.221
Autologous Blood	2.0(1.0-2.0)	2.0(2.0-2.0)	0.001
Pre-Op ACT	95.0(92.0-105.0)	97.0(92.0-105.0)	0.928

Abbreviations: Body Mass Index (BMI), Ejection Fraction (EF), Hemoglobin (Hb), Prothrombin Time (PT), Creatinine Clearance Ratio (CCR), Serum Glutamic Pyruvic Transaminase (SGPT), Serum Glutamic Oxaloacetic Transaminase (SGOT), White Blood Cells (WBCs), Activated Clotting Time (ACT)

Intraoperative Variables:

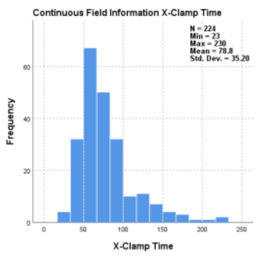
Key intraoperative parameters are summarized in Table 4. Cardiopulmonary bypass (CPB) and aortic cross-clamp times did not differ significantly between the HS and MHS groups as show in Figure1 and Figure 2. The type of surgical procedure performed was evenly distributed. Both groups received comparable volumes of cardioplegia solution, differing only in the composition of the final Hot Shot dose.

Table 4: Intraoperative Variables

Parameter	**Type of Hotshot**		***p*-Value**
	Hotshot (n=112)	**Modified Hotshot (n=112)**	
Prime Replacement	300.0 (0.0-450.0)	300.0 (200.0-400.0)	0.023
Pre-Bypass Hb	12.90 (11.0-14.0)	13.10 (11.70-14.6)	0.07
During-CPB Hb	8.60 (7.8-9.8)	8.50 (7.82-9.9)	0.686
During-CPB ACT	531.0 (461.0-692.0)	526.0 (455.5-633.0)	0.452
X-Clamp Time	69.0 (57.0-84.0)	71.0 (55.2-92.8)	0.896
CPB Time	123.0 (104.0-149.0)	122.0 (101.2-152.50)	0.725
Cooling T	31.0 (30.2-32.8)	32.0 (30.0-33.0)	0.248
Plegia Volume	1000.0 (1000.0-1200.0)	1000 (1000.0-1000.0)	0
Hotshot Volume	500.0 (450.0-500.0)	500 (470.0-572.5)	0.005
During-CPB Urine	1200 (900.0-1400.0)	1000 (850.0-1200.0)	0.011
Transfusion (No of Bags)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.951

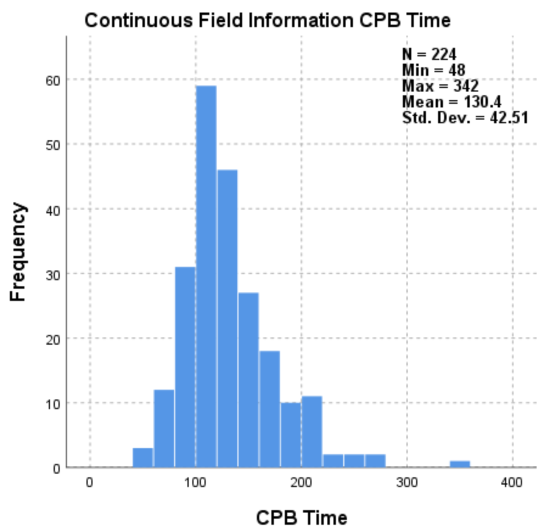
Abbreviations: *Hemoglobin (Hb), Cross Clamp (X clamp), Cardiopulmonary Bypass (CPB), Temperature (T)*

Figure 1: Distribution of aortic cross-clamp times among study patients



Distribution of aortic cross-clamp times among study patients. The histogram illustrates the frequency of patients across different cross-clamp time intervals

Figure 2: Distribution of cardiopulmonary bypass (CPB) times among study patients



Distribution of cardiopulmonary bypass (CPB) times among study patients. The histogram demonstrates the spread of CPB times recorded during surgery. Abbreviation: CPB, cardiopulmonary bypass.

Postoperative Outcomes:

Postoperative outcomes are presented in Table 5. Patients in the MHS group demonstrated significantly lower incidence of arrhythmias compared with the HS group. Similarly, as shown in Figure 3 and Figure 4, biochemical markers of myocardial injury were reduced in the MHS group, with lower mean CK-MB and troponin levels in the early postoperative period ($p<0.005$ for both). The need for intra-aortic balloon pump (IABP) support was significantly less frequent in the MHS group ($p<0.05$). ICU stay was also shorter among patients receiving MHS ($p<0.005$).

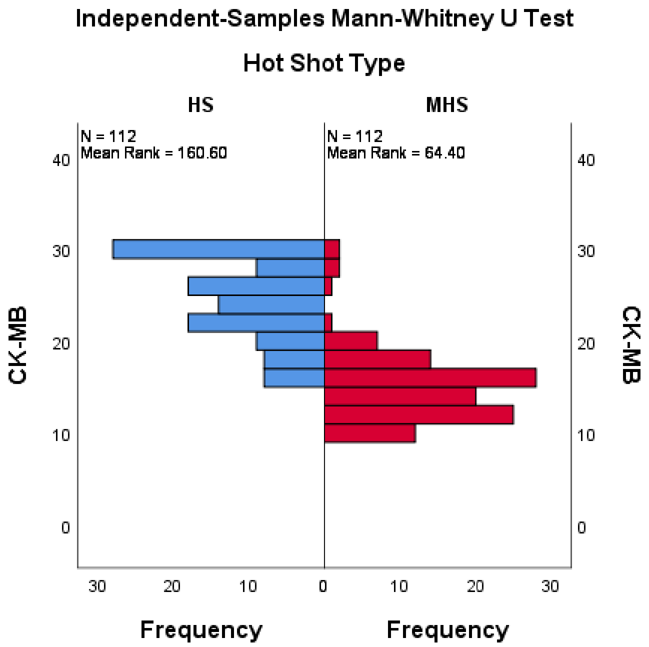
Table 5: Post-Operative Variables, Complications and Mortality

Parameter	Type of Hotshot		*p*-Value
	Hotshot (n=112)	Modified Hotshot (n=112)	
Post-Operative Phase			
After-CPB Hb	9.30 (8.4-11.2)	9.08(8.3-10.2)	0.093
After-CPB ACT	98.0 (92.0-109.0)	99.0 (94.0-109.0)	0.301
Post-CPB Urine	500.0 (400.0-800.0)	600.0(400.0-900.0)	0.226
Post-Op CCR	81.02 (64.3-102.9)	74.79(0.1-102.3)	0.078
Post-Op PT	14.0 (13.0-15.9)	14.0(13.0-15.3)	0.279
ICU ACT	125.0 (107.0-156.0)	120.0(107.0-144.0)	0.432
Donor Blood (No of Bags)	1.0 (0.0-1.0)	0.0(0.0-1.0)	0.201
Donor FFPs(No of Bags)	0.0 (0.0-0.0)	0.0 (0.0-1.0)	0.163
Adrenaline (min)	1200.0 (300.0-1920.0)	870(300.0-1890.0)	0.276
Nor-Adrenaline (min)	1680.0 (1080.0-2580.0)	1140(780.0-2025.0)	0.013
Dopamine (min)	2400.0 (1260.0-3000.0)	1200(240.0-2520.0)	0.001
Blood Drainage	890.0 (600.0-1210.0)	550(365.0-1095.0)	0.001
Post-Urea	30.25 (25.0-39.3)	32.0(26.1-43.0)	0.162

Post-Creatinine	0.96 (0.8-1.2)	0.91(0.6-1.1)	0.054
Post-SGPT	30.60 (21.6-44.0)	31.50(23.0-46.0)	0.639
Post-SGOT	41.50 (33.0-60.5)	51.50(39.0-81.5)	0.009
Post-WBCs	12.90 (10.6-16.1)	17.20(13.2-19.7)	0.000
Post-Platelets	181.25 (145.6-244.3)	166.5(139.3-210.7)	0.259
Troponin-T	400.0 (350.0-478.0)	230.0(165.3-275.00	0.001
CK-MB	24.0 (21.0-29.0)	14.0(12.0-16.0)	0.001
K- Level	4.30 (4.1-4.7)	4.40(4.1-4.9)	0.509
ICU Stay (days)	6.0 (5.0-8.0)	5.0(4.0-6.0)	0.000
Defibrillation; yes; n (%)	10 (8.9)	6 (5.4)	0.01
IABP; yes; n (%)	3 (2.7)	0 (0)	0.01
Mortality; yes; n (%)	2 (1.8)	0 (0)	0.01

Abbreviations: *Hemoglobin (Hb), Activated Clotting Time (ACT), Fresh Frozen Plasma (FFPs), Minutes (min), Serum Glutamic Pyruvic Transaminase (SGPT), Serum Glutamic Oxaloacetic Transaminase (SGOT), White Blood Cells (WBCs), Creatine Kinase-Myoglobin Binding (CK-MB), Potassium (K), Intra-Aortic Ballon Pump (IABP)*

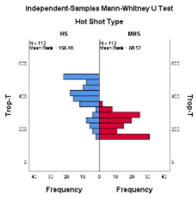
Figure 3: Postoperative distribution of CK-MB levels in HS and MHS groups



Postoperative distribution of CK-MB levels in Hot Shot (HS) and Modified Hot Shot (MHS) groups. The graph displays the comparative frequency distribution of CK-MB enzyme levels following surgery. Abbreviations: HS, Hot Shot; MHS, Modified Hot Shot; CK-MB, creatine kinase–MB.

Patients receiving MHS had a significantly lower incidence of postoperative renal failure requiring dialysis ($p<0.05$). Other postoperative complications, including low cardiac output syndrome, bleeding requiring re-exploration, and respiratory complications, were less frequent in the MHS group, although the differences were not statistically significant. Overall, in-hospital mortality did not differ significantly between the two groups (HS vs. MHS, $p=0.3$).

Figure 4: Postoperative distribution of troponin-T levels in HS and MHS groups



Postoperative distribution of troponin-T levels in HS and MHS groups. The histogram illustrates the frequency distribution of troponin-T enzyme levels in the immediate postoperative period. Abbreviations: HS, Hot Shot; MHS, Modified Hot Shot.

DISCUSSION

This study evaluated the efficacy of Modified Hot Shot (MHS) delivery compared with conventional Hot Shot (HS) in patients undergoing cardiac surgery with cardiopulmonary bypass (CPB). The principal findings were that MHS significantly reduced the incidence of postoperative arrhythmias, lowered CK-MB and troponin levels, decreased the need for intra-aortic balloon pump (IABP) support, shortened intensive care unit (ICU) stay, and reduced renal complications. Importantly, overall mortality was similar between groups.

The concept of terminal warm blood cardioplegia, or the "Hot Shot," has been widely studied as a strategy to improve metabolic recovery and reduce ischemia-reperfusion injury.9 Several clinical trials have demonstrated reductions in arrhythmias and improved myocardial recovery with HS use, although the magnitude of benefit has varied.10,11 In the present study, we observed that the addition of metabolic substrates and electrolytes in the MHS formulation provided incremental benefit beyond standard HS, particularly in reducing enzyme release and postoperative morbidity.

Biochemical markers such as CK-MB and troponin are established indicators of myocardial injury.12 Consistent with our findings, previous studies have shown that optimized reperfusion strategies are associated with lower enzyme release, reflecting improved myocardial protection.13 The reduced enzyme levels in the MHS group likely reflect better metabolic support during reperfusion, attributable to the inclusion of glutamate and aspartate, which enhance oxidative metabolism and ATP regeneration.14

Arrhythmia reduction in the MHS group also aligns with earlier work highlighting the stabilizing effect of magnesium in cardioplegia solutions.15 By limiting calcium influx and stabilizing cell membranes, magnesium supplementation may prevent reperfusion arrhythmias and support early hemodynamic stability.16 These mechanisms provide a plausible explanation for the lower IABP requirement observed in the MHS group.

Renal dysfunction remains a significant complication after cardiac surgery, contributing to morbidity and mortality.17 In our study, patients receiving MHS had a lower incidence of renal failure requiring dialysis. Although the exact mechanism is uncertain, it may relate to improved myocardial performance and reduced systemic inflammatory burden, thereby preserving renal perfusion. Previous literature supports the link between effective myocardial protection and better renal outcomes.18

Despite these advantages, we did not observe a mortality difference between groups. This finding is consistent with prior studies where myocardial protection strategies reduced morbidity but did not significantly affect short-term survival.19,20 Mortality in contemporary cardiac surgery is influenced by multiple perioperative and patient-related factors, and a single modification in cardioplegia is unlikely to independently shift this endpoint. 21

The present study has important clinical implications. Incorporating MHS into surgical protocols may improve perioperative outcomes, reduce postoperative complications, and shorten ICU stay. These benefits not only enhance patient recovery but also contribute to reduced healthcare costs and resource utilization, which is especially relevant in resource-limited healthcare systems.

However, several limitations merit consideration. First, this was a retrospective single-center study, which carries inherent risk of selection and information bias. Second, the follow-up was limited to the in-hospital period; longer-term outcomes such as late survival, ventricular function, and quality of life were not assessed. Third, the study did not include detailed hemodynamic or biochemical analyses that could further clarify the mechanisms underlying the observed benefits. Finally, although the groups were well matched at baseline, unmeasured confounders cannot be excluded.

CONCLUSION

The Modified Hot Shot strategy was associated with superior perioperative myocardial protection compared with conventional Hot Shot. Patients receiving MHS experienced reduced arrhythmias, lower cardiac enzyme release, shorter ICU stay, and fewer renal complications, without a significant difference in mortality. These findings suggest that MHS may be a valuable adjunct in routine cardiac surgical practice. Future randomized controlled trials with larger cohorts and long-term follow-up are needed to validate and expand upon these results.

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