

Intraaortic Balloon Counterpulsation: Principles and Review of Clinical Outcomes

SHANE C. TOWNSEND, MB, BS, FANZCA, FJFICM

Staff Intensive Care Specialist, Royal Melbourne Hospital Intensive Care Unit, Grattan St, Parkville, Melbourne, Victoria

Dr Townsend graduated with Honours from the University of Queensland in 1989. During his anaesthesia training in Brisbane, he was awarded both the Renton and Cecil Grey Prizes. While a staff specialist anaesthetist at Prince Charles Hospital in Brisbane from 1999 to 2001 he gained experience working with cardiac surgical patients and aspects of managing shock states with circulatory assist devices. He is now a full time intensivist at The Royal Melbourne Hospital, where he is undertaking a Doctorate of Medicine through the University of Melbourne.

Introduction

Patients with end-stage heart failure consume significant health resources throughout the world. Poorer surgical candidates are undergoing cardiac and non-cardiac surgical procedures. Cardiogenic shock remains a very challenging condition to treat with a high associated mortality. There have been significant advances in the pharmacotherapy of heart failure and ischaemic heart disease in recent years with improved outcomes and greater patient expectations from treatment. Invasive and expensive modalities of managing acute circulatory failure deserve a review of the evidence for their efficacy. It is against this backdrop that a reappraisal of the experience with intraaortic balloon counterpulsation (IABC) is timely.

Balloon counterpulsation as a means of supporting the circulation was first proposed in 1962 and applied clinically later that decade by Kantrowitz.¹ The initial experience was mixed; while resulting in better haemodynamics, mortality failed to significantly improve. However, interest was reignited by a report in 1972 demonstrating the utility of the balloon pump in separating cardiac surgical patients from bypass.²

Principles and Equipment

The principle goal of IABC is a reduction of cardiac afterload, permitting myocardial rest and a decrease in inotropic drug doses. The peak diastolic blood pressure is augmented above the assisted systolic pressure, theoretically improving coronary perfusion. The diastolic pressure-time index is increased while the systolic pressure-time index is reduced. The combined result is reduced myocardial ischaemia. A modest increase in cardiac output is achieved, but this may be as low as 10 to 15%. Mitral valve regurgitation associated with a low cardiac output state and pulmonary congestion is likely to benefit significantly from counterpulsation by an improvement in forward flow and decreased end-diastolic filling pressures.

The intraaortic balloon pump (IABP) consists of an external console and pneumatic

pump connected to a specialised arterial catheter. The catheter possesses a lumen for transduction of the aortic pressure wave and a lumen to conduct helium gas to and from the distal balloon. Inflation is triggered by the patient ECG, pacing spike or aortic pressure wave signal. The device can be triggered internally. Timing and augmentation can be adjusted in relation to the displayed aortic pressure wave, by examining the contour of assisted and unassisted systole. A pressure trace from the balloon is displayed and can be interrogated for signs of incorrect inflation or gas leaks. Alarms detect inadequate augmentation, gas leaks indicative of balloon failure and inability to detect the patient's ECG or cardiac pacing spike.

The balloon catheter can be placed into the aorta transthoracically at the time of surgery, occasionally a necessity in severe vasculopathies. Most commonly it is placed percutaneously via the femoral artery under radiological guidance, into the descending aorta just distal to the origin of the left subclavian artery. Surgical cut-down to the femoral artery is also an option. Correct positioning may be confirmed by transoesophageal echocardiography in the operating theatre or ICU. Placement of the balloon counterpulsator into the pulmonary artery to assist right ventricular dysfunction has also been described. The approach to insertion has traditionally incorporated a vascular sheath and sleeve, analogous to a pulmonary artery flotation catheter. This necessitates a larger aperture in the femoral artery, which may be related to subsequent complications. Newer, finer 8 French gauge catheters inserted without a sheath have improved the ease of insertion and helped to minimise vascular complications in arteriopathies.

Paediatric application imposes several equipment design constraints. A volume limiting chamber has been employed for balloon volumes less than 20 ml. Paediatric balloons matched to the aortic diameter have tended to be too long, threatening renal and mesenteric vascular occlusion. Selection of a balloon volume estimated to be 1/2 the recipient's stroke volume is recommended. The narrow 4 or 5 French femoral catheters necessary in children and high physiological heart rates mandate rapidly responsive pneumatics. A sinusoidal pressure waveform has been shown to be clinically effective and mechanically easier to achieve.

Optimal timing of balloon counterpulsation requires reference to the aortic pressure wave trace. In a dog model of counterpulsation, balloon deflation during the isovolumic contraction phase was found to improve ventriculoarterial coupling and mechanical efficiency.³ Early and late inflation or deflation of the balloon will adversely affect ventricular afterload, augmentation of diastolic pressure and the balance between myocardial oxygen supply and demand. Arrhythmias may interfere with counterpulsation timing owing to the irregularity of systolic and diastolic periods. Atrial fibrillation may require extending the interval of balloon inflation for optimal efficiency. Correct placement of the balloon catheter immediately distal to the origin of the left subclavian artery and appropriate selection of catheter volume relative to patient height and weight are essential to achieve ideal haemodynamic performance.

Anticoagulation is necessary to prevent arterial thrombosis and embolism and degradation of catheter performance. Intravenous heparin infusion to achieve therapeutic systemic anticoagulation has been standard. Because clot formation is related to stasis of blood elements, maintenance of IABP catheter pulsation while *in vivo* is important and initially may suffice, particularly in coagulopathic patients and immediately post cardiac surgery. Low molecular weight heparin and antiplatelet drugs may be alternative strategies in suitable patients. Strict monitoring and control

of anticoagulation is required to avoid haemorrhagic complications. Heparin pharmacokinetics during balloon counterpulsation are comparable with other clinical situations, with a measured elimination $t_{1/2}$ of 2.4 ± 0.08 hr after discontinuation and a continuous infusion requirement of 16 ± 2.5 U/kg/hr in one study.⁴

Indications

Traditional indications for balloon insertion have encompassed shock, myocardial ischaemia, failure to separate from cardiopulmonary bypass and severe acute mitral regurgitation. More recently, balloon counterpulsation has been suggested to prevent coronary re-occlusion following angioplasty and has been combined with thrombolysis in acute myocardial infarction and cardiogenic shock. A role in stabilising patients for transfer to a tertiary referral centre with cardiac surgical and interventional cardiological services is gaining acceptance. Although not suitable for bridging long-term to cardiac transplantation, the intraaortic balloon pump has been useful in “bridging to partial recovery” of myocardial function after ischaemic insults, facilitating later cardiac transplantation as an elective procedure. As well, counterpulsation has been applied successfully in the stabilisation of patients suffering ventricular arrhythmias refractory to medical therapy. There may be a role for the balloon pump in supporting poor-risk cardiac patients undergoing non-cardiac surgery. Studies have also employed the IABP to augment cerebral blood flow in subarachnoid haemorrhage. Application of mechanical circulatory support has been suggested in septic shock.

Severe aortic regurgitation is a contraindication to insertion of the device.

Published Clinical Audits

Three large clinical series summarising the accumulated experience with over 6000 intraaortic balloon pump insertions, have been published. Creswell's group from Washington University⁵ published their experience with 669 patients over a five year period. In their series nearly 10% of cardiac surgical procedures were attended by balloon insertion. Thirty day mortality was significantly lower with preoperative insertion of the balloon pump, although most devices being inserted either intra- or post-operatively. The St. Louis University⁶ group reported that cardiac surgical patients receiving a balloon pump had an overall operative mortality of 44%. Interestingly, they noted that the majority of survivors were in a favourable New York Heart Association functional class and survived long-term. The largest series reported to date is from the Massachusetts General Hospital.⁷ In their practice, the majority of balloon pumps were inserted preoperatively and for control of myocardial ischaemia. In a retrospective analysis of independent predictors of mortality for this series, insertion of the IABP for ongoing ischaemia, isolated CABG or angioplasty carried a better prognosis. The authors argued the improved mortality in these subgroups warrants earlier insertion of the device. Mortality increases sharply with later insertion of the balloon pump in cardiac surgical patients. This may reflect the benefits of stabilising ischaemia preoperatively versus attempts at salvage once cardiogenic shock is established. Selection bias and the retrospective nature of the data preclude firm conclusions.

Trends in balloon pump usage since 1968 reveal a growing number of patients receiving counterpulsation for control of myocardial ischaemia.⁷ The number of patients receiving counterpulsation for haemodynamic indications has remained relatively unchanged, while overall mortality has improved.

Myocardial Infarction and Cardiogenic Shock

In spite of advances in treatment of acute myocardial infarction during the interventional era, patients who present with cardiogenic shock continue to suffer a high mortality. Practices relating to counterpulsation have changed over the last 25 years,⁷ with myocardial ischaemia now a common indication, while rates of IABP insertion post-cardiotomy have remained largely unchanged.

Use of the IABP remains uncommon among patients who develop cardiogenic shock complicating acute myocardial infarction,⁸ perhaps as a consequence of the perceived potential for complications as opposed to the lack of definitive prospective evidence for its efficacy. A number of studies have reported lower mortalities for cardiogenic shock treated with intraaortic balloon counterpulsation. Survival in these studies is most strongly correlated with coronary revascularisation; the balloon pump playing an adjunctive role in stabilising the patient until angioplasty or surgery could be scheduled.

Results of two randomized prospective trials^{9, 10} conducted in the pre-thrombolytic era did not show a survival advantage in cardiogenic shock patients treated with counterpulsation without undergoing revascularisation. More recent data, suggesting a survival advantage for patients who achieve infarct-related artery patency, has renewed interest in the role of the IABP in opening occluded coronary arteries and preventing reocclusion in low coronary flow states. Several retrospective studies^{8, 11, 12} have supported the combination of thrombolysis with intraaortic balloon counterpulsation in patients developing shock as a complication of acute myocardial infarction.

Using a canine model, Gurbel et al¹³ demonstrated more rapid clot lysis and coronary reperfusion with counterpulsation after administration of intravenous rTPA. A critical left anterior descending stenosis was created by an occluder with injection of a blood and thrombin mixture into the artery. Dogs treated with rTPA infusion and concomitant counterpulsation demonstrated reperfusion occurring three times faster than animals treated with rTPA alone ($P=0.02$). They did not show an increase in mean coronary blood flow during IABC and suggested that reperfusion was enhanced by pressure effects, possibly disrupting the thrombus and increasing surface area exposed to thrombolytic agent. In another animal study, Prewitt et al¹⁴ injected radioactive blood clot into the left anterior descending artery of dogs, which subsequently underwent phlebotomy to a systolic blood pressure of approximately 90 mmHg. In this model of cardiogenic shock, IABC significantly increased the rate of thrombolysis with rTPA and exhibited a trend to increased peak diastolic coronary blood flow.

In the GUSTO-1 Study,⁸ 315 patients presented with cardiogenic shock. IABC was instituted within 24 hours in 62 patients (20%). Compared to the late insertion or no-IABP group, those patients receiving early insertion of an IABP showed a trend toward lower 30-day mortality, which persisted at one year. However, the early IABP group recorded a greater number of adverse events, perhaps reflecting survival of a sicker cohort of patients. There were also more frequent episodes of moderate bleeding. Interestingly, 32% of shocked patients received IABC in the United States, whereas the corresponding figure for other participating countries was only 7.2%.

Historically, thrombolysis was a relative contraindication to insertion of a balloon pump. A retrospective study conducted by Stomel et al¹¹ examined survival in acute myocardial infarction and cardiogenic shock patients treated with thrombolytic therapy and IABC in a community hospital. Those patients treated with combined

thrombolysis and insertion of an IABP were more often stabilised and transferred to a tertiary referral centre for revascularisation and had a significantly greater survival (68%) compared to those treated with thrombolysis alone (23%) or IABC alone (28%) $P=0.0049$. A further study by Kovack et al,¹² also in the setting of two community hospitals, examined retrospectively 46 patients who presented in cardiogenic shock and who received thrombolysis within 12 hours of acute infarction. Twenty-seven of these patients had an IABP inserted. The IABP group had a significantly higher survival in the community hospital (93% vs 37% $P=0.0002$) and a greater proportion were transferred (85% vs 37%). Overall hospital and one year survival was also greater in the IABP group (67% vs. 32% $P=0.019$). Results from these retrospective studies must be interpreted cautiously, a major weakness being potential selection bias favouring those patients chosen for IABP insertion. The contribution of IABC to survival is difficult to distinguish in those patients subsequently undergoing transfer and revascularisation at a second institution.

The SHOCK Trial Registry¹⁵ randomised 302 patients with cardiogenic shock due to acute infarction to receive either initial medical therapy or early revascularisation. There was a non-significant trend to a lower 30-day mortality in the revascularisation group and a 12% reduction in mortality at 6 months. Interestingly, the majority of controls received combined thrombolysis and counterpulsation with an overall mortality of 56% at 30 days for medical therapy. This result is superior to other published reports and may provide indirect evidence for employing counterpulsation and thrombolysis when cardiac catheterisation is not readily available.

Cardiac Surgery

Post-cardiotomy, the balloon pump has proven useful to assist in separation from cardiopulmonary bypass. Unfortunately, mortality rates of approximately 30% are reported for this indication and rise even higher if the balloon pump is inserted later in the intensive care unit in an attempt to salvage the patient. Certain groups also fare less well with insertion of a balloon pump, notably valvular surgery and graft failure after cardiac transplantation.

Aortic counterpulsation has steadily increased as an adjunct to management of cardiac surgical patients, with the largest series published by the Massachusetts General Hospital⁷ reporting IABP insertion in 12.3% of all cardiac surgical procedures. IABC is applied perioperatively with the aim of preoperative stabilisation and control of refractory ischaemia, management of low cardiac output states and to facilitate separation from cardiopulmonary bypass. Mortality remains high in most series reporting IABP insertion in cardiac surgical patients, ranging from 16.3% to 48.4%.^{5, 6, 7, 16, 17} It is likely that this variability results from differing philosophies in selecting patients for IABP insertion.

Examining 193 intraoperative balloon placements, Torchiana et al⁷ identified age, mitral valve replacement, prolonged cardiopulmonary bypass, urgent surgery, preoperative renal dysfunction, and complex ventricular ectopy or right ventricular failure after cross clamp removal as independent predictors of mortality. However, many of these factors are general predictors of operative mortality and do not discriminate between those patients who will benefit from IABP support and those requiring a ventricular assist device. Timing of IABP insertion was shown to be significant, with a worse outcome after placement to wean from bypass or after emergency reinstatement of bypass. Torchiana et al⁷ drew attention to the better

outcome observed with a bias favouring preoperative balloon insertion (70.6% of devices inserted), reporting a 16.3% overall perioperative mortality. This data is retrospective and subject to selection bias; however, the authors contend that liberal use of the IABP to stabilise myocardial ischaemia in the preoperative phase may have an operative survival advantage. Creswell et al⁵ found similar results with a 19.6% mortality for patients receiving an IABP preoperatively versus 32.3% intraoperatively and 40.5% postoperatively ($P < 0.001$).

Cardiac transplant patients receiving an IABP were also noted to fare better if counterpulsation was used as a preoperative bridge to transplantation. However, intraoperative insertion carried a 40% mortality, perhaps reflecting poor donor organ preservation or the pre-transplant condition of the recipient.

Long-term survival after IABP support in cardiac surgical patients was also related to specific procedures. Cardiac transplant and isolated CABG patients enjoyed the highest long-term survival, whereas CABG and MVR, CABG and AVR, CABG and left ventricular aneurysm repair, isolated MVR and isolated AVR were associated with poorer survival.⁵

Naunheim et al⁶ studied 580 cardiac surgical patients who received a perioperative IABP. A multivariate analysis identified six independent prognostic indicators; preoperative NYHA class, transthoracic route of insertion, preoperative nitroglycerin infusion, age, female gender and preoperative balloon insertion. However, the r^2 value in the linear regression model was 0.128, permitting only a small proportion of deaths to be attributed solely to these variables. Survivors enjoyed good long-term cardiac function; 81% of patients at follow-up were classified as NYHA class I or II. Non-survivors of cardiac surgery despite IABP support, have been studied by Baldwin et al.¹⁶ They identified four variables which significantly predicted mortality in a logistic regression model; complete heart block, advanced age, preoperative BUN, and female gender. The derived equation was then prospectively validated against a further 330 patients at another institution.

The value of defining such predictors of mortality among patients otherwise eligible for IABC, lies in triaging patients to alternative forms of circulatory support. The IABP may achieve only modest increments in cardiac output, in the order of 10%. Non-survivors despite IABC may have received inadequate haemodynamic support and are potential candidates for ventricular assist devices, provided that they can be identified early. A further study¹⁷ of 129 consecutive patients receiving IABP support found that acute myocardial infarction with severe ventricular dysfunction (LVEF $< 30\%$) carried a high associated mortality. Fifty per cent of the 64 non-survivors died from cardiac failure, reinforcing the concept that the limited haemodynamic support achievable with the IABP may be inadequate faced with extensive infarction and severe ventricular failure. Aggressive measures including ventricular assist devices may be more appropriate.

Christenson et al¹⁸ performed a randomised controlled trial on 60 high-risk patients undergoing CABG. Those patients randomised to pre-operative insertion of an intra-aortic balloon pump had a significantly lower mortality, shorter bypass time, higher post-operative cardiac index and shorter length of stay in the ICU and hospital. The benefit was realised with insertion just 2 hours prior to surgery. Earlier studies^{19, 20, 21, 22} also support the elective use of counterpulsation to improve outcome in high-risk patients undergoing coronary surgery. Preoperative insertion of an IABP in 101 high-risk elective cardiac surgical cases was found to significantly reduce risk-adjusted

mortality versus predicted mortality (5.7% vs 20% $P=0.0014$) in a recent Australian study.²³

Myocardial Ischaemia and Coronary Angioplasty

There are no randomised controlled trials for when unstable angina is the indication to insert an IABP. Nevertheless, this clinical approach enjoys a long tradition with a relatively low mortality. The emphasis in recent years has shifted from managing haemodynamic decompensation to control of ischaemia as an indication for IABP insertion, with 51.6% of devices placed for ischaemia in the Massachusetts General Hospital series.⁷ This series revealed an 11.9% mortality for balloon placement to control ischaemia, whereas placement for haemodynamic instability had a higher (38.2%) mortality. Angioplasty recipients supported by IABC had an overall mortality of 14.7%.

Myocardial function does not recover immediately with reperfusion and coronary blood flow is often impaired in the early reperfusion period. IABC may support myocardial function by afterload reduction, augment coronary blood flow and enhance the efficacy of chemical and mechanical methods of reperfusion. A prospective analysis of 810 consecutive patients entered into the TAMI trials,²⁵ treated with thrombolytic therapy for acute myocardial infarction, found 85 patients who received an IABP. Patients presenting in established cardiogenic shock were excluded. The IABP group were characterised by greater haemodynamic instability, more prevalent multivessel and left anterior descending coronary artery disease, were older and more likely to suffer from diabetes and hypertension. The hospital mortality for the IABP group was significantly higher (32% vs 4%), possibly reflecting the selection of patients with higher acuity. No death was attributable directly to insertion of the IABP. Bleeding complications necessitating transfusion were greater in the IABP group, although only 6% required surgical repair for vascular injury. Recovery of global and non-infarct zone left ventricular function was greater among patients receiving IABP support. Non-infarct zone myocardial function has been identified as a prognostic factor.²⁶ The IABP may preserve non-infarct zone function by reducing myocardial oxygen consumption, increasing flow across critical stenoses, or by improving collateral flow through the subendocardium. Reinfarction or reocclusion of the infarct-related artery was not observed in the IABP group. The IABP may confer a survival advantage in high-risk patients, especially the “rescue angioplasty” group who appear particularly at risk from reocclusion.

Survival following acute myocardial infarction is independently related to both patency of the infarct-related artery and left ventricular function. In a study undertaken by Ishihara et al,²⁷ 114 patients with anterior myocardial infarcts underwent emergency percutaneous transluminal coronary angioplasty (PTCA). Forty-eight of these subsequently had an IABP inserted. Reinfarction was not observed in the IABP cohort and reocclusion was significantly lower (2.4% vs 17.7% $P<0.05$). There was a marginally significant improvement in left ventricular ejection fraction in the IABP-treated group ($9.2\pm 13.0\%$ vs $4.5\pm 12.2\%$ $P=0.08$). There was no significant difference in hospital mortality. Patients were not randomised and changes in angioplasty technique over time may have confounded the results.

A prospective randomised multicentre trial of prophylactic IABC for 48 hours following emergency PTCA in acute myocardial infarction, was conducted by Ohman and co-workers.²⁸ One hundred and eighty-two patients were enrolled, with 96 assigned

to IABC and 86 to standard management. Patients randomised to the IABP arm had a significantly lower rate of reocclusion of the infarct-related artery at follow-up angiography (8% vs 21% $P < 0.03$). IABC also achieved a reduction in adverse events, with a composite clinical end-point of death, stroke, reinfarction, urgent angioplasty or surgical revascularisation, and recurrent ischaemia (13% vs 24% $P < 0.04$). Patients presenting in established cardiogenic shock were excluded, however, on the grounds that it would have been unethical to withhold IABC from these individuals

The adjunctive role of IABC in coronary angioplasty will need to be re-evaluated in the light of newer pharmacological therapies, specifically the platelet aggregation inhibitors abciximab and clopidogrel.

Paediatrics

The intraaortic balloon pump was slow to find widespread acceptance in paediatric practice during the late 1970s and early 80s. An early report by Pollock et al²⁹ suggested that it was not a successful strategy in children under five years of age and overall survival was significantly less than 50%. Technical challenges confronting enthusiasts for counterpulsation included difficulties in balloon insertion, a limited range of balloon volumes and lengths, pumping consoles restricted to delivering volumes no less than 20 ml at lower rates, and poor diastolic pressure augmentation in young children with a highly distensible aorta. Right ventricular failure and pulmonary hypertension may contribute to low cardiac output states in children and may portend a poor response to the balloon pump. However, a range of balloons from 2.5 to 15 ml is now readily available and consoles using helium instead of CO₂ can deliver smaller volumes at higher heart rates.³⁰ Good outcomes and associated clinical improvements in haemodynamics and renal function have been noted, despite inability to achieve suprasystolic diastolic augmentation.³¹

Webster and Veasy³² reported a series of 18 children who underwent counterpulsation. Of these, 50% survived to wean from the IABP, with 86% of these survivors weighing less than 15 kg. In this series, 16 patients had undergone corrective cardiac surgery or coronary bypass grafting and two suffered cardiogenic shock, one from viral myocarditis and the other *Haemophilus influenzae* sepsis. These authors suggested indications for IABP should include selected congenital heart lesions, myocarditis and sepsis if myocardial recovery is anticipated. However, there were only five long-term survivors among their cohort. A further nine children undergoing balloon counterpulsation for refractory ventricular failure, inability to wean from cardiopulmonary bypass and myocardial ischaemia were reported by Park et al.³⁰ Four survived weaning from the IABP after support extending to 96 hours. In another study of 14 children with a median age of 3 years, a 71% rate of successful weaning from IABP support was observed leading to a 57% long-term survival following cardiac surgery.³³

Traditionally ECMO has been used for postcardiotomy support of children, with reports of 44% successfully weaning.³³ The association between congenital heart defects, right ventricular failure and abnormal pulmonary vascular resistance often compounds the left ventricular dysfunction ensuing from complicated surgery with long cross clamp times. ECMO may be expected to achieve greater success under these circumstances. The balloon pump assists the left ventricular ejection phase while augmenting diastolic coronary perfusion, improving the endocardial viability ratio. Thus, IABC is ideally suited to conditions characterised by myocardial ischaemia and permits a reduction in inotrope dosages while preserving organ perfusion. Patients

undergoing the Fontan Procedure might be expected to benefit from IABP assisted reduction of left ventricular afterload and filling pressures, but clinical experience has been mixed. Long-term survival of children requiring counterpulsation after Fontan has varied from 11% to 28% in small published series.^{33,34} Many of the deaths reported in the literature have occurred in cardiac surgical patients subsequently shown at autopsy to have severe residual cardiac lesions incompatible with long-term survival, rather than as a direct consequence of balloon pump complications or a failure to favourably alter haemodynamics and end-organ perfusion.^{32,33}

Complications from balloon counterpulsation in children have been comparable to adults. They range from mild limb ischaemia³² and loss of distal pulses without associated tissue necrosis³⁰ to fatal mesenteric ischaemia.³³ Premature removal of the IABP mandated by life- or limb-threatening complications appears uncommon.

New Directions

Subarachnoid haemorrhage

New applications for the balloon pump have been reported in the literature. Counterpulsation has been proposed to support patients with cerebral vasospasm and ventricular dysfunction after subarachnoid haemorrhage.^{35,36} It may assist in sustaining cerebral perfusion in conjunction with hypervolaemic resuscitation, haemodilution and systemic hypertension. While an attractive approach to minimising vasopressor doses and improving haemodynamic stability among recipients of nimodipine, it necessitates anticoagulation in patients who are at risk of further cerebral haemorrhage.

High-risk cardiac patients undergoing general surgery

These patients may benefit from perioperative circulatory support using the balloon pump,³⁷ although questions regarding risk-benefit, patient selection and postoperative care need to be addressed.

Refractory arrhythmias

A recent report suggested that patients experiencing ventricular arrhythmias, refractory to conventional medical therapy, may respond to intraaortic counterpulsation.³⁸ The authors speculate that ventricular unloading (mechano-electrical feedback) and reduced catecholamine levels, rather than protection against ischaemia, may explain the beneficial effect on cardiac rhythm.

Septic shock

Advanced septic shock may deteriorate to a hypodynamic state as a consequence of decreased coronary perfusion and cytokine mediated myocardial depression. An early laboratory study by Roberts et al³⁹ employing a dog model of Klebsiella-induced sepsis tested the hypothesis that intraaortic counterpulsation would favourably affect cardiorespiratory, metabolic and haematological responses. They found that IABP supported animals at 24 hours after bacterial infusion exhibited better preserved left ventricular stroke work and myocardial performance, less metabolic acidosis and recovery of circulating leukocyte count. Application in clinical septic shock has been studied infrequently. One early report notes the survival of two patients with coronary artery disease complicated by severe septic shock managed by IABC.⁴⁰

Right heart failure

Right ventricular infarction and consequent failure may lead to overdistension and compromised left ventricular filling despite volume resuscitation owing to ventricular interdependence. Right ventricular ischaemia will be exacerbated by high end-diastolic filling pressures, which increase oxygen demand while imperilling coronary supply. Intraaortic counterpulsation may play a role in treating right heart failure refractory to inotropic support.⁴¹ Massive pulmonary embolism accompanied by right ventricular overload and ischaemia has similarly been proposed as an indication amenable to IABC.⁴²

To date, these proposed indications for the balloon pump remain novel therapies with only anecdotal or small retrospective case series for support. Further research is necessary before any recommendations can be made.

Weaning and Removal

Discontinuation of balloon pump support remains a difficult judgement based on the initial indication for counterpulsation, the degree of myocardial recovery as demonstrated by echocardiography and invasive haemodynamic monitoring, the level of inotropic support and the natural history of the disease process. Catheters are readily maintained in-situ up to seven days and beyond, however risks of infection and vascular injury or thromboembolic complications assume greater importance over time.

The nature of the circulatory assistance offered by the IABP is subtle, being the nett interaction of afterload reduction, relief from ischaemia, enhanced end organ perfusion, and, perhaps, protection against serious arrhythmias. Except for severe refractory ventricular failure, placing the IABP console into stand-by mode will be unlikely to precipitate discernible change in haemodynamics initially. Over the ensuing hours a persistent low cardiac output state may manifest in progressive metabolic acidosis, oliguric renal failure and respiratory failure. One approach is to wean the augmentation or ratio of IABP support over several hours, while observing signs of end-organ hypoperfusion associated with an inadequate cardiac index. Myocardial recovery may be ascertained by echocardiography prior to catheter removal. Having achieved a reduction in inotropic support as a beneficial consequence of cardiac rest and recovery offers scope to offset the withdrawal of mechanical circulatory assistance by adjusting inotropic doses upwards.

Choosing the sequence for discontinuing IABP and ventilatory support depends on the condition of the individual patient. Factors to be considered include mobilisation of a supine patient tethered to a femoral catheter following extubation, the propensity for pulmonary congestion after weaning from mechanical ventilation and withdrawal of circulatory support, and relative priorities in avoiding respiratory and vascular complications.

Complications

Morbidity attributable to balloon pumps has included balloon rupture, aortic dissection and perforation, haemorrhage, limb ischaemia, mesenteric infarction, renal ischaemia and infection. However, with the advent of the percutaneous approach, narrow gauge catheters and sheathless insertion technique and, perhaps, greater vigilance and early removal in the event of complications, serious adverse outcomes and deaths have declined sharply. In the largest series published by the Massachusetts

General Hospital,⁷ catastrophic vascular complications including iliac or aortic perforation, mesenteric infarction and amputation were less than 1%. Naunheim et al⁶ also found that balloon pump related complications did not adversely affect survival. The renewed interest in combining IABC with thrombolysis in the treatment of acute myocardial infarction has raised concern over possible bleeding. Serious morbidity occurred in 10 to 15% of patients, although there were no deaths as a consequence of thrombolysis and IABC in two studies conducted in community hospitals.^{11, 12} The GUSTO-1 Study⁸ recorded bleeding outcomes in 62 patients who underwent IABC within 24 hours following thrombolysis. Patients receiving early IABC had significantly more moderate bleeding complications and required greater transfusion of packed cells ($P=0.0001$). However, the incidence of severe or life-threatening complications was not significantly different between the IABP and no-IABP groups ($P=0.16$).

The duration the IABP catheter is maintained in-situ has been identified as an independent risk factor for sepsis, carrying an odds ratio of 1.5 for each pump day.⁴³ Recently a prospective study of 60 cardiac surgical patients managed with an IABP catheter found a 15% incidence of true bacteraemia and a 12% incidence of sepsis, raising the question of whether antibiotic prophylaxis would be appropriate.⁴⁴

Iatrogenic vascular injury from balloon pump catheter insertion is commonly reported with 25 out of 90 patients suffering vascular complications in one retrospective analysis over a 10-year period.⁴⁵ Female gender and peripheral vascular disease were identified as significant risk factors, but the site and difficulty of insertion, duration of counterpulsation, anticoagulation and antibiotics were not predictive of vascular complications.⁴⁵ The sheathless insertion technique has been demonstrated to reduce the incidence of vascular complication (8.8% vs 25.9% $P<0.01$) and lower limb ischaemia in particular.⁴⁶ In a study of 509 patients over a 15-year period, major vascular complications were identified in 8%, with a notable reduction in the incidence of complications over the last five years of the analysis.⁴⁷ The authors attributed the improvement in iatrogenic injury to the use of catheters with smaller diameters. They noted that the presence of vascular complications per se was not a significant independent predictor of mortality or other serious morbidity.⁴⁷ Lower limb ischaemia associated with balloon pumps in the absence of peripheral vascular disease may be amenable to pharmacological therapy with PGE₁ infusion via the intra-aortic catheter.⁴⁸

Conclusion

In light of current knowledge, are we using the balloon pump appropriately?

As estimated from the GUSTO-1 study,⁸ 32% of shocked patients underwent insertion of an intraaortic balloon in the United States. The corresponding figure for the other participating countries was only 7.2%, and this figure is likely to represent local practice. International data on usage from the Benchmark Registry recorded 20.6% for haemodynamic support associated with catheterisation, 18.8% cardiogenic shock, 16.1% for weaning from cardiopulmonary bypass, 13% preoperative insertion in high-risk patients and 12.3% refractory unstable angina as indications for counterpulsation.⁴⁹ These figures suggest a broader application of the technique than occurs locally. Perhaps our fear of complications, lack of availability and unfamiliarity with counterpulsation results in fewer patients benefiting from the device than might otherwise be the case. The literature clearly supports early insertion rather than

salvage therapy. In contrast, clinical practice in many centres has seen the majority of balloons inserted "after the fact" in theatre or, even later, in the ICU, possibly disadvantaging our patients in terms of morbidity and survival.

At this stage, combining lysis with counterpulsation in cardiogenic shock remains controversial, although promising. If proven to be of benefit, the implications particularly for regional hospitals without a cardiac surgical service would be significant. Acquisition of the equipment and training of personnel in regional centres would pose substantive logistical challenges.

A study of the major determinants of survival with counterpulsation, published in the *American Heart Journal* in 1995,¹⁷ found that myocardial infarction with a LVEF <30% carried a high associated mortality. The limited haemodynamic support offered by the balloon pump may be inadequate in the face of severe shock. Identifying these patients early and triaging to a ventricular assist device may be more appropriate.

The decision to wean from counterpulsation remains a difficult balance between the potential for further recovery and the likelihood of complications should we delay. Upon withdrawal of the balloon pump, deterioration may be slow, manifesting hours later. Many questions regarding timing and the order of weaning from cardiorespiratory support remain unanswered by available research.

In conclusion, the intraaortic balloon pump has gained in popularity as a means of controlling refractory myocardial ischaemia and may further offer protection against coronary reocclusion and reinfarction after angioplasty. A potential new role in treating cardiogenic shock in combination with thrombolysis may offer a survival advantage, especially to those patients presenting to peripheral centres denied immediate access to revascularisation procedures. The use of IABP in cardiac surgery has remained largely unchanged, however retrospective data suggests that earlier preoperative insertion of the IABP may confer a survival advantage by stabilising shocked patients at risk of further ischaemia and infarction. Prospective randomised trials are in progress to answer questions regarding the efficacy and safety of these approaches to balloon counterpulsation in modern practice.

References

1. Kantrowitz A, Tjonneland S, Freed PS, Phillips SJ, Butner AN, Sherman JL. Initial clinical experience with intraaortic balloon pumping in cardiogenic shock. *JAMA* 1968; 203:135-140.
2. Buckley MJ, Craven JM, Gold HK. IABP assist for cardiogenic shock after cardiopulmonary bypass. *Circulation* 1972; 46(Suppl):II76.
3. Sakamoto T, Suzuki A, Kazama S, Komatsu S, Sasaki S, Shoji Y. Effects of timing on ventriculoarterial coupling and mechanical efficiency during intraaortic balloon pumping. *ASAIO J* 1995; 41:M580-583.
4. Jacob AS, Steingart RH, Schweger MJ. Heparin elimination following continuous infusion during intra-aortic balloon counterpulsation. *Cathet Cardiovasc Diagn* 1985; 11:389-392.
5. Creswell LL, Rosenbloom M, Cox JL et al. Intraaortic balloon counterpulsation: patterns of usage and outcome in cardiac surgery patients. *Ann Thorac Surg* 1992; 54:11-20.
6. Naunheim KS, Swartz MT, Pennington DG et al. Intraaortic balloon pumping in patients requiring cardiac operations: risk analysis and long-term follow-up. *J Thorac Cardiovas Surg* 1992; 104:1654-1661.
7. Torchiana DF, Hirsch G, Buckley MJ et al. Intraaortic balloon pumping for cardiac support: trends in practice and outcome, 1968-1995. *J Thorac Cardiovas Surg* 1997; 113:758-769.
8. Anderson RD, Ohman EM, Holmes DR et al. Use of intraaortic balloon counterpulsation in patients presenting with cardiogenic shock: observations from the GUSTO-1 study. *J Am Coll Cardiol* 1997; 30:708-715.
9. O'Rourke MF, Norris RM, Campbell TJ, Chang VP, Sammel NL. Randomized controlled trial of intraaortic balloon counterpulsation in early myocardial infarction with acute heart failure. *Am J Cardiol* 1981; 47:815-820.

10. Flaherty JT, Becker LC, Weiss JL et al. Results of a randomized prospective trial of intraaortic balloon counterpulsation and intravenous nitroglycerin in patients with acute myocardial infarction. *J Am Coll Cardiol* 1985; 6:434-446.
11. Stomel RJ, Rasak M, Bates ER. Treatment strategies for acute myocardial infarction complicated by cardiogenic shock in a community hospital. *Chest* 1994; 105:997-1002.
12. Kovack PJ, Rasak MA, Bates ER, Ohman EM, Stomel RJ. Thrombolysis plus aortic counterpulsation: improved survival in patients who present to community hospitals with cardiogenic shock. *J Am Coll Cardiol* 1997; 29:1454-1458.
13. Gurbel PA, Anderson RD, MacCord CS et al. Arterial diastolic pressure augmentation by intraaortic balloon counterpulsation enhances the onset of coronary artery reperfusion by thrombolytic therapy. *Circulation* 1994; 89:361-365.
14. Prewitt RM, Gu S, Schick U, Ducas J. Intraaortic balloon counterpulsation enhances coronary thrombolysis induced by intravenous administration of a thrombolytic agent. *J Am Coll Cardiol* 1994; 23:794-798.
15. Hochman JS, Sleeper LA, Webb JG et al. Early revascularization in acute myocardial infarction complicated by cardiogenic shock. *NEJM* 1999; 341:625-634.
16. Baldwin RT, Slogoff S, Noon GP, Sekela M, Frazier OH, Edelman SK, Vaughn WK. A model to predict survival at time of postcardiotomy intraaortic balloon pump insertion. *Ann Thorac Surg* 1993; 55:908-913.
17. Pi K, Block PC, Warner MG, Diethrich EB. Major determinants of survival and nonsurvival of intraaortic balloon pumping. *Am Heart J* 1995; 130:849-853.
18. Christenson JT, Simonet F, Badel P, Schmuziger M. Optimal timing of preoperative intraaortic balloon pump support in high-risk coronary patients. *Ann Thorac Surg* 1999; 68:934-939.
19. Gunstensen J, Goldman BS, Scully HE, Huckell VF, Adelman AG. Evolving indications for preoperative intraaortic balloon pump assistance. *Ann Thorac Surg* 1976; 22:535-546.
20. Christakis GT, Weisel RD, Fremes SE et al. Coronary artery bypass grafting in patients with poor ventricular function. *J Thorac Cardiovasc Surg* 1992; 103:1083-1092.
21. Dietl CA, Berkheimer MD, Woods EL, Gilbert CL, Pharr WF, Benoit CH. Efficacy and cost-effectiveness of preoperative IABP in patients with ejection fraction of 0.25 or less. *Ann Thorac Surg* 1996; 62:401-409.
22. Christenson JT, Simonet F, Badel P, Schmuziger M. Evaluation of preoperative intraaortic balloon pump support in high-risk coronary patients. *Eur J Cardiothorac Surg* 1997; 11:1097-1103.
23. Kang N, Edwards M, Larbalestier R. Preoperative intraaortic balloon pumps in high-risk patients undergoing open heart surgery. *Ann Thorac Surg* 2001; 72:54-57.
24. Tung C, Sauri D, Fintel D, Gheorghiade M. Management of high-risk subsets in unstable angina. *Cardiology Clinics* 1999; 17:415-437.
25. Ohman EM, Califf RM, George BS et al. The use of intraaortic balloon pumping as an adjunct to reperfusion therapy in acute myocardial infarction. *Am Heart J* 1991; 121:895-901.
26. Grines CL, Topol EJ, Califf RM et al. Prognostic implications and predictors of enhanced regional wall motion of non-infarct zone after thrombolysis and angioplasty therapy of acute myocardial infarction. The TAMI study groups. *Circulation* 1989; 80:245-253.
27. Ishihara M, Sato H, Tateishi H, Uchida T, Dote K. Intraaortic balloon pumping as the postangioplasty strategy in acute myocardial infarction. *Am Heart J* 1991; 122:385-389.
28. Ohman EM, George BS, White CJ et al. Use of aortic counterpulsation to improve sustained coronary artery patency during acute myocardial infarction. Results of a randomized trial. *Circulation* 1994; 90:792-799.
29. Pollock JC, Charlton MD, Williams WG, Edmonds JF, Trusler GA. Intraaortic balloon pumping in children. *Ann Thorac Surg* 1980; 29:522.
30. Park JK, Hsu DT, Gersony WM. Intraaortic balloon pump management of refractory congestive heart failure in children. *Pediatr Cardiol* 1993; 14:19-22.
31. Christensen DW, Veasy LG, McGough EC, Dean JM. Intraaortic balloon counterpulsation in children: a review of 29 patients. *Crit Care Med* 1991; 19:S75.
32. Webster H, Veasy LG. Intraaortic balloon pumping in children. *Heart and Lung* 1985; 14:548-555.
33. Akomea-Agyin C, Kejriwal NK, Franks R, Driscoll Booker P, Pozzi M. Intraaortic balloon pumping in children. *Ann Thorac Surg* 1999; 67:1415-1420.
34. Del Nido PJ, Swan PR, Benson LN. Successful use of intraaortic balloon pumping in a 2-kg infant. *Ann Thorac Surg* 1988; 46:574-576.

35. Apostolides PJ, Greene KA, Zabramski JM, Fitzgerald JW, Spetzler RF. Intraaortic balloon pump counterpulsation in the management of concomitant cerebral vasospasm and cardiac failure after subarachnoid haemorrhage: technical case report. *Neurosurgery* 1996; 38:1056-1059.
36. Nussbaum ES, Sebring LA, Ganz WF, Madison MT. Intraaortic balloon counterpulsation augments cerebral blood flow in the patient with cerebral vasospasm: a xenon-enhanced computed tomography study. *Neurosurgery* 1998; 42:206-213.
37. Masaki E, Takinami M, Kurata Y, Kagaya S, Ahmed A. Anaesthetic management of high-risk cardiac patients undergoing noncardiac surgery under the support of intraaortic balloon pump. *J Clin Anesth* 1999; 11:342-345.
38. Fotopoulos GD, Mason MJ, Walker S et al. Stabilisation of medically refractory ventricular arrhythmia by intraaortic balloon counterpulsation. *Heart* 1999; 82:96-100.
39. Roberts AJ, Hoover EL, Alonso DR, Combes JR, Dineen P, Gay WA, Subramanian VA. Prolonged intraaortic balloon pumping in klebsiella-induced hypodynamic shock: cardiopulmonary, hematological, metabolic, and pathological observations. *Ann Thorac Surg* 1979; 28:73-86.
40. Foster ED, Subramanian VA, Vito L et al. Response to intra-aortic balloon pumping. *Am J Surg* 1975; 129:464.
41. Hollenberg SM, Kavinsky CJ, Parrillo JE. Cardiogenic Shock. *Ann Intern Med* 1999; 131:47-59.
42. Weber KT, Janicki JS. Intraaortic balloon counterpulsation. A review of physiological principles, clinical results, and device safety. *Ann Thorac Surg* 1974; 17:602-636.
43. Aksnes J, Abdelnoor M, Berge V, Fjeld NB. Risk factors of septicaemia and perioperative myocardial infarction in a cohort of patients supported with intraaortic balloon pump (IABP) in the course of open heart surgery. *Eur J Cardiothorac Surg* 1993; 7:153-157.
44. Crystal E, Borer A, Gilad J et al. Incidence and clinical significance of bacteraemia and sepsis among cardiac patients treated with intraaortic balloon counterpulsation pump. *Am J Cardiol* 2000; 86:1281-1284.
45. Alle KM, White GH, Harris JP, May J, Baird D. Iatrogenic vascular trauma associated with intraaortic balloon pumping: identification of risk factors. *Am Surg* 1993; 59:813-817.
46. Tatar H, Cicek S, Demirkilic U, Ozal E, Suer H, Aslan M, Ozturk OY. Vascular complications of intraaortic balloon pumping: unsheathed versus sheathed insertion. *Ann Thorac Surg* 1993; 55:1518-1521.
47. Arafa OE, Pedersen TH, Svennevig JL, Fosse E, Geiran OR. Vascular complications of the intraaortic balloon pump in patients undergoing open heart operations: 15-year experience. *Ann Thorac Surg* 1999; 67:645-651.
48. Nakano T, Tominaga R, Shiraishi K, Yasui H. Prostaglandin E₁ from the tip of an intraaortic balloon catheter for lower limb ischaemia. *Ann Thorac Surg* 1998; 65:1158-1160.
49. Ferguson JJ, Cohen M, Freedman RJ, Stone GW, Miller MF, Joseph DL, Ohman EM. The current practice of intraaortic balloon counterpulsation: results from the benchmark registry. *J Am Coll Cardiol* 2001; 38:1456-1462.