A Review of the Literature on Pulmonary Artery Balloon Counterpulsation and a Successful Application of Concomitant Balloon Counterpulsation

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Abstract

The intraaortic balloon pump is the most common method of left ventricular support in use today. Various types of ventricular assist devices and centrifugal pumps are also used at many institutions for both single and biventricular support. Balloon pump technology can also be used to support the right ventricle, as we were able to recently demonstrate in a successful application of concomitant aortic and pulmonary artery balloon counterpulsation.

Introduction

Since the earliest days of open-heart surgery, surgical teams have been confronted with patients whose myocardial function was inadequate to permit separation from the heart-lung machine. Some patients benefit from a period of resting, vented myocardial reperfusion on the heart-lung machine, while some have profited from the introduction of the intraaortic balloon pump (IABP), first employed in the 1960s.

Use of the IABP was greatly facilitated with the development of percutaneous methods of insertion, enabling it to be used in satellite areas such as Coronary Care Units and Catheterization Labs to stabilize the patient and preserve myocardium without the need for arterial cutdown. Post-operative open-heart patients often benefit from the ability of the IABP to provide diastolic unloading of a compromised left ventricle (LV). A study published in 1981 by Myers et al found that 6.7% of elective patients could not be weaned from cardiopulmonary bypass (CPB) and received IABP support. Ultimately, 1.5% could not be weaned at all.

Much research has also been devoted to more aggressive means of ventricular assist devices (VADs), including the development of centrifugal pumps, valved diaphragmatic assist chambers, and total artificial hearts. Some programs report an overall success rate of approximately 46% using these devices in various positions. This paper will present information on how the IABP, when used in the pulmonary position, can provide adequate right heart support in the clinical setting of mild to moderate right ventricular (RV) failure, and will report on a recent successful application of concomitant balloon counterpulsation (CBCP) at our institution. It is our opinion that this option should be considered at other institutions where more advanced methods of ventricular support are not available.

Literature Review

Use of the IABP in the aortic position has been shown to have beneficial effects on right ventricular hemodynamics. Kopman was able to show in a clinical patient that the IABP reduced the central venous pressure (CVP) from 20 to 10 torr while augmenting the aortic systolic pressure, presumably due to better coronary perfusion which aided in functional RV recovery. In a study of the interaction of the right heart with the mechanically-assisted left heart, Farrar et al pointed out that although RV failure may be further taxed by the increased venous return associated with an augmented left heart, beneficial effects on RV preload and filling may be produced when the interventricular septum is shifted back to the left by improved LV diastolic unloading. Also, RV afterload may be passively reduced when pulmonary artery (PA)
pressures drop secondary to reductions in left atrial (LA) pressure. They also reported that in a multi-institutional study of 213 patients who required left heart assist, 49 (23%) exhibited RV failure as well. Spence et al have advocated use of the IABP in all cases of RV failure, since an improvement in myocardial perfusion may enhance LV function and augment the septal contribution to RV contraction. They reiterated Farrar’s conclusions that a decrease in LA pressure would also decrease the hydrostatic gradient across the lung, facilitating RV unloading.

From the first days of successful clinical application of the IABP, investigators were interested in the utility of the device in the pulmonary artery (PA) position. Kralios et al first published investigations in this area in 1969. In an ovine (sheep) model for acute pulmonary embolism and resultant RV failure, they were able to show decreases in right atrial pressure and pulmonary vascular resistance (PVR) and increases in left atrial (LA) pressure, cardiac output (CO), and mixed venous oxygen saturation (MVVo2). In a canine model of cardiogenic shock and RV failure secondary to elevated PVR, Opravil et al demonstrated that pulmonary artery balloon counterpulsation (PABCp) increased CO by 53%, arterial blood pressure (BP) by 55%, and RV Minute Work (RVMW) by 62%, while decreasing RV preload by 22%. Spence et al have worked extensively with porcine modes of PABCp and consistently shown improvements in RV output and stroke work while reducing preload. Using a flow probe around a large branch of the right PA, they found that balloon inflation caused flow through the pulmonary circulation and that ventricular systole resulted in filling of the graft conduit which had been constructed to the main PA in order to facilitate the balloon insertion. During ventricular fibrillation, inflation and deflation of the balloon produced only a to-and-fro movement of the blood in the pulmonary system without net forward flow. They concluded that PABCp was capable of restoring RV output to normal as long as it was not depressed to less than 50% of its baseline value.

Other researchers have published data on comparative results of various methods of RV assist, and PABCp proved to be moderately successful compared to more active forms of ventricular assist. Jett et al showed that PABCp was able to decrease CO by 39%, RV Stroke Work Index (RVSWI) by 49%, and aortic systolic pressure by 27%, while decreasing the RA pressure by 21%. A pneumatically driven VAD was able to increase CO by 209%, RVSWI by 78%, and aortic systolic pressure by 60%, while effecting a 36% reduction in RA pressure. Gaines et al placed goats on pulsatile LA-to-descending-aorta bypass and then induced ventricular fibrillation as a model of RV failure. They then investigated right heart flow under four conditions: passive flow through the fibrillating RV due to the RA/LA pressure gradient, PABCp, PA counterpulsation with a single-port sac-type pulsatile assist device (PAD), and an RA/PA conduit with a valved pneumatic VAD. PABCp increased Cardiac Index (CI) by 43% over passive flow, while the PAD and the VAD increased CI by 106% and 228%, respectively.

The first published reports of clinical experience with CBBCp appeared in 1980, reported by Miller and associates at Stanford. They were able to effect satisfactory biventricular support, although the patient ultimately succumbed to ventricular ectopy. Other teams reported their successful hemodynamic experience with the technique over the years, only to be frustrated when patients ultimately expired due to complications such as sepsis and unstable ventricular rhythms. Symbas et al reported in 1985 on a series of three patients who received CBBCp, with one long-term survivor. Flege et al reported in 1984 on a successful application of isolated PABCp. In a recent series by Karaçoğz et al, no survivors were reported in a series of three patients undergoing PABCp, while three out of seven patients survived who underwent a technique of pulmonary artery venting where blood was shunted from the PA to the aorta via a membrane oxygenator. These PA venting patients received an IABP, while the PABCp patients did not. It should also be noted that the mean duration of support in this study was a matter of several hours (133 minutes for PABCp, versus 121 minutes for PA venting), not the usual trial of several days as often advocated by centers with extensive experience in ventricular support efforts.

Case Report

A 64-year-old woman was brought to the operating room of the Dartmouth-Hitchcock Medical Center on May 1, 1987, to undergo elective aortic valve replacement. The patient was placed on CPB with a membrane oxygenator in the standard fashion, and cardiac arrest was effected by infusion of cold potassium cardioplegia into the aortic root. Arrest was noted despite the catheterization findings of trace aortic insufficiency. The native aortic valve was excised and a tilting-disc prosthesis was placed. The heart defibrillated spontaneously when the cross-clamp was removed after 57 minutes. The patient was weaned from CPB with no major difficulty on low-dose neosynephrine and epinephrine support, and the venous cannula removed. The patient was transfused from the heart-lung machine until it was felt that hemodynamic stability had been achieved, and the protamine was given.

Cardiovascular collapse immediately occurred, necessitating a return to CPB. An IABP was inserted on bypass, and the patient was once again weaned, this time with infusions of neosynephrine, nitroglycerin, isoproterenol,......
lidocaine, and norepinephrine. The patient once more exhibited total cardiovascular collapse when only a small test dose (20mg) of protamine was administered. Despite continued efforts at reperfusion recovery and increasing levels of pharmacologic support, we were unable to wean the patient and prominent RV failure was noted at the surgical field whenever the patient’s hemodynamics deteriorated. Intraoperative echocardiography showed hypokinesis of the right ventricle and the anterior septum. In light of the grave situation, the decision to attempt PABCP was made. Using the methods as described by both Miller and Flege, a counterpulsation chamber was constructed in an end-to-side fashion to the main PA using a 20cm long, 22mm diameter piece of double velour vascular graft, into which a 50cc IABP catheter was inserted. A ligature was placed around both the graft material and the shaft of the balloon catheter to maintain hemostasis. Balloon console stroke volume was set at 40cc in deference to the pulmonary vasculature, and concomitant counterpulsation was begun. Balloon timing was adjusted such that inflation occurred at the dicrotic notch of both the aortic and pulmonary pressure traces and that diastolic unloading was evident in both traces as well. [Experimental data has been reported to indicate that the onset of PA balloon inflation should be later than that used for the aortic balloon.\(^{[6]}\) CBCP and high levels of pharmacologic support enabled us to move the patient to the Intensive Care Surgical Unit after nearly six hours on CPB and fourteen hours in the operating suite, although not without intermittent hemodynamic and electrocardiographic instabilities.

By the third post-operative day, the patient had demonstrated an ability to sustain herself without the aid of PABCP, so she was returned to the operating room to have the catheter removed. Both the balloon and conduit material were examined and proved to be free of clot. The conduit material was closed over the main PA in a patch angioplasty fashion. On the fourth post-operative day, the IABP was also removed.

On the twenty-seventh post-operative day, the patient was discharged home. Before she left, her ventricular function was judged to be satisfactory by both echocardiography and resting gated blood pool scan, which showed left and right ventricular ejection fractions of 69 and 47%, respectively. Now, more than fifteen months later, she continues to do well, with no orthopnea, exertional angina or presyncopal episodes.

**Discussion**

We were very pleased with the success of our initial application of CBCP. It proved to be easy to accomplish with equipment which the hospital already owned, the insertion procedure was not particularly difficult, and satisfactory biventricular support was effected in the clinical picture of mild to moderate RV failure, as suggested by the research presented earlier in this paper. This mode of support should be kept in mind by all institutions which would find it difficult to justify the purchase and maintenance of other types of ventricular assist equipment based upon the frequency of need. Specific uses for this technique include protamine reaction, RV infarction, noncompliant RV following CPB, and RV dysfunction unresponsive to the usual pharmacologic measures. One must also be aware of some inherent risks, including the formation of thrombus in the PA, pulmonary infarction, and perforation of the PA. The use of PABCP or CBCP is more widespread than has been reported in the literature and it should not be overlooked as a viable method of support at those institutions not possessing other VAD capabilities.

**Bibliography**

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