Weaning from Cardiopulmonary Bypass: A Practical and Simplified Overview

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Abstract

Weaning off cardiopulmonary bypass is a simple process that may occasionally prove very difficult or virtually impossible. Preparation for weaning includes the adjustment of temperatures, tissue oxygenation, hematocrit, pH, electrolytes, and cardiac rhythm and rate. Cardiac action as routinely assessed will allow patients to be classified into 3 groups. Group A includes patients which will obviously offer no difficulties to remove from CPB. Group B comprises patients with mild to moderate dysfunction; they will require some physiological (Starling law) or pharmacological (inotropes, vasoactive drugs) support to be disconnected from pump. Group C are the patients with poor or no cardiac action, which will require either an aggressive pharmacological support or prolonged mechanical support as alternatives to sustain life. Resources for prolonged supportive bypass and mechanical devices shall be available and their application to difficult situations should be part of CPB protocols.

INTRODUCTION

Weaning a patient off cardiopulmonary bypass (CPB) is an exceedingly important part of cardiac surgical procedures. Emergence from CPB is a time for planned action and cooperation among the cardiac operating team. The return of the heart and lungs to the circulation after CPB represents a period of potential stress for the heart. Although most techniques, conduction and management of CPB are well standardized, separating patients from perfusion occasionally involves decisions based on empirical therapies. This is apparently compounded by some controversies surrounding the use and benefits of several inotropes, vasodilators, and vasoconstrictors agents. In most circumstances weaning off CPB is a straightforward process that requires no particular measures other than reestablishing ventilation to the lungs and slowly turning the arterial pump off. In a number of cases however, weaning may be specially difficult, and in a few situations simply impossible. Separation of CPB may occasionally require special protocols, in accordance to the status of the patients, to their particular age group and the conduction of bypass.

Weaning off small children after prolonged, difficult and complex operations may represent a challenge to the surgical team. Weaning off CPB is best conducted in a coordinate fashion with prior discussion of general reatment protocols. The surgeon directs the weaning process with some input from anesthesia and perfusion. A skillful anesthesiologist usually shares the control of weaning with the surgeon. This allows the surgeon to drive full attention to the grafts position, valve function, security of suture lines and final gross hemostasis. When this arrangement fails or there is no free communication in the team, it is not unusual while separating a patient from bypass to observe a perfusionist retaining more volume into a hypotensive patient while the anesthesiologist administers a vasopressor, both ignoring the surgeon's observation that the heart is distending. Inadequate weaning and separation from CPB can prolong recovery and increase morbidity and mortality.

PREPARING FOR WEANING

Cardiopulmonary bypass is associated with various insults to

normal physiology which include anticoagulation, hemodilution, hypothermia, ischemic or chemical cardiac arrest, increased endogenous cathecolamine and vasopressin release, electrolyte disturbances, platelet activation, aggregation and destruction, and activation of complement and other plasma protein systems. These multiple interacting factors represent a number of potential routes for myocardial dysfunction or injury [1]. Weaning off cardiopulmonary bypass is initiated after review and adjustment of certain patient-linked variables, such as temperature, tissue oxygenation, hematocrit level, acid-base and electrolytes status, and cardiac function. Requirements of analgesic, narcotic and paralyzing drugs usually increase during rewarming from hypothermia and the necessary adjustments are made with avoidance of myocardial and circulatory depressant agents [2].

While most preparations are standard and common to all cases, evaluation of cardiac function
may disclose situations which will require specific measures such as the use of temporary
pacemaker, inotropic or vasoactive drugs or mechanical support.

TEMPERATURE

Cardiopulmonary bypass is systematically accompanied by heat loss even when hypothermia is not employed. Preparation for terminating CPB includes rewarming of patients to the normal or near normal temperature. Rewarming should be initiated as early as necessary so that its completion coincides with completion of the surgical procedure or soon afterwards. Patient temperature is monitored in at least two sites such as nasopharyngeal, tympanic, esophageal, rectal or bladder. The most common combination is nasopharyngeal and rectal temperatures. As nasopharyngeal temperature reaches 36.5 to 37 degrees (C), rectal temperature is usually two to three degrees lower. A larger than four degrees gradient between the nasopharyngeal and rectal temperatures is indicative of inadequate rewarming or increased vasoconstriction. In these situations there may occur a two to three degrees decrease in nasopharyngeal temperature during sternal closure and transfer to intensive care unit, which may predispose the patients to unstable cardiac rhythm, shivering, and hypertension [3,4]. This afterdrop is attributed to redistribution of heat within the body as the normal pulsatile blood flow opens up some relatively colder and constricted vascular beds (1,2).

A slow infusion of nitroprusside or other vasodilators may provide a more homogenous rewarming and reduce the occurrence of significant temperature gradients. Some authors propose the use of pulsatile flow to attain the same results [5]. Warming blankets will not systematically be effective to correct the temperature drift, due to the increased peripheral constriction and may occasionally cause burns. Small children may better benefit from warming blankets and ventilation with heated and humidified gases.

TISSUE OXYGENATION

Metabolic status is assessed and abnormalities are corrected before initiating the weaning
process. The venous line carries true mixed venous blood. Venous oxygen saturation and PO2 are
satisfactory indicators of tissue metabolism while arterial PO2 and saturation will best reflect the
oxygenator performance. Inadequate tissue perfusion and oxygenation is manifested by increased
lactate production, decreased pH, and decreased mixed venous saturation and PO2. A venous
oxygen saturation of 75% and a minimum venous PO2 of 35mmHg are satisfactory to start
weaning from CPB.

HEMATOCRIT

Hemodilution is universally used as an adjunct to cardiopulmonary bypass. Blood viscosity and oncotic pressure are reduced while tissue perfusion and oxygenation and cerebral flow are enhanced by the levels of hemodilution commonly used in clinical settings. Hematocrit values from 20 to 25% are usual with most perfusion protocols. By the end of rewarming, depending on renal function and the use of diuretics hematocrit may reach 24 to 30%. Hearts with severe preoperative myocardial dysfunction will perform better immediately after termination of CPB with a hematocrit level above 34%. Red cells transfusion during rewarming may be necessary to adjust the hematocrit prior to discontinuing perfusion [6].

ACID BASE STATUS

Regardless of the lowest temperature attained or the acid-base management protocol used (alpha or pH stat) during CPB, by the end of rewarming a pH of 7.4 and a PCO2 higher than 35 mmHg are mandatory to safely disconnect a patient from the pump. Any degree of acidosis should promptly be corrected because it depresses myocardial contraction, diminishes the action of inotropes, and increases pulmonary vascular resistance.

ELECTROLYTES

Potassium is the critical ion that may present acute changes during CPB, followed by calcium. Others ions rarely show significant changes and their correction is less demanding for the weaning to take place. Potassium has pronounced effects on cardiac conduction, and hyperkalemia may result in atrioventricular block. After adoption of blood cardioplegia a higher potassium level is more commonly seen at the end of perfusion. In the presence of a normal renal function, a mild hyperkalemia represented by a serum level of 6 mEq/L will not require special treatment and resolve spontaneously. If a higher potassium level exists in the presence of a heart block or bradicardia a more regular rhythm should be secured with temporary pacemaker wires and the hyperkalemia should be treated with insulin, glucose and furosemide (2,3). Hypokalemia if present should be treated to avoid the risks of atrial and ventricular arrhythmias. During CPB it is preferable to administer potassium chloride in small frequent doses instead of continuous infusion. Doses of 5 mEq may be repeated after proper evaluation of serum levels. Ionized calcium levels usually decrease during CPB and appears to recover fast thereafter. Administration of calcium chloride was widely employed in the past during separation from perfusion, because of its positive inotropic effect. Elevated serum calcium levels have been associated with increased vascular resistance on the peripheral, coronary, renal and cerebral microcirculation (1,7). Calcium chloride administration has been associated with coronary arteries and mammary grafts spasms and is usually avoided in the revascularization patient. Some concern exists as to the potential role of an elevated serum calcium level in the aggravation of reperfusion injury ([8]). Valvular and pediatric patients with a sluggish myocardial contraction frequently show some transient improvement after a small bolus (10 to 15mg/Kg) of calcium chloride immediately before discontinuing CPB.

CARDIAC ACTION

During CPB several interacting factors can predispose the myocardium to injury or dysfunction. Some myocardial injury may be added or produced after aortic unclamping, during the reperfusion phase. The period preceding complete separation from bypass is critical and its duration is conditioned by myocardial recovery. Regardless of the myocardial protection strategy and method even short periods of aortic cross-clamping can be followed by temporary functional depression. The usual situation is represented by a mild and very transient functional impairment shortly followed by resumption of effective cardiac action. The experience accumulated with ischemic arrest has demonstrated that most hearts will benefit from a period of rest after releasing the aortic cross-clamp. An average of 15 to 20 minutes of supportive CPB will usually provide a good recovery time for each hour of clamping. This is easily accomplished by properly timing surgery and rewarming (1,3,[9]).

By the end of rewarming and other preparations for weaning, maximal myocardial recovery from the arrest period has been attained. Assessment of cardiac function immediately prior to discontinuing perfusion is usually performed by visual observation, electrocardiogram, ventricular filling pressures and afterload, and transesophageal echocardiography if available.

Simple visual observation of heart contraction and relaxation may provide valuable information on myocardial performance. Experienced teams can accurately predict the chances of immediate difficulties to terminate CPB by visually inspecting the heart action alone. The cardiac rhythm and the adequacy of ventricular rate are evaluated by the electrocardiogram monitor tracing. Slow ventricular rates are adjusted by ventricular pacing and atrioventricular dissociation is corrected by atrioventricular sequential pacing. Preload is indirectly evaluated by ventricular filling pressures. Left ventricular preload is inferred from left atrial mean pressure or pulmonary artery diastolic pressure; right atrial pressure reflects the preload conditions of right ventricle. During weaning preload is pump-dependent and can be adjusted by balancing blood volume between patient and oxygenator. Ventricular afterload is evaluated by the status of peripheral vascular resistance. This is represented by the ratio between mean systemic arterial pressure and pump flow. Elevated peripheral resistance can be reduced by the administration of vasodilators. An occasional patient will present in a state of deep vasodilation and hypotension even when pump flow is adequate or elevated ([10]). These will require a vasoconstrictor infusion to restore a normal peripheral resistance. Transesophageal echocardiography is useful to verify the adequacy of surgical repair in congenital and valvular cases; it can also offer valuable information on ventricular volumes and the quality of myocardial contractility ([11]).

Retrospective experience has demonstrated that after adjusting cardiac rhythm and rate, preload

and systemic arterial resistance, the assessment of cardiac function immediately before CPB
termination allows the patients to be classified into 3 groups:

Group A. Patients that will obviously offer no difficulty to disconnect from perfusion. This
group comprises the majority of patients. Most teams will administer a slow infusion of an inotrope
(dopamine or dobutamine) or, less frequently a vasodilator, based only on routine protocols or past
experience. This "safety" infusion is usually discontinued as soon as the patient
arrives to the intensive care area or is maintained for a few hours thereafter.

Group B. Patients with a mild to moderate degree of cardiac dysfunction that will require some support to disconnect from the pump. This support may be physiological (Starling law) or pharmacological (inotropes, vasodilators or both). Some patients in this group can benefit from intra-aortic balloon pumping ([12,13]).

Group C. Patients with severe cardiac dysfunction that will prove difficult to be removed from CPB, despite physiologic and pharmacological support. For these patients CPB will have to be prolonged. A few hours of circulatory assistance and intensive inotropic and vasodilator drugs therapy may turn some of these patients into group B. The remaining patients are candidates to a form of total circulatory mechanical support (if available) or they will not likely survive disconnection from pump ([14,15,16]).

TERMINATION OF CPB

The termination of CPB can be guided by the previous grouping of patients, according to their
cardiac action. For group A patients, after reestablishing ventilation to the lungs, pump flow can be
gradually reduced while venous return to the oxygenator is decreased until bypass is minimal.
Arterial pump is stopped and venous line is clamped. Final adjustment of cardiac performance is
made off pump, by slowly administering residual volume from the oxygenator until ideal preload is
attained. These patients will maintain an adequate cardiac output; this can be confirmed by normal
atrial and arterial pressures, arterial and venous blood gases and pH and increased spontaneous
diuresis. Group B patients require a more elaborated protocol for CPB termination. Final
preparations are made on partial bypass. Blood volume is

adjusted according to left atrial or
pulmonary artery pressures and inotropes are commenced. Peripheral resistance is estimated and
vasodilators or constrictors are instituted as required. After the drugs effectiveness is assessed,
pump flow is decreased in small increments while venous return in proportionately adjusted to
maintain a constant filling pressure. Arterial pump is stopped and venous line is clamped. Most
patients in group B will perform as group A patients. Some patients may have to return to pump for
better adjustment of drugs, or to have an intra-aortic balloon inserted if a marginal cardiac output is
present, as demonstrated by atrial and arterial pressures, arterial and venous blood gases and pH,
and spontaneous diuresis. An occasional patient in group B will not tolerate CPB termination even
after a few trials. These few exceptions turn into group C patients. Group C patients are by
definition the hardest cases to manage. A few of these patients by the end of rewarming will have
minimal or no cardiac activity which precludes any trial of disconnection from pump. The
remaining patients may be given a short trial off pump after optimization of preload, afterload and
contractility by a criterious combination of inotropes and vasoactive agents. Some of these patients
will tolerate CPB removal, under maximal physiological and pharmacological support, and a few in
the group may be further improved by an intra-aortic balloon pump. The patients with minimal
cardiac activity and those in whom the trial off pump was unsuccessful are temporarily maintained
on cardiac support with the heart-lung machine. A few hours on pump support may be a sufficient
rest period to allow recovery of cardiac function and removal of CPB support in a small number of
cases. For the others, a decision has to be made as to either advance to a mechanical device for
prolonged support or terminate the efforts to recover cardiac action.

The proportion of patients on each group is dependent upon the dominant type of cases
refereed for surgical treatment. Past experience indicates that the broadest spectrum of patients,
which includes elderly, reoperations, emergencies and neonates will result in an approximate 70%
of patients in group A, 25% in group B and 5% in group C.

Weaning and disconnecting CPB is a team effort and requires clear planning and integrated performance. Despite being a simple procedure, interrupting perfusion can be elaborated, extremely difficult or virtually impossible. Resources for prolonged supportive bypass and mechanical devices shall be made available and their application to the difficult situations should be a part of CPB protocols.

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