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IABP deployment in critical care

Hafil B. Abdulgani, Dicky A. Wartono

Abstract

The Intra Aortic Balloon Pump (IABP) is an established support in addition to pharmacologic treatment of the failing heart after myocardial infarction, unstable angina, cardiac surgery and percutaneous coronary intervention (PCI). The indication for IABP in acute myocardial infarction expanded to include support of severely ill patient during acute cardiac catheterization and myocardial revascularization both percutaneous and surgical. An international randomized trial, SHould we emergently revascularized Occluded Coronaries for cardiogenic shocK? (SHOCK) reported that cardiogenic shock patients treated with the combination of IABP support followed by early angiography and myocardial revascularization, and/or thrombolytic therapy had the lowest observed in-hospital mortality. The Benchmark Registry revealed plausible IABP economic benefits in total hospital costs; whereas, the potential benefits of careful use of IABP therapy are unlikely to be offset by vascular and hemorrhagic complications. The inference, whether IABP can be appropriate initial therapy at hospitals without revascularization facilities, if followed by prompt transfer to tertiary centers in the developing world, requires careful assessment.

Keywords: intra-aortic balloon pulsation, IABP, critical-care, shock.

"We are always guilty of oversimplification when we stress only one of several relevant principles"
(Elton Trueblood, *General Philosophy*, New York: Harper & Row, 1963)

Historical perspective

Historically it was shown that removing a certain blood volume from the femoral artery during systole and replacing this volume rapidly during diastole could increase coronary perfusion, decrease cardiac workload, and reduce myocardial oxygen consumption [1]. In 1953 Kantrowitz first proposed that elevation of aortic diastolic pressure could improve coronary blood flow and could benefit patients with coronary insufficiency [2]; however, this method of treatment was limited because of problems with access (need for arteriotomies of both femoral arteries), turbulence and development of massive hemolysis by the pumping apparatus. In the early 1960s Moulopoulus, Topaz, and Kolff developed an experimental prototype of the intra-aortic balloon (IAB) whose inflation and deflation were timed to the cardiac cycle [3]. By 1968 Kantrowiz and colleagues first applied IABP in clinical setting [4].

Initial IABP catheter size invented was a 15 French gauge; and, an open surgical insertion and removal were required. With the current 8 French gauge catheter available commercially, percutaneous IABP insertion becomes possible with less complication [5].

IABP is currently widely accepted as an established support in addition to pharmacologic treatment of the failing heart after myocardial infarction, unstable angina, cardiac surgery and percutaneous coronary intervention (PCI).

Physiologic effects of IABP therapy

The physiologic principle of counterpulsation is a rapid decrease in intra-aortic pressure. This rapid reduc-

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tion in aortic pressure is synchronized to left ventricular ejection followed by a rapid increase in intra-aortic pressure during left ventricular isovolumic relaxation [19].

The main physiologic effects of the intra-aortic balloon pump (IABP) are reduction of left ventricular afterload and an increase in aortic root and coronary perfusion pressure. Important related effects include reduction of left ventricular systolic wall tension and oxygen consumption, reduction of left ventricular end-systolic and diastolic volumes, reduced preload, and an increase in coronary and collateral vessel blood flow. IABP increases cardiac output due to improved myocardial contractility secondary to an increase in coronary blood flow along with reduction in afterload and preload. IABP reduces peak systolic wall stress (afterload) by 14% to 19%; and, left ventricular systolic pressure is also reduced by approximately 15% [1]. Since peak systolic wall stress is related directly to myocardial oxygen consumption, myocardial oxygen requirement is therefore reduced proportionately. Cardiac work is reduced and myocardial demand is decreased with concomitant increase in myocardial oxygen supply.

Because coronary blood flow is subject to autoregulation, IABP does not increase flow until hypotension reduces coronary blood flow to less than 50 mL/100 g ventricle/min [1]. When measured by trans-esophageal echocardiography (TEE) and color flow Doppler mapping, peak diastolic flow velocity increases by 117% and the coronary flow velocity integral increases 87% with counterpulsation [6]; which mean collateral blood flow to ischemic areas increases up to 21% at mean arterial pressures higher than 190 mm Hg [7].

Ryan and Foster showed TEE images and schematic diagram indicating augmented coronary blood flow during IABP support of a patient with reduced left ventricular contractile function following a three vessels coronary artery bypass graft surgery and a mitral valve repair [6]. The intra-aortic pressure and ECG tracings after surgery are shown in **Figure 1**. During continuous atrioventricular sequential pacing and 2:1 IABP counterpulsation, enhanced early diastolic aortic pressure (arrows) and reduced aortic end-diastolic pressure during every second cardiac cycle are demonstrated. TEE demonstrating a postoperative pericardial collection and diastolic flow in an epicardial vessel (arrow in **Figure 2**). A Doppler signal of this vessel demonstrates increased flow velocity with alternative cardiac cycles (**figure 3**); which, was absent without IABP inflations (**Figure 4**).

Khir and colleagues studied 20 patients in the intensive care unit, less than 36 hours following cardiac surgery [7]. They recorded left anterior descending coronary artery and transmitral E-wave flow velocities using TEE pulse Doppler; and, recorded left ventricular long axis free-wall movement using M-mode. The intra-aortic balloon pump was set to full augmentation and re-

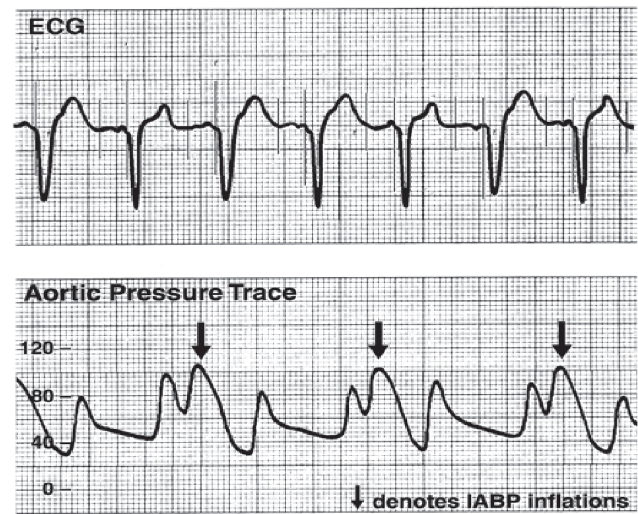

Figure 1. ECG (top) tracing showing atrioventricular sequential paced rhythm. Aortic pressure trace (bottom) in mm Hg showing augmentation of aortic pressure by an IABP in the descending aorta and synchronized to inflate during alternate cardiac cycles, denoted by arrows. (Reproduced by permission, from Ryan EW, Foster E. Augmentation of coronary blood flow with intra-aortic balloon counter-pulsation. Circulation 2000; 102:364).

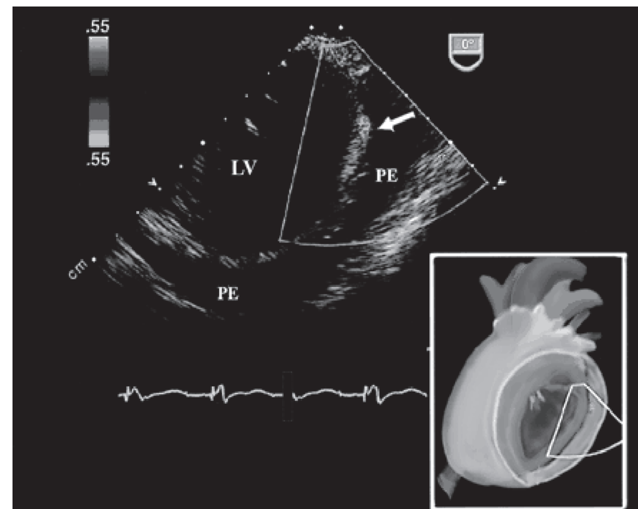

Figure 2. TEE 2D image with color Doppler and (inset) schematic diagram. Pericardial effusion (PE) surrounds left ventricle (LV). Color Doppler shows epicardial diastolic flow (arrow). (Reproduced by permission, from Ryan EW, Foster E. Augmentation of coronary blood flow with intra-aortic balloon counter-pulsation. Circulation 2000; 102:364)

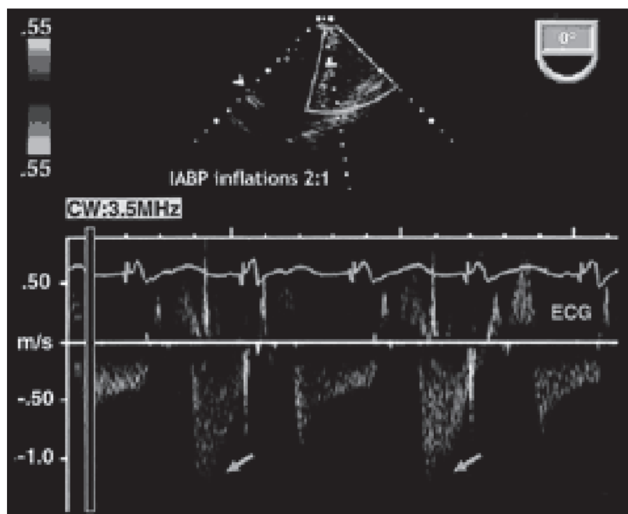

Figure 3. Spectral Doppler recordings of epicardial vessel. Augmented diastolic velocity is noted with alternate cardiac cycles (top) during 2:1 IABP counterpulsation. (Reproduced by permission, from Ryan EW, Foster E. Augmentation of coronary blood flow with intra-aortic balloon counter-pulsation. Images in Cardiovascular Medicine. Circulation 2000; 102: 364)

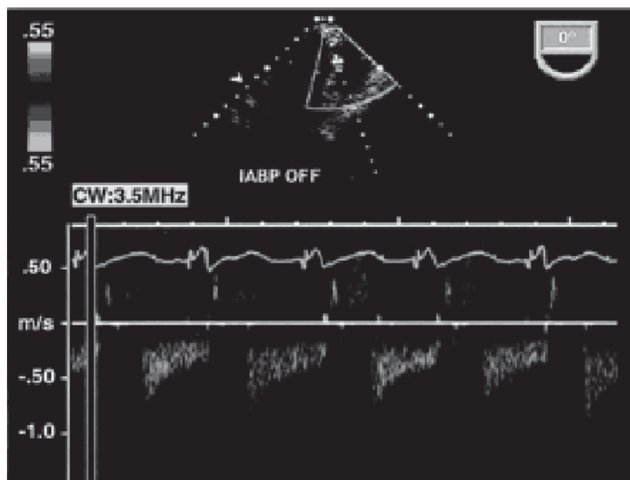

Figure 4. Spectral Doppler recordings of epicardial vessel. Augmented diastolic velocity with alternate cardiac cycles is absent without IABP inflations. (Reproduced by permission, from Ryan EW, Foster E. Augmentation of coronary blood flow with intra-aortic balloon counter-pulsation. Images in Cardiovascular Medicine. Circulation 2000; 102: 364)

cordings were made at pumping cycles 1:1, 1:2, 1:3, and when the pump was on stand-by, leaving a minimum of 5 min between the pumping modes to allow the return to control conditions. The peak diastolic left anterior descending coronary artery and transmitral E-wave flow velocities, and left ventricular free-wall early diastolic lengthening velocity increased significantly with intra-aortic balloon pumping cycles 1:1, 1:2 and 1:3 compared to their value with the pump on stand-by, all $P<0.001$. The increase in peak transmitral E-wave flow velocity correlated with the increase in peak left anterior descending coronary artery diastolic flow velocity ($r=0.74$, $P=0.02$), and with the increase in left ventricular free-wall early diastolic lengthening velocity ($r=0.80$, $P<0.001$). This investigation showed that although coronary flow is epicardial and mitral flow is intracardial, their close relationship suggests an improvement in left ventricular diastolic function with intra-aortic balloon pump.

Toyota and colleagues showed, in a canine model, that high shear rate of IABP is one of the major stimuli for the release of endothelium-derived nitric oxide leading to coronary arteriolar dilation [8]. IABP mechanically enhances shear rate and diastolic-to-systolic flow oscillation; and, augments coronary blood flow by dilating coronary arterioles in diastole, more significantly in small arterioles than in large arterioles. Endothelium-derived nitric oxide inhibition markedly attenuated these effects; and, contributed to mechanical enhancement of the coronary blood flow with diastolic arteriolar vasodilation during intraaortic balloon pumping.

Biological factors influencing IABP hemodynamic performances

Biological factors that influence the in situ hemodynamic performance of the IABP include heart rate and rhythm, mean arterial diastolic pressure, competence of the aortic valve, and the compliance of the aortic wall [1]. By far the most important biological variables are heart rate and rhythm. Optimal performance requires a regular heart rate with an easily identified R-wave or a good arterial pulse tracing with a discrete aortic dicrotic notch. Current balloon pumps trigger off the electrocardiographic R-wave or from the arterial pressure tracing. Both inflation and deflation are adjustable, and operators should attempt to time inflation, so that it coincides with closure of the aortic valve and descent of the R-wave [1]. During tachycardia the IABP usually is timed to inflate every other beat; during chaotic rhythms the device is timed to inflate in an asynchronous fixed mode that may or may not produce a mean decrease in afterload and an increase in preload. In unstable patients every effort is made to establish a regular rhythm, including a paced rhythm, so that the IABP can be timed properly [1].

Intraaortic balloon counterpulsation (IABP) timing errors during arrhythmia may result in afterload increases

which may negatively influence left ventricular (LV) ejection and LV mechanical desynchronize. Schreuder and colleagues [9] demonstrated that premature IAB inflation decreased SV by 20% ($p < 0.0001$) due to abrupt increase of LV afterload during late ejection. Late IAB deflation increased SV and stroke work by 18% ($p < 0.0001$) and 16% ($p < 0.01$) respectively, due to increased afterload during early ejection and decreased afterload during late ejection.

Furthermore they developed Windkessel algorithm to calculate real time aortic flow from aortic pressure for intrabeat dicrotic notch prediction (DNP) in real time IABP inflation timing control [10]. The dicrotic notch was predicted using a percentage of calculated peak flow; and, automatic inflation timing was then set at intrabeat predicted dicrotic notch and was combined with automatic intra-aortic balloon deflation. Automated DNP-IABP inflation combined with R-wave or predictive deflation provided accurate automatic timing allowing fully automatic intrabeat IABP timing, in all patients studied, during both regular and severe arrhythmia.

Complications

Reported complication rates of the intra-aortic balloon pump vary between 12.9% and 29% and average approximately 20% [1]. Life-threatening complications are rare; leg ischemia is by far the most common complication (incidence 9% to 25%) with up to 47% have evidence of ischemia during the time the IABP is used [11]. With considerable changes in IABP usage and management in high risk patients before surgical and/or interventional treatment, the percentage of elective prophylactic IABP insertion has been, indeed, gradually increasing [12]. The extended use of preoperative IABP has been also followed by a significant evolution of the technique of insertion; and, the sheathless percutaneous insertion technique has become the recent technique to consider reducing post-IABP vascular complication [13].

Menon and colleagues [14] demonstrated that out of their 179 patients receiving an 8 French gauge catheter with sheathless insertion, none of the 35 deaths (19%) were related directly to the insertion and/or the presence of the IABP. Furthermore, among the 144 survivors only one (0.67%) experienced limb ischemia requiring embolectomy and three patients (2.1%) experienced limb ischemia that resolved with balloon removal. Their results, therefore, concur with those reported from the Benchmark Registry [15].

Evidence-Based Medicine

- **SHOCK Trial Registry (16)**

The **SH**ould we emergently revascularize **O**ccluded **C**oronaries for cardiogenic shoc**K**? (The SHOCK trial) assessed the effect of 30-day mortality of a direct invasive strategy (emergency early coronary angiography and revascularization), compared with a strategy of initial medical stabilization (including thrombolysis and IABP) followed by delayed mechanical revascularization as clinically determined. This SHOCK Trial Registry represented the largest prospective study in patients with cardiogenic shock due to left ventricular failure; and, revealed that revascularization by percutaneous trans-coronary angioplasty (PTCA) or coronary artery bypass surgery (CABG), IABP unloading and, to a lesser extent, thrombolytic therapy (TT) was associated with a lower in-hospital mortality rates than treatment with standard medical therapy.

- **Benchmark registry (17, 18)**

The Benchmark counterpulsation outcomes registry is a prospective registry of all patients with myocardial infarction who receive an intra-aortic balloon counterpulsation (IABP) at participating institutions. An overview of the outcomes revealed that IABP complication rates are low; although, all cause in-hospital mortality remains high, particularly in high-risk patients, (**Figure 5**). The economic benefit (USD 16,000 savings) of IABP is depicted in **Figure 6**.

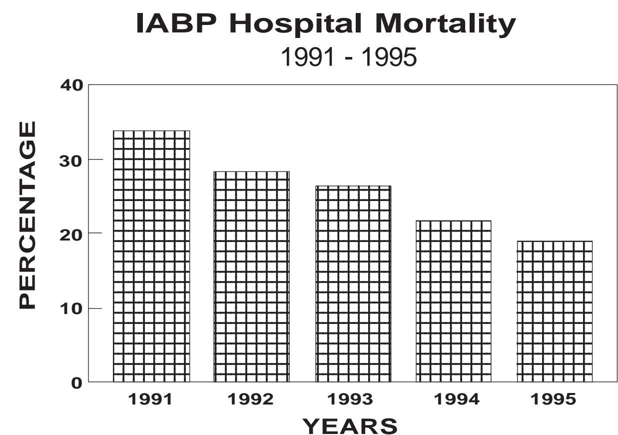

Figure 5. The Benchmark registry on hospital mortality, showing improvement in IABP therapy. (Reproduced by permission from: Cohen M, Urban P, Christenson JT, Joseph DL, Freedman RJ, Jr, et al. Intra-aortic balloon counterpulsation in US and non-US centres: results of the Benchmark® Registry. Eur Heart J 2003; 24(19):1763-1770).

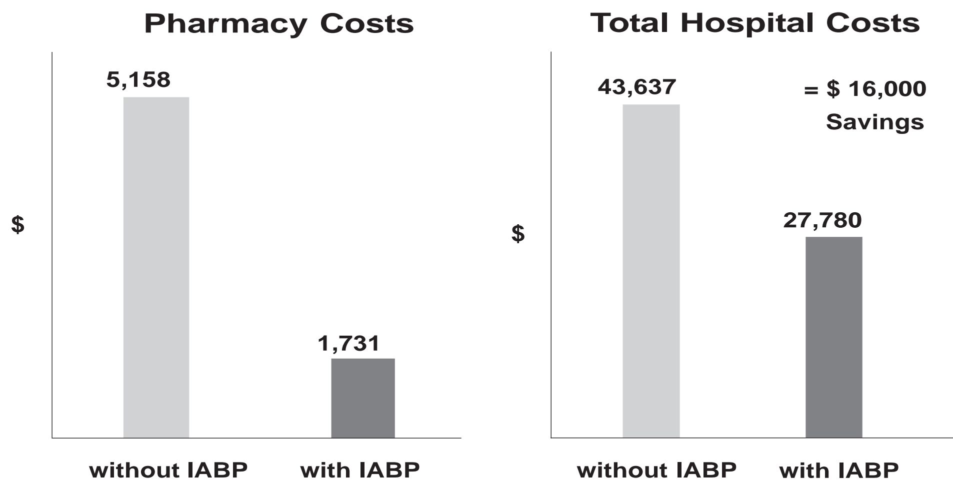

Figure 6. The Benchmark registry showing pharmacy costs in patients who were managed by IABP assist, which were less than patients managed without IABP assist (left figure). Similarly, the total hospital costs were less in patients with IABP vs without IABP (right figure). (Reproduced by permission, from: Cohen M, Urban P, Christenson JT, Joseph DL, Freedman RJ, Jr, et al. Intra-aortic balloon counterpulsation in US and non-US centres: results of the Benchmark® Registry. Eur Heart J 2003; 24(19):1763-1770).

- **Blackpool Victoria Open Heart Registry (20)**

This U.K. based registry sought to use a range of current and novel statistical techniques to obtain an optimal clinical scoring system, which will be an invaluable tool to guide pre-operative IABP placement for prospective studies into early IABP placement, and will also be useful to compare differences in treatment and outcomes in high-risk patients among institutions (**Table 1**).

Indonesian multicenter trial (21)

This trial was performed in coronary artery surgical patients who required IABP support. ICU stay was shorter and mortality was lower in patients whom IABP was deployed early preoperatively as compared to those whom IABP was placed intra- or postoperatively (**Table 2**).

Permanent IABP (22)

Jeevanandam and colleagues implanted permanent IABP or the Kantrowitz Cardio Ventricular-assist-device (KCV) in patients with end-stage cardiomyopathy refractory to medical treatment and who were not transplant candidates. This initial human trial demonstrates the abil-

Table 1. The Blackpool score uses ten variables including inotrope usage, cardiogenic shock, priority, left main stem disease, ejection fraction, re-do operation, and recent catheterization to predict the need for an IABP. A score of above 10 predicts 50% of patients that went on to require a balloon pump, with a specificity of 96.5%. (Adapted by permission, from: Dunning J, Au JKK, Millner RWJ, Levine AJ. Derivation and validation of a clinical scoring system to predict the need for an intra-aortic balloon pump in patients undergoing adult cardiac surgery. Interactive Cardiovascular and Thoracic Surgery 2003; 2:639-643).

The Blackpool IABP rule: optimal score	Score
One intravenous inotrope	2
LMS>50%	2
Mod impairment of EF (30-50%)	3
Cardiac catheter on this admission	3
Cardiogenic shock	5
Emergency priority	6
Salvage priority	9
Poor EF (<30%)	8
Two or more inotropes	9
Previous cardiac surgery	3

IABP, intra-aortic balloon pump; LMS, left main stem disease; EF, ejection fraction.

Table 2. Indonesian multicenter trial on IABP performed at the participating institutions in Jakarta in 1995. (Adapted by permission from: Abdulgani HB, Murni TW, Mustafa I. Early versus late intra-aortic balloon pulsation deployment in coronary artery surgery. Abstract. Indonesian Shock Society Meeting, Bali 2000).

Period of IABP deployment	Inotropic Agents	ICU Stay (days)	Mortality (%)
Preoperative (n=14)	none	2	0
Intra/Post-operative (n=4)	epinephrine, dopamine, dobutamine	20	66.6

ity of the device to be used intermittently without anticoagulation, and documents hemodynamic and functional improvement in the status of these patients.

The KCV drive consoles consist of the microprocessor that automatically analyzes electrical signals from the heart and actuates shuttling of compressed air to the device (**Figure 7**).

KCV is a novel nonobligatory device that can be turned on/off at will by the patient without increasing the risk of thromboembolic events. It has no valves or internal electronics and requires no anti-coagulation. KCV could be disconnected to allow for increased patient comfort. The disadvantages are that it provides only "partial" support. It increases cardiac output by approximately 40% depending on the afterload condition of the patient. It depends on native heart activity to function and cannot be placed in patients with severe biventricular function, uncontrolled tachyarrhythmias, or with native valvular disease.

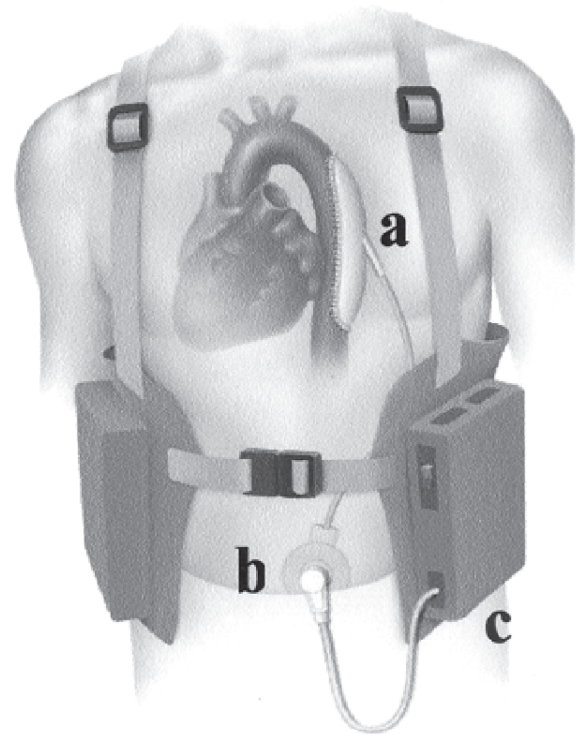

Figure 7. Components of the Kantrowitz CardioVAD (KCV): a) blood pump, b) percutaneous access device (PAD), c) mobile drive console. (Reproduced with permission from: Jeevanandam V, Jayakar D, Anderson AS, Martin S, Piccione, W Jr, et al. Circulatory Assistance With a Permanent Implantable IABP: Initial Human Experience. Circulation 2002; 106:I-183).

At one month patients follow up, there was reduction in pulmonary capillary wedge pressures, and right atrial pressures with an increase in cardiac index. Further investigation; however, is necessary for a world-wide clinical application.

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