Case 22

A 75-year-old man with severe coronary artery disease is scheduled for coronary artery bypass surgery under general anesthesia. He experiences a tightness in his chest, and shortness of breath with exercise. These symptoms are increasing in frequency, and relieved by 0.2 mg of nitroglycerine within 2 minutes.

He has diabetes and well-controlled hypertension. His medications include metoprolol, metformin, and nitroglycerine. He has never had surgery, and has no known allergies to any medications. He continues to smoke 1 pack per day, and has done so for almost 40 years. His review of systems is otherwise negative.

The patient's blood chemistries are normal, his hemoglobin is 13, and hematocrit 39. His chest x-ray is normal, but his ECG showed inverted T waves in leads II and III, and aVF. A cardiac catheterization showed multiple occlusions of left main artery, left anterior descending artery (LAD), left circumflex artery (CX), and right coronary artery (RCA), and an ejection fraction of 55%. The echocardiogram showed no valvular disease, and confirmed the ejection fraction.

- What are the components of a cardiopulmonary bypass (CPB) machine?
- Why do patients have to go on CPB?
- What are the most common complications of CPB?

ANSWERS TO CASE 22:

Management of a Patient on Cardiopulmonary Bypass Machine

Summary: A 75-year-old male patient with history of diabetes and hypertension with no past surgical history is undergoing coronary artery bypass graft (CABG) surgery. As part of the procedure, he will be placed on cardiopulmonary bypass.

- **Components of coronary bypass machine:** An oxygenator, a heat exchanger for warming and cooling, a venous reservoir, and pumps.
- **Reason for CPB machine:** Because of the likelihood of hemodynamic instability during cardiac surgery without it. CPB also allows the surgeons to access parts of the heart that would not otherwise be accessible.
- **Most common complications of cardiopulmonary bypass:** Acute complications: hypotension, anemia, light anesthesia, lack of suitable neuromuscular blockade. The most common long-term complications are postoperative cognitive dysfunction, renal failure, and disseminated intravascular coagulopathy (DIC).

ANALYSIS

Objectives

1. Understand the basics of the CPB machine.
2. Understand why CPB is necessary in some patients but not in others.
3. Become familiar with the common complications of CPB, and how they may be prevented.

Considerations

The special concerns in the patient preparing for cardiopulmonary bypass are the continuance of his "cardiac" medications, particularly beta blockers, on the morning of surgery. Discontinuance of beta-blocker therapy has been associated with an adverse outcome in some cohorts of patients. As with all elective cases, the patient must be NPO. Blood and blood products must be ready and available in advance, and the CPB readied by the perfusionist.

A large-bore peripheral intravenous line is placed to facilitate transfusion if necessary, and similarly, an arterial catheter is placed for instantaneous blood pressure measurement and for the repeated arterial blood gas sampling. Large-bore central venous access is obtained, but a pulmonary artery catheter may or may not be used for CABG surgery.

After standard monitors are placed, anesthesia was induced using 2 mg of midazolam, 100 mg lidocaine, 20 mg of etomidate, and 100 mg of succinylcholine. The patient was easily intubated using Miller #3 blade with an 8.0 endotracheal tube. Blood pressure is carefully controlled, with either vasopressors for hypotension, or contrarily, a vasodilator anesthetic such as propofol or labetalol for hypertension.

The chest is opened by sternotomy, and the internal mammary artery and saphenous vein are dissected. In preparation for CPB, 3 mg/kg of heparin is administered as per surgeon's request, and the heparin-induced anticoagulation confirmed by the activated clotting time (ACT). After the ACT has reached 480, the patient is placed on the cardiopulmonary bypass machine (CPB, the "pump"). The patient's ventilator is turned off.

APPROACH TO
Management of a Patient on Cardiopulmonary Bypass Machine

The CPB Machine

In its simplest form, the CPB machine consists of pumps, an oxygenator, a heat exchanger which can either heat or cool the blood, a venous reservoir. In preparation for CPB, the entire "pump" system is "primed," or filled with a crystalloid solution. Large cannulae from the pump are also flushed with crystalloid, and then connected to smaller cannulae that have been inserted into the patient's heart and allowed to fill with blood. Thus, one liquid-filled tube is inserted into another liquid-filled tube to minimize air emboli. The venous cannula drains blood from the patient to the CPB machine by gravity. An aortic (arterial) cannula delivers blood pumped from the CPB machine to the patient. The heart is isolated from this aortic cannula, the CPB circuit, and the body by the aortic clamp. While on CPB, the patient's circulatory volume expands by the amount of fluid used to prime the pump and its associated cannulae.

Heparin is administered prior to the institution of CPB to prevent clotting which could occlude the cannula and the CPB machine. The efficacy of the heparin is measured by the activated clotting time (ACT) to confirm anticoagulation prior to the institution of bypass. This large dose of heparin can be associated with hypotension, which should be anticipated and promptly treated with vasopressors if necessary. Tragedies have occurred when the patient was placed on CPB but not anticoagulated: either the heparin was inadvertently omitted, or following a medication error, protamine, a heparin

antagonist, was administered accidentally. To prevent the accidental administration of protamine, by convention, protamine is kept in a location that is different from the other anesthetic drugs, and the package or vial remains unopened until it is needed.

CLINICAL APPROACH

Most patients undergoing cardiac surgery will need to be placed on CPB to allow surgery to be performed on a motionless heart under controlled circumstances (Figure 22–1). Without CPB, surgery would be performed on a beating heart, substantially increasing the degree of technical difficulty. Moreover, some cardiac

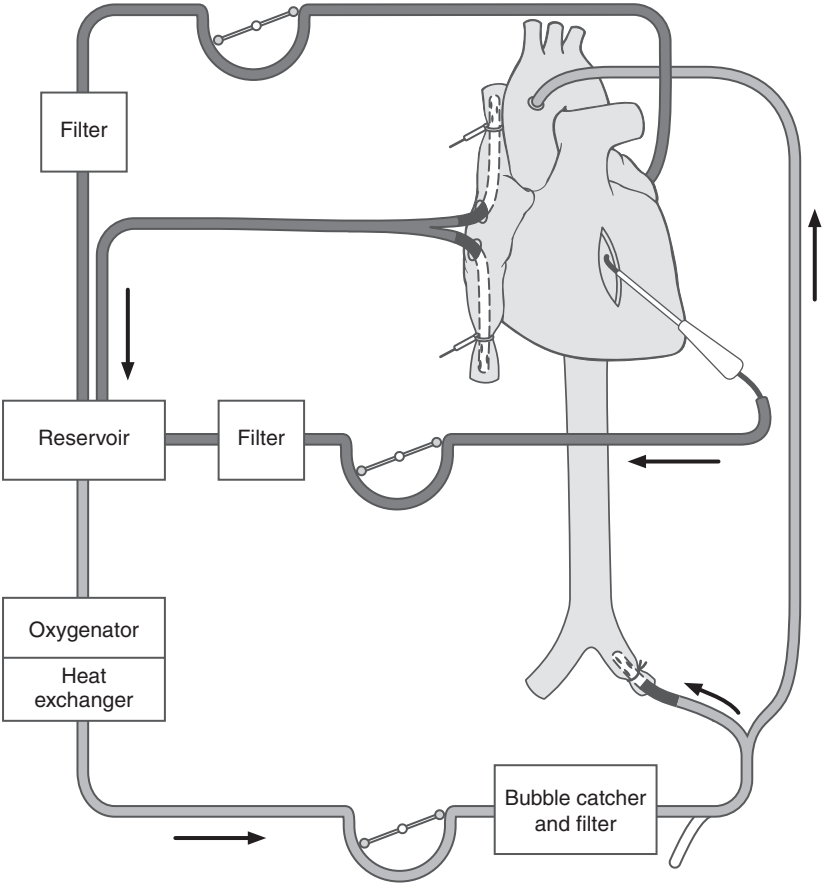

Figure 22–1. Diagram demonstrating how a patient is connected to the cardiopulmonary bypass machine. [dark grey] represents alternate pathways from patient to pump. [light grey] represents alternate pathways from pump to patient. (*Redrawn with permission from Dr. Joseph Reeves-Viets.*)

lesions are anatomically difficult to access in the beating heart, and manipulation of the heart in and of itself can make the patient unstable.

In addition to possible myocardial damage, the most common complication of CPB is short-term memory loss (cognitive defect), which can occur in a significant proportion of patients. The need to reduce the risk of postoperative cognitive dysfunction is probably the most important indication for an "off pump" CABG procedure.

Other complications associated with CPB include:

1. Hypotension
2. Renal failure
3. Light anesthesia and intra-op awareness
4. Coagulopathy and bleeding, including DIC
5. Stroke
6. Death

Hypotension following the institution of CPB generally indicates one of three things. After the patient's blood mixes with the 2 L of crystalloid used to "prime the pump" (usually Plasmalyte), the hematocrit can be seriously reduced, even by as much as 10%. If the hematocrit falls to below 24%, blood transfusions should be given. Hemodilution also reduces blood viscosity and systemic vascular resistance, and thus decreases the blood pressure. Hypotension resulting from hemodilution should be anticipated, and any tendency toward hypotension should be treated early with a vasopressor like phenylephrine or norepinephrine. Hypotension can also result from the dilution of catecholamines by the crystalloid "pump prime," and is also treated with vasopressors such as phenylephrine or norepinephrine. Less common, but equally critical causes of hypotension post institution of CPB include inadequate pump flow, kinked tubing, and aortic dissection following cannula placement.

It is also possible for components of the CPB machine to stimulate an allergic reaction, thus resulting in hypotension. In some patients, when the patient's blood comes in contact with the components of CPB machine, chemical mediators are released causing vasodilation. Currently, there are no diagnostic tests which are immediately available to confirm this scenario. Vasopressors are the appropriate treatment, and may also include a vasopressin infusion. Similarly, simply traversing the CPB machine causes a constant injury to the blood components. In some patients, disseminated intravascular coagulopathy (DIC) may result. DIC also can be a part of systemic inflammatory response syndrome (SIRS). Both syndromes can be triggered by an unusually long CPB run, and both can be associated with stroke, renal failure, diastolic dysfunction of the myocardium, and death.

Hemodilution also increases the volume of distribution of anesthetic agents, potentially leading to light anesthesia and even intra-op awareness. Estimates of the incidence of awareness in cardiac surgical procedures vary, but may approach 10%. Many centers advocate neurophysiologic monitoring

for awareness in cardiac surgical patients. Levels of neuromuscular blocking agents and narcotics are also decreased significantly, possibly allowing patient movement as well. To anticipate this situation, just prior to the institution of bypass patients should receive an additional neuromuscular blocking agent, a narcotic, and a benzodiazepine (which may provide amnesia) to ensure therapeutic levels. Once CPB has been initiated, an inhalational anesthetic can be administered using a vaporizer mounted on the CPB machine.

Myocardial injury is unavoidable during CPB, since the heart largely reverts to anaerobic metabolism accompanied by the release of inflammatory mediators, and operative trauma. Myocardial stunning, apoptosis, and myocardial infarction may result. In an attempt to protect the myocardium and minimize such complications, oxygen consumption is reduced by cooling the heart and inducing asystole with potassium containing cardioplegia solution.

Following the surgery, the patient is warmed to a core temperature of 36°C (known as the "rewarming period"). Once this temperature is reached, he or she is "weaned" from bypass by incrementally reducing the venous drainage into the pump and the pump's arterial flow out into the patient. This is an incremental process, as vasodilation from warming increases the circulating volume. Appropriate volume resuscitation is estimated by the pulmonary artery pressure. Arterial pressure is also monitored closely. If too high, stroke or bleeding may result; if too low, organ hypoperfusion with stroke, renal failure, and multiple system organ failure can result.

As the patient is warmed, the cardioplegia stopped, and the aortic clamp separating the heart from the CPB circuit and body is opened, the heart usually begins beating on its own. The anesthesiologist resumes mechanical ventilation, confirms that the core temperature is indeed 36° C or above, that the hematocrit and arterial blood gases are suitable, and that the perfusionist has an adequate remaining volume in the pump's reservoir to maintain circulating volume as bypass is discontinued. (For the anesthesiologist's checklist prior to separating from bypass, please see Table 22–1.) Should ventricular fibrillation occur, the patient is promptly cardioverted to avoid any unnecessary increases in myocardial oxygen consumption.

Table 22–1 ANESTHESIOLOGIST'S CHECKLIST PRIOR TO "COMING OFF" BYPASS

- Confirm that the patient's core temperature is $\geq$ 36°C.
- Confirm that mechanical ventilation has resumed.
- Confirm that the CPB reservoir contains sufficient volume to maintain MAP, PAP, and CI as bypass is discontinued.
- Ensure that arterial blood gases are conducive to the discontinuance of bypass.
  - pH $\geq$ 7.30
  - K $\leq$ 5.5 (K^+ is contained in cardioplegia and packed RBCs, and increased by acidosis)
  - Hct $\geq$ 24

"Coming off bypass" is often a tumultuous period as the heart, postarrest, progresses toward the resumption of normal function. The post-bypass heart usually requires support in the form of vasopressors and inotropes, in particular, epinephrine, norepinephrine, dobutamine, and milrinone. Cardioplegia often impairs electrical conduction in the heart, so pacing is often required and the need for cardioversion for ventricular fibrillation is not unusual. The delicate balance between the progressive vasodilation that accompanies warming, the possibility of continued surgical bleeding, and a heart that may be prone to failure make separation from bypass one of the most challenging periods in anesthesiology and cardiac surgery.

Rarely but occasionally, there is a malfunction of the CPB machine. This usually reflects a problem of the machine, but can also result from the failure of both the main and auxiliary power sources of the institution. In this event, the CPB can be powered by a hand crank. As might be expected, a malfunction of the CPB machine can also lead to stroke, renal failure, and death. A good understanding of the working of the CPB machine, as well as the physiologic changes it induces is important for the anesthesiologist managing these complicated procedures.

Comprehension Questions

22.1. Which of the following cardiac surgery may be done without using CPB?
- A. Mitral valve repair
- B. Coronary artery bypass surgery
- C. Tricuspid valve surgery
- D. Replacement of the ascending aorta

22.2. Why do patients who are going to be on CPB need a higher dose of heparin (at least 3 mg/kg) when compared to a vascular case which does not need CPB machine?
- A. Use of oxygenators on CPB
- B. Tubing in the CPB machine
- C. Heat exchanger in CPB machine
- D. Using kinetic pump on CPB machine

22.3. What is the most common complication of CPB machine?
- A. Renal failure
- B. Myocardial infarction
- C. DIC
- D. Short-term memory loss

22.4. Shortly after the institution of CPB, the patient became severely hypotensive (mean blood pressure of 30 mm Hg or less) and started moving on the OR table. Which is the most likely cause of this scenario?

A. Myocardial infarction resulting from sudden exposure to the cold solution.
B. Hemodilution from mixing the 2 L of crystalloid "pump prime."
C. Hemodilution has significantly reduced the hematocrit and increased the SVR.
D. Hemodilution has caused a myocardial infarction.

ANSWERS

22.1. **B.** Even though majority of the CABG surgeries are done on CPB machine, some of them can be done without CPB machine ("off pump"), depending on the patient's anatomy. Good candidates for "off pump" procedures include patients with one vessel disease like a single LAD occlusion not involved with hemodynamic instability, or in a patient who is at a high risk for stroke (calcified aorta etc).

22.2. **A.** The oxygenator is the most thrombogenic component of the CPB machine. Heparin dose of 1 mg/kg, which is normally used in vascular cases, is not enough to prevent clots with certainty in the CPB machine. On the other hand, a heparin dose of 1 mg/kg is sufficient to prevent clots in the other components of CPB.

22.3. **D.** Short-term memory loss (cognitive defect) is the most common complication of CPB, though DIC and renal failure are very common complications as well. The need to reduce the risk of postoperative cognitive dysfunction is the most important indication for an off pump CABG procedure.

22.4. **B.** On the CPB machine, the additional saline in the pump prime is associated hemodilution. Concentrations of the medications decrease, leaving the patient lightly anesthetized and not paralyzed, possibly resulting in movement. This could be prevented by giving additional doses of neuromuscular blocking agents and narcotics just prior to the institution of bypass, and adding an inhalation anesthetic from the CPB machine. Hemodilution can also reduce hematocrit sufficiently to reduce SVR, resulting in hypotension. Hypotension should be promptly treated with vasopressors. Should the hematocrit fall below 24%, blood should be transfused.

Clinical Pearls

- Familiarity with the CPB machine and its functions are vital for the anesthesiologist.
- Recognizing and promptly treating (or even pretreating in anticipation of the complications that occur while on CPB can avoid disastrous consequences. Vasopressors should be used immediately, the hematocrit checked, and other less likely scenarios considered if appropriate.
- Instituting cardiopulmonary bypass in a patient who is not anticoagulated can have disastrous consequences.

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