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Intra Aortic Balloon Pump in Coronary Artery Patients: Effectiveness, Trends and Complication

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A B S T R A C T

Intra Aortic Balloon Pump (IABP) is the most commonly used mechanical circulatory assist device in cardiac patients. IABP can improve ventricular function by decreasing the preload and increasing systolic output with significant improvement in myocardial oxygen supply/demand ratio. As the proportion of high risk patients with coronary artery disease, submitted for interventional cardiology or surgical procedures increases, use of Intra Aortic Balloon Counterpulsation (IABC) has increased, especially as preoperative therapy which reduces hospital mortality and shortens ICU stay significantly. The introduction of sheathless insertion kits has reduced the incidence of vascular complication rates. In this review indication, contraindication, the equipment needed to facilitate IABP, the physiologic aspects of IABP, complication of its use, the use of the IABP in special situation, outcome as well as current and future IABC practices, in relation to coronary artery disease are high-lighted.

Keywords: Intra Aortic Balloon Pump, Coronary blood flow, Oxygen supply/demand, Proactive Counter Pulsation, high-risk patients, complication, coronary artery disease

1. Introduction

IABP is the most common mechanical circulatory assistant device used in the clinical practice since the last 35 years. Initially mechanical support was developed in 1951 and was use for open intra-cardiac operations (heart-lung machine). Later, to help the patients with acute left ventricular systolic dysfunction in association with excessive preload, assist pumps were devised, which work by temporary diversion of excess preload from the heart and its return to the patient. This helps the failing heart to recover. [1]

In 1960s, the concept of counter-pulsation was introduced. The fundamental basis of this concept was dependence of coronary blood flow on diastolic blood pressure. This was achieved by rapid withdrawal of arterial blood from the femoral artery during systole and by its re-infusion during diastole. Thus, systolic unloading and diastolic augmentation were accomplished. This concept led to the development of the intra-aortic balloon pump by Moulopoulos et al. [1, 3, 4]

2. Intra Aortic Balloon Counterpulsation for Coronary Artery Disease

Experimentally, IABC is effective in increasing coronary blood flow when mean arterial blood pressure is below 60 mmHg and coronary are patent. [2] Experimental studies have shown the effectiveness of intra-aortic balloon counterpulsation in decreasing the severity of myocardial ischemic injury from coronary artery occlusion. [5-6] Clinically, the IABC has proved efficacious during acute episodes of cardiac ischemia associated with unstable angina, early acute myocardial infarction (AMI), [8] AMI with impending extension, [9] and malignant ventricular tachyarrhythmia.

The rationale for the use of IABC in patients with acute myocardial ischemia is the evidence that it decreases myocardial oxygen demand [10] and may improve coronary collateral blood flow to the area of ischemia and its surrounding zones. [11] In support of this opinion are various hemodynamic improvements, such as increase in cardiac index and a decrease in LV end-diastolic pressure and volume, [10] as well as amelioration of contraction in the

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ischemic myocardial zones using IABC. [12]

The combination of IABC with various pharmacological agents may influence the eventual size of the infracted area, perhaps by preventing its extension. [13] Patients with early (less than6 hours) acute myocardial infarction, pharmacological management, with beta-blockers, calcium channel blockers, and intravenous nitroglycerin, followed by thrombolytic therapy and angioplasty, should be routinely applied. [15] In these patients, the hospital and follow up mortality and re-infection rate have declined significantly. [15]

3. IABP for Unstable Angina

Patients with acute cardiac ischemia (unstable angina), who do not respond to antianginal therapy, severe left main coronary artery disease with LV dysfunction, are candidates for urgent cardiac catheterization, followed by interventional therapy to achieve rapid myocardial reperfusion. These patients are candidates for IABC therapy who are unstable before or during the course of cardiac catheterization or remain unstable thereafter (hypotension, ventricular arrhythmia, cardiac arrest), should have urgent placement of the IABC. [16]

4. IABC for Acute Myocardial Infarction

During the early phase of AMI, IABC is used with the hope of accomplishing four goals; a) limit the eventual size of AMI, b) maintain hemodynamic stability, c) prevent infarct expansion and d) decrease the complication of AMI. In these situations, IABC is used as a temporary support measure before definite interventional therapy to achieve myocardial perfusion, regardless of if that will be PTCA or surgery. [2]

5. IABC for ventricular Tachyarrhythmia

Persistent ventricular tachyarrhythmia is frequently observed in the course of acute myocardial infarction. This complication has a poor prognosis. These include metabolic factors, such as myocardial ischemia, infarction and imbalance of oxygen/ demand ratio, oxygen-derived free radicals, and mechanical factors, such as fiber stretch [17]. All these factors affect the excitation-contraction coupling, as well as the duration of action potential, which may evoke cardiac tachyarrhythmia. [17]

Malignant tachyarrhythmia usually results from abnormalities of ventricular activation. When persistent, they are due to early activation of ischemic areas that surround an infarcted segment. [18] Revascularization of the ischemic area or improvement in blood flow or decrease in oxygen demand of the segment, with IABC, is frequently effective in diminishing the frequency or arrhythmic episodes. [19]

Common indication and contraindication of IABP therapy [1]

Table 1 indication and contraindication of IABP

Indication	Contraindication
Left ventricular failure [20]	Aortic dissection
Acute myocardial infarction	Severe aortic insufficiency
Cardiogenic shock or pump failure	Severe peripheral vascular disease
Refractory unstable angina	Irreversible brain damage
Failure to wean from cardiopulmonary bypass	
High-risk PTCA [21]	
Failed PTCA	
Thrombolytic therapy	
Bridge to cardiac transplantation	
Stunned myocardium	
Stabilization of high risk patients for general anesthesia	
Hemodynamic or ECG instability	
Low cardiac output syndrome	
Acute mitral valve insufficiency	
Post-infarction ventricular septal rupture	
Bride to cardiac transplantation	
Other	
Cardiomyopathy	
Myocarditis	
Severe myocardial contusion	

6. Trends in current use of IABP

Evidence suggests that the IABP can also be used to support primarily right ventricular failure, particular in the transplant population. [23] Longer-term IABP use has been effectively used as a bridge to transplant, although its role in the era of long-term safe ventricular assist devices may be more limited.
Over the past 5 years, use of preoperative IABPs has increased in some centers [24, 25]. This increase has been associated with a decrease in mortality. It remains difficult to identify those patients who will benefit most from the IABP, while minimizing the device-related complications. The trend has been toward prophylactic use to avoid rather than treat ischemia. [24, 26]
As compared with the European counterparts, US investigators in the GUSTO trial [3 0] were five times as likely to use IABC (35% versus 7%). The foregoing favorable pattern was consistent with an overall trend toward more aggressive percutaneous cardiac interventions in the US, including significantly higher rates of cardiac catheterization, CABG, and PTCA, as well as significantly more frequent use of beta-blockers and inotropic agents. Institution of IABC was among several independent risk factors significantly correlated (inversely) with 30-day mortality in patients with cardiogenic shock in the GUSTO-trial. Longer time to treatment was again a significant prognostic factor for mortality in this study [30].

7. Balloon Pump Console

The drive console consists of a pressurized gas reservoir, a monitor for ECG and pressure wave re-cording, adjustments for inflation/deflation timing and triggering selection switches. It is portable, light weight and has the option of mains and battery operation. There are two types of consoles, Stationary and Portable. Stationary consoles are used at the bedside and for short distance transport. Portable consoles are used for long distance transfer. The gases used for inflation are either helium or carbon dioxide. Helium has low density and rapid diffusion coefficient. However carbon dioxide has an increased solubility in blood, which reduces the potential consequences of gas embolization following a balloon rupture [1].

Figure 1.Console for intra aortic balloncounterpulsation

A standard console comprises the following features:
Rear panel which consists of DC input, IAB fill and drain port, helium supply, and patient connection

- Monitor which displays alarms, ECG, IAB status, pressure source, operation mode, battery and helium indicators.
- Key pad controls
- Recorder to record ECG, pressure and balloon pressure waveform
- System battery which displays charges status and portable operation
- Doppler storage facility

8. Balloon Catheter

Balloon catheters are presented in a sterile insertion kit and are disposable and single use only. Balloon catheters are made up of polyurethane and are manufactured in sizes varying from 8.5F to 10.5F. For children sizes are available between 4.5F to 7F. The adult catheters have a standard length of 32.5 inches. The volume of the balloon is 30-40 ml in adults and 2.5-25 ml in children.

Insertion technique

Since 1979, a percutaneous placement of the IAB via the femoral artery using a modified Seldinger technique allows an easy and rapid insertion in the majority of situations. The patients are heparinised prior to insertion of catheter providing there are no contraindications such as recent surgery. After puncture of the femoral artery a J-shaped guide wire is inserted to the level of the aortic arch and then the needle is removed. The arterial puncture side is enlarged with the successive placement of an 8Fr to 10.5Fr dilator/sheath combination.

Continuing, the balloon is threaded over the guide wire into the descending aorta just below the left subclavian artery. The sheath is gently pulled back to connect with the leak-proof cuff on the balloon hub, ideally so that the entire sheath is out of the arterial lumen to minimize risk of ischemic complications to the distal extremity. Recently sheathless insertion kits are available. Removal of a percutaneously placed IAB may either be via surgical removal or closed technique [28].

9. Alternative Routes of Intra Aortic Balloon Pump Insertion

Alternate routes of IABP insertion can be used when occlusive aortoiliac disease or prior abdominal aortic or femoral artery operation prevents femoral artery insertion [29]. Insertion of the IABP through the ascending aorta, iliac, subclavian, and axillary arteries has all been reported [30, 31]. Of these methods, transthoracic arch insertion is the most frequently used and has been reported in 1.9% to 6.2% of all IABP procedures [25, 29]. Transthoracic arch insertion of IABPs occurs intra- or postoperatively in patients in whom femoral insertion had failed; the mortality is similar to that reported overall for intra- and postoperative use in larger series (25% to 73%) [22, 32].

Pinkard and associates [33] found in analyzing a series of 123 IABPs inserted for weaning from bypass in CABG patients (42 transthoracic and 81 femoral) that the increased mortality in the arch insertion group was a result of the greater co- morbidities rather than the route of insertion. Additionally, no increase in complications was noted in the aortic insertion group, whereas the patients with femoral insertion had a higher incidence of leg complications. The largest reported series of transthoracic IABP insertion (n -100) also demonstrated no increased mortality and complication rates similar to those of femoral insertion. There is Class I level C evidence and general agreement that arch insertion is a good second choice if femoral insertion is not possible [29,33, 47].

10. Physiology of Coronary Circulation

Myocardial blood supply is from the right and left coronary arteries. The dependence of coronary blood flow on diastolic pressure is due to the mechanical compression of coronary blood vessels within the myocardium during systole. Left heart pressures are much higher than the right side. As a result the right side of the heart is better perfused during systole compared to the left side. The coronary vascular bed is auto regulated balancing myocardial oxygen supply and demand (Table 3). Coronary vascular resistance is influenced by neural, metabolic and hemodynamic factors. The coronary arteries are innervated by the sympathetic and parasympathetic nervous systems. Alpha receptor stimulation causes vasoconstriction while stimulation of the beta-2 receptor and the vagus nerve causes vasodilatation.

Regional perfusion is regulated by metabolic factors. Several mediators such as carbon dioxide, adenosine, hydrogen ions, phosphate, prostaglandins and potassium cause vasodilatation. When coronary perfusion pressure falls to below 60 mmHg, autoregulation is lost, the coronary vessels become maximally dilated and blood flow depends only on perfusion pressure. Hemodynamic factors that affect coronary perfusion include arterial pressure (diastolic pressure), diastolic time and the intra-ventricular pressure [1].

11. Physiologic effect of IABP therapy

Inflation and deflation are synchronized to the patients' cardiac cycle. Inflation at the onset of diastole results in proximal and distal displacement of blood volume in the aorta. Deflation occurs just prior to the onset of systole (Fig.2).

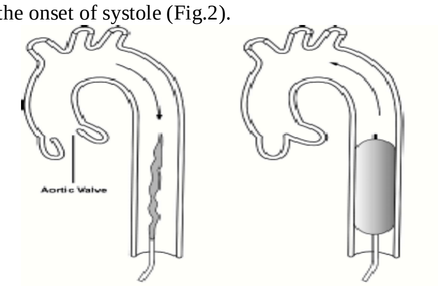

Fig 2 Insertion of IABP

The primary goals of IABP treatment are to increase myocardial oxygen supply and decrease myocardial oxygen demand. Secondary, improvement of cardiac output (CO), ejection fraction (EF), an increase of coronary perfusion pressure, systemic perfusion and a decrease of heart rate, pulmonary capillary wedge pressure and systemic vascular resistance occur [28,35,36,37] (Tab.2 goals of IABP)

Table 2 Hemodynamic effects of IABP Therapy (goal of IABP)

Aortic pressure	Cardiac	Blood flow	LV pressure	Left ventricle
↓**Systolic**	↓ After load	Coronary blood flow	↓ Systolic	↓ volume
Diastolic	↓ preload	Cardiac output	↓ end diastolic	↓ wall tension
		Renal blood flow		Cardiac output
				Ejection fraction

There are several determinants of oxygen supply and demand.

Table 3 Determinants of O2 Supply and Demand

Oxygen supply	Oxygen demand
Patency of coronary arteries	Heart rate
Auto regulation of coronary vascular resistance	Contractility
Diastolic perfusion gradient	Preload
Diastolic time interval	After load

12. Intra aortic Balloon Pump Timing

The balloon should inflate during the diastolic phase of the cardiac cycle. Counterpulsation should be achieved during deflation of the intra aortic balloon during the systolic phase of the cardiac cycle. The intra aortic balloon identifies the R wave as a triggering event in most cases. Once the R wave has been identified the balloon pump inflates. Deflation will continue throughout the systolic phase of the cardiac cycle. During the diastolic phase of the cardiac cycle inflation occurs. By setting the inflation marker at the dicrotic notch, inflation will continue until the next R wave of the next QRS occurs [38].

13. Complications

Although the incidence of complications has decreased significantly as experience with the device has increased, IABP therapy in today's patients` population does still hold a risk for complications (Tab. 4). Because today's patient population is elderly (68 - 80 years), very often female and may suffer from severe peripheral vascular disease and hypertension or diabetes. The most common vascular complication is limb ischemia. It may occur in 14-45% of patients receiving IABP therapy [40, 41] . Therefore the patient must be consistently observed for any symptoms of ischemia during IABP counterpulsation. If signs of ischemia appear the balloon should be removed.

Vascular injuries should be dealt with directly by surgical interventions and repair. Balloon related problems and infection require removal and / or replacement of the IAB [28]. Septic complications include fever, bacteremia, superficial and deep wound infection. Positive blood cultures will guide to appropriate antibiotic therapy. Wound infections may need surgical intervention. Hemorrhagic complication results from bleeding from insertion site or systemic anticoagulation therapy. Balloon dependent patients can be adequately protected with low molecular weight dextran [1].

Table 4 complication

Vascular related	Balloon related	Miscellaneous
Arterial injury(perforation, dissection)	Perforation	Hemorrhage
Aortic perforation Aortic dissection	Tear	Infection
Femoral artery thrombosis	Rupture	Entrapment
Peripheral embolization	Incorrect positioning	
Femoral vein cannulation	Gas embolization	
Limb ischemia		
Visceral ischemia		

14. Hemodynamic monitoring and Assessment

It plays an important role in the management of patients with heart failure. The variables which help in assessment include heart rate, central venous pressure, arterial blood pressure, pulmonary artery pressure, pulmonary capillary wedge pressure (PCWP) and cardiac output. Hemodynamic monitoring includes a reduction in PCWP, an increase in arterial blood pressure, cardiac output and stroke work index.

It may be best to position the patients horizontally to gain the full benefits of balloon counterpulsation to the coronary circulation [1, 39]. The efficacy of diastolic augmentation can be assessed by clinical improvement in patient's condition and hemodynamic parameters. Other parameters include a change in skin temperature, reduction in sweating, a decrease in heart rate and episodes of arrhythmia, an improvement in urine output and the appearance of peripheral pulses.

15. Data Acquisition

Data acquisition includes calculation of clinically useful data. They are cardiac index, left to right shunt, stroke volume, stroke index, stroke work, left ventricular stroke work index and systemic vascular resistance. These parameters can be calculated using appropriate formula [1, 40].

1) Cardiac index= CI($l/min/m^2$)= cardiac output/body surface area
2) Stroke volume=SV(ml)= cardiac output/heart rate
3) Stroke work= SW(gm)= MAP-PCWP*CO 0.0136/HR
4) Left ventricular stroke work index= LVSWI(gm/m^2)= SW/BSA
5) Systemic vascular resistance= SVR($dyne/sec/cm^{-5}$)= (MAP-CVP)80/ CO

(MAP- mean arterial blood pressure, PCWP- pulmonary capillary wedge pressure, CO- cardiac output, HR- heart rate, BSA- body surface area, CVP- central venous pressure)

16. Trouble shooting when using IABP

Problems may arise while using the equipment for counterpulsation. Knowledge of the basic problem encountered will increase efficiency in management (table 5) [1].

Table 5 Trouble shooting during counterpulsation

Problem	Causes	Action
ECG trouble shooting		
• Interference on ECG	Faulty lead/electrodes	Check electrodes contact, replace electrodes
• Intermittent ECG	Faulty lead/electrodes/ patients cable	Check electrodes contact, replace electrodes
• Weak ECG signal	Electrodes position or poor quality	Try to alternate lead configuration. Adjust ECG gain to increase size
Trigger trouble shooting		
• System does not trigger	ECG signal too small	Increase ECG gain
• System triggers erratically	Large A-pacer tails in ECG trigger. Demand pacer in V/A-V mode	Select A Pacer trigger
• System triggers every other cardiac cycle in pressure trigger	Pressure trigger needs resynchronization	Select ECG or pressure trigger Start resynchronization
Balloon trouble shooting		
• Balloon requires frequent pre-loading	Leak in safety disc Loose attachment of patient balloon or fill hose	Check and replace Check and tighten Replace if necessary
• Poor augmentation pressure regulators	Leak in balloon Clogged filter, mufflers, faulty	 Call service representative
• Cannot auto-fill	Leak in balloon, safety disk No helium Malfunction in auto-fill	Check and replace Replace helium cylinder Use manual fill
Power-up trouble shooting		
• Cannot pump in portable mode	Low battery charge	Recharge battery to full

17. IABP in special circumstances

Patients with impaired cardiac function are at high risk of developing complication when undergoing general anesthesia and surgery. The use of IABP has been recommended for patients with blunt cardiac injury and overdose of certain drugs, who fail to respond to conventional treatment [41-42]. IABP in conjunction with cardiopulmonary resuscitation has been shown to improve coronary perfusion pressure.

IABP therapy has been used in children with cardiac anomalies and heart failure. IABP therapy can serve as an alternative to ECMO-membrane oxygenation **[43].**

18. Discussion, conclusion and the recent advances

IABP therapy for patients with cardiovascular and systemic condition is currently well established. Pre-operative IABP therapy in high risk patients has been significantly cost-beneficial [44]**.** In the modern day practice of IABP therapy, complication rates are generally low**.** Advances in technology have permitted patients to be treated with greater safety and effectiveness.

Recently IABP balloon catheter which can be used in patients irrespective of their physical size has been developed. A long soft tip is used, which is designed to avoid damage to blood vessels and the catheter can be used as a multifunctional balloon catheter, that allows simultaneous percutaneous coronary intervention (PCI).

Contemporary trends towards more frequent percutaneous placement in the cardiac catheterization laboratory, on a proactive basis, rather than in the operating room as a last resort response to cardiogenic shock, reflect the numerous potential hemodynamic and clinical benefits associated with counterpulsation, particularly among high-risk patients undergoing percutaneous cardiac interventions or surgical procedures [3].

The safety of this catheter has been proven scientific studies [45]. Reports show that specially trained critical care paramedics can safety transfer IABP dependent patients to definitive cardiac surgical care without additional medical escort [46].

IABP therapy will continue to have a lead role in providing temporary mechanical cardiovascular support in near future.

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