Review Article

Intra-aortic balloon pump postcardiac surgery: A literature review

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Intra-aortic balloon pump (IABP) has been the most commonly used mechanical assist circulatory device in many postcardiotomy low output disorders for decades. Mechanism of IABP is based on its inflation in time of the diastolic pressure in the aortic root resulting increase in the blood and oxygen amount of the coronary artery and its deflation in left ventricular afterload during the systolic period. Prophylactic and postoperative application of IABP has been suggested by researchers, which has been commonly used in high-risk patients undertaking coronary artery bypass grafting surgery or percutaneous coronary intervention. Other researchers put forward the idea of the percutaneous IABP insertion throughout the left axillary artery as a reliable and relatively well-tolerated approach and also as a recovery tool to bridge patients with end-stage heart failure to heart transplantation. The current review was aimed to give further insight into routine IABP application by presenting the basic principles and trends in the incidence, management, role of IABP recovery, and long-lasting mortality outcomes in patients with cardiovascular disorders and discussing previous and current evidence.

Key words: Cardiac surgery, intra-aortic balloon pump, postoperative

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INTRODUCTION

Application of intra-aortic balloon pumps (IABPs) has been introduced by Kantrowitz *et al.* in 1968.[1] The theory of IABP has been first applied in patients with cardiogenic shock (CS) after myocardial infarction (MI).[2] They are commonly used as tools for short-term mechanical care in patients with complicated or advanced heart failure (HF).[3] They function to provide sufficient myocardial oxygen amount through increasing diastolic coronary blood flow.[4] In perioperative period of cardiac procedures, application of IABPs as an adjunctive treatment has recommended in patients with ischemic myocardial dysfunction or low cardiac output syndrome.[4,5] Another application of IABPs is in myocardial ischemia leading to hemodynamic instability which is used in critical clinical states.[6,7] Despite its wide range application and its priceless features in improving postoperative survival in high-risk patients with cardiac and ventricular dysfunction, the overall hospital mortality rate is still high.[8] All possible complications of IABP including balloon rupture, aortic or iliac artery dissection, thromboembolism, distal ischemia, and thrombocytopenia are attributable to its mechanical action on platelets.[9] It has been found that the time of IABP application is essential in optimal effect outcomes.[8] It has been shown that mortality rate of patients who received IABP was low (18.8%–19.6%) in preoperative circumstances and was medium and high in intraoperative (27.6%–32.3%) and postoperative (39%–40.5%) insertions, respectively.[10] In a study performed in 2001, data showed that preoperative prophylactic IABP application was more effective in high-risk patients.[11] In another study, postcardiopulmonary bypass (CPB) insertion of IABP was associated with highest recovery rate when preoperative infarction or intraoperative ischemic had occurred.[5] Several clinical trials[12-16] in patients

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with CS showed valuable effects of applying IABP. Other studies have been reported the use of significant amount of intra-aortic balloons in high-risk circumstances through or after cardiovascular interventions and in refractory angina cases.[17] An IB indication was conferred to post-MI-CS by the American College of Cardiology/American Heart Association (ACC/AHA) guidelines.[18]

IABP application in cardiac surgery with function of the balloon within the arterial tree is of interest. Since several approaches regarding IABP application in pre/postoperative condition have been described, we aimed to review the previous and recent experiences in this regard and evaluate the potential management of IABP application, with specific focus on postcardiac surgery.

HISTORICAL REVIEW OF INTRA-AORTIC BALLOON PUMP ORIGINS

As it is indicated by previously published studies, the principal step for coronary perfusion is cardiac diastole which it is enhanced by rising the diastolic aortic pressure or "diastolic augmentation."[2,19] In the original model of IABP, the counterpulsation term is referred to removal and reinjection of blood into the aorta in opposite way or vice versa to the cardiac cycle.[20] Counterpulsation then led to add sufficient volume of blood to the aorta during the diastole which increased oxygen availability and diastolic blood and perfusion pressure to the coronary and systemic circulation.[20] Practicability of counterpulsation in failing left ventricle recovery had been observed by early experiments, but until then, this approach was not clinically practical.[1,21]

By application of a rubber tube between aorta and coronary artery in 1953 which is the base of IABP technology, Adrian and Kantrowitz succeed to postpone the systolic pulsation movement into diastole.[22] A catheter or tube with a volume compartment was applied to fill or empty by a gas such as helium or carbon dioxide for hemodynamic homeostasis.

In 1962, in order to develop a long-lasting cardiac support tool, a cardiac cycle-triggered intra-aortic counterpulsation using a carbon dioxide-driven latex balloon was practically used by Moulopoulos *et al*.[23] and Clauss *et al*.[24] The nonflexible polyurethane balloon derived from "faster" helium shuttle gas was evaluated[25] and IABP applied in clinical practice.[1] The hemodynamic benefit of IABP with improvement in coronary perfusion has been indicated by Scheidt *et al*. in 1973.[4] In 2011, the helium as the drive gas was more applied in all IABP systems in order to its low molecular weight to optimize inflation and deflation.[20]

ADVANTAGES, BENEFITS, AND APPLICATION OF INTRA-AORTIC BALLOON PUMP

Intra-aortic balloon counterpulsation (IABC) is more applied than bypass devices and total heart replacement, after almost 50 years.[26] IABPs are applicable in both left and right ventricular myocardium through both systole and diastole.[2]

The major advantages of them are that they are minimally invasive, prevent from blood handling outside the body, function in series with the heart, inhibit hemolysis, and easily apply by both physicians and cardiologists.[26,27] The less documented benefit of IABC is the relationship which appears between its relief rate and the left ventricular output.[27] The "garden hose effect" is a phenomenon which increases myocardial contractility.[28]

Recommended indications[2] for application of IABP comprise disorders including ongoing instable angina, acute myocardial ischemia/infarction associated with percutaneous transluminal coronary angioplasty, perioperative low cardiac output syndrome, CS after MI, congestive HF, and connection to heart transplantation.[29-32]

LIMITATION OF THE INTRA-AORTIC BALLOON COUNTERPULSATION

One of the most important limitations of IABC is its limitation in systolic aortic pressure <50–60 mm Hg. The balloons in the aortic space have one inflow valve , but no outflow valve which is resolved by using two balloons in the aorta. In order to overcome the problem of insufficient flow during the cardiac arrest, physicians try to combine an intra-aortic balloon with a spherical balloon in the left ventricle.[33]

THE MOST COMMON COMPLICATIONS RELATED WITH INTRA-AORTIC BALLOON PUMP

Common problems which observed after IABP insertion composed of vascular complications with high incidence rate, limb ischemia, local and systemic infection, balloon rupture/damage, passage failure, thrombectomy, vascular repair, and aortic perforation/dissection.[2] The main risk factors of vascular complications include history of peripheral vascular disease, female gender, smoking history, diabetes mellitus, and postoperative IABP replacement.[2]

BRIDGE TO RECOVERY: TRANSAXILLARY ARTERY INTRA-AORTIC BALLOON PUMP PLACEMENT

This replacement applies to extend mechanical circulatory support of patients with postcardiotomy shock.[34] In a literature review, a study of case series has been found that transaxillary artery IABP was well tolerated by patients who had postcardiotomy HF.[34] No infection, thromboembolic, cerebrovascular, bleeding, or IABP malpositioning or movement complications was not observed in patients.[34] Transaxillary artery IABC has been introduced as a tool for early ambulation and aggressive physical therapy in patients needing prolonged support.

PERFUSION THERAPY WITH EITHER PERCUTANEOUS CORONARY INTERVENTION OR CORONARY ARTERY BYPASS GRAFTING IN PATIENTS WITH CARDIOGENIC SHOCK

Several studies have compared the mechanical support of different devices as abridge to recovery of patients before and after cardiac surgery.[35-39] CS considered as a physiologic state in which cardiac pump function is malfunctioned to permeate the tissues.[36,39] Due to organ dysfunction in patients with CS, it is essential to recognize and treat its myriad of signs and symptoms ranging from subtle hemodynamic alterations to overt cardiovascular collapse quickly.[39] Application of mechanical devices along with either percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) for blood circulation support is common in those CS patients who do not respond to pharmacologic therapy.[35,39]

Different tools including IABP, percutaneous ventricular assist device (pVAD), and extracorporeal life support (ECLS) have been introduced as common tools for CS recovery.[39] Due to the lack of sufficient evidence, one-to-one superiority has not yet been proven. The IABP has been introduced as the most common mechanical device in CS therapy.[40] However, there is a lack of evidence concerning its efficacy in patients' outcomes.[40] Indeed, IABP has been recommended for patients who do not response to the pharmacologic therapies such as vasopressor, and inotropes based on ACC/AHA ST-Elevation Myocardial Infarction (STEMI) guidelines recommend IABP.[41] Evidence showed that the pVAD is the better choice with more robust role in circulatory support than the IABP.[42] ECLS is considered as a novel supporting device with better outcome and progressive mortality rate in patients suffering from CS.[43] Extracorporeal membrane oxygenation (ECMO) including veno-venous ECMO and veno-arterial ECMO is the most applicable kind of ECLS.[43]

TIME SCHEDULE OF INTRA-AORTIC BALLOON PUMP EFFECTIVENESS

Timing is a promising issue in favorable hemodynamic effects of IABPs.[20] It is the process to monitor the periods during the cardiac cycle caused by the balloon inflation, its inflation length, and the exact time of its deflation.[20] Many cardiovascular health-care systems have adjusted the timing setting to incorporate modifications in heart pulse rate. However, it is better that the physicians set and record the initial timing and hemodynamic changes. These difficulties have been matched with advanced technologies and use of automatically timing settings.

Two generally approaches has been accepted for IABP timing; conventional and real-time (R-wave deflation). The most obvious difference between these two timing methods is the inflation and deflation of the IABP. In conventional timing, IABP inflation and deflation totally occur within the diastolic phase, while, in real-time method, deflation occurs during the preejection or early systolic ejection phase which may cause stroke volume due to active deflation through the systolic ejection.[21,44-47]

THE SOUND ALARMS OF THE INTRA-AORTIC BALLOON PUMP DURING AORTIC COUNTERPULSATION TREATMENT

With the purpose of increase in myocardial perfusion and subsequently, in the decreased possibility of fatal arrhythmias, including ventricular fibrillation, ventricular tachycardia, and acute coronary syndrome, the IABP-cycling technologies should be equipped with a system of clinical alarms such the asynchronism alarm.[48] These alarms have been designed to alert the professional teams to be aware of a possible lack in synchronism processes causing life risk of patients.[49] Complications of setting off in asynchronism alarm result in myocardial perfusion reduction perfusion and consequently in fatal arrhythmias.[49]

In an observational and descriptive study, the role of alarms in IABP management was evaluated with the aim to reduce the alarm fatigue occurrence and to offer a safety in patients who depend on this technology.[48] Their finding showed the pivotal role of medical equipment in the monitoring of patients which themselves need to care cautiously to decrease complications in patients who use these devices.[48]

APPLICATION OF INTRA-AORTIC BALLOON PUMP AND ITS TIMING IN OFF-PUMP CORONARY ARTERY BYPASS GRAFTING SURGERY

Application of IABP is recommended in the case of complications including CS, low cardiac output syndrome, left ventricular failure, mechanical complication of myocardial infarction (such as ventricular septal defect, severe acute mitral valve regurgitation, and papillary muscle rupture), refractory unstable angina, and during high-risk PCI.[50] One of the best surgical methods to eliminate CPB complications is off-pump CABG (OPCAB).[51-53] It is a kind of surgery accompanied by hemodynamic instability due to the heart displacement to expose target vessels.[54] It has been shown that the prophylactic insertion of IABP has benefit before OPCAB resulting improvement of cardiac performance and ease in target vessel accessibility without any hemodynamic instability.[54] Findings confirmed that preoperative insertion of IABP more than 2 h before OPCAB has better efficacy, especially in high-risk patients with higher EuroSCORE.[54] OPCAB surgery has gained widespread acceptance because it eliminates the problems associated with CPB.

VENTRICULAR MAGNETIC RESONANCE IMAGING-BASED (THREE-DIMENSIONAL) ELECTROMECHANICAL MODEL

Despite the efficacy of IABP application in mitral regurgitation (MR), it is normally contraindicated in aortic regurgitation (AR).[55] Coexistence of AR along with the IABP application is of clinical significance.[56]

IABP efficacy on ventricular workload could be evaluated and quantified by indirect parameters including the mean systolic pressure, product of heart rate and peak systolic pressure, and pressure–volume.[56] However, there is a lack of evidence in terms of IABP workload quantification due to low spatiotemporal resolution of myocardial energy use through the ventricular volume.[56] Computational modeling has been developed as an alternative method to overcome this limitation.

Methods such as three-dimensional (3D) model of cardiac electrophysiology for monitoring of failing ventricles have been developed in combination with a lumped model of the circulatory system.[57,58] Another approach with the aim to evaluate failing ventricles with mitral and aortic valve regurgitations and the local contractile energy consumption of the myocardium quantification has also been introduced.[59]

In recently published study, combination of 3D electromechanical model and a lumped parameter model of valvular regurgitation was assessed valvular insufficiency condition including the AR and MR in failing ventricle and the IABP therapy.[56] The clinical contraindication of IABP was observed in AR patients compared to its effective role in the MR condition.[56]

DISCUSSION

Coronary blood flow could be increased by the application of IABPs resulting in left ventricular afterload reduction.[60] IABP technology is applied to increase the time of heart recovery in patients with low cardiac output condition undergoing a CPB or ischemic events. Postoperative HF has been suggested as the single indication of IABP application in previously published studies.[61,62] Several factors such as advanced age could be altered the duration of postoperative recovery in different complications including cardiovascular disease. Patients with advanced age need a longer postoperative recovery time compared to patients with middle age or younger. For this reason, patients with advanced age may require more mechanical support, especially in the cases of low cardiac output following CPB or CABG. Despite the reported complications of IABP such as bleeding, aorta-iliac injury, and thrombocytopenia, it is widely used in recent times. In order to decrease inhospital mortality rate of patients (ranging 26%–50%) with the cardiac problems, application of IABP support is highly recommended.[63,64] With increase in the number of patients with advanced age who undergone CABG, IABP application is more highlighted in clinical practice.[65-68]

Although several studies have shown efficacy of IABP in surgical mortality rate of patients, there have been insufficient evidence regarding clinical outcomes of IABP in surgical patients. In the current review, we aimed to evaluate and compare IABP application in different conditions of CVD with specially focus on in postoperative aspects, clinical features, timing, intensive care unit, hospital stays, and morbidity and mortality rates in patients who had required IABP support and undergone different cardiac surgeries such as CABG or CPB. As previously described in the 1960s, IABPs had been applied in clinical practice as a CS therapy after MI and drug therapy-resistant unstable angina.[48] Findings of a study performed in 2011 showed that IABP was associated with decrease in the mortality rates of patients with low cardiac output and severe myocardial ischemia in the preoperative period and avoid medically refractory arrhythmias in the postoperative period of patients in intensive care unit.[69] In another study in 2015, IABP was applied to recover low cardiac output, persistent angina pectoris, or arrhythmia in preoperative phase of patients with myocardial ischemia.[60] Thiele *et al*. in 2013 found that IABP counterpulsation had no significant effect on mortality rate of patients with CS.[70] In contrast, Remeo *et al*. indicated that IABP was efficient in reperfusion quality of patients with primary PCI after thrombolytic therapy without any increase inhospital mortality. Other randomized clinical trial in 2012 demonstrated that IABP counterpulsation had no different effect on cardiac output, left ventricular stroke work index among the patient group compared to the control one.[71] In a meta-analysis of 1034 patients, the significant role of preoperative IABP application in high-risk patients and in mortality rate reduction has been suggested.[72] Another finding indicated that preoperative IABP was effective on the length of the hospital stay without any positive effect on morbidity and mortality rates.[73] Saha *et al*. observed complete revascularization in patients with hemodynamic instability who had an IABP.[74] In a cohort study, data showed no association between IABP insertion and a long-term survival benefit.[75] Zelano *et al*. demonstrated that inflation and deflation of the left ventricle occur in different time. Therefore, counterpulsation therapy goals should be determined before selection of the timing method or settings.[76]

To overcome worse outcome of cardiovascular disorders diseases, it should be essential to protect cardiac system during cardiac surgery. Therefore, therapeutic strategies are needed to decrease postoperative complications in which IABP has become as the myocardial protective strategy of choice. However, a number of variations should be considered in IABP insertion, including advanced age, duration and timing of IABP support intervention with no complications, several physiological and nonphysiological factors such as the patient's cardiac function, hemodynamic circumstances, the position and size of the intra-aortic balloon catheter, the anatomy of the coronary arteries, the condition of the myocardium, and its indication quality and reliability. Therefore, the optimum time of IABP prophylactic therapy requires further study, since the intervention timing had not accurately been assessed in previous studies.[20]

Since IABP clinical benefit is still debated and also there is a controversy between the findings of different studies, physicians, cardiologists, and surgeon should be knowledgeable about the possible factors that interrupt IABC efficacy and this information should be considered in IABP hemodynamic evaluation.[77] As a general rule, the application of IABC in the era of interventional revascularization is highly recommended by many cardiologists and cardiac specialists at high-risk patients. In conclusion, IABP support should be still applied after cardiac surgery in high-risk cohort of patients with postcardiotomy low output syndrome.

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Conflicts of interest

There are no conflicts of interest.

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