Cardiomyopathy and Pulmonary Resection – a Problem Based Learning Discussion

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OBJECTIVES
At the conclusion of the PBLD the participant will be able:

1. To understand the cardiovascular effects of general anesthesia, mechanical ventilation, and one lung ventilation (OLV) in normal patients.

2. To understand the implications of general anesthesia, mechanical ventilation, and one lung ventilation on cardiovascular function in patients with severe ventricular dysfunction.

3. To understand the potential impact of pulmonary resection surgery via thoracotomy and thoracoscopy on patients with severe ventricular dysfunction.

4. To develop anesthetic management strategies to optimize perioperative outcomes in patients with severe ventricular dysfunction undergoing pulmonary resection surgery.

DISCLOSURES: None
INTRODUCTION

Interactions between the cardiovascular and respiratory systems are complex. General anesthesia and positive pressure ventilation affect cardiovascular function. In patients presenting for pulmonary resection, additional effects due to one lung ventilation, surgical procedures, and contraction of the pulmonary vascular bed may impose an additional physiologic burden. For patients with adequate pulmonary and cardiovascular reserve, these effects are usually well tolerated. However, the thoracic anesthesiologist may be asked to provide anesthetic care for patients with significantly reduced cardiac function who require potentially curative pulmonary resection for lung cancer. These patients present a major perioperative challenge and a thoughtful approach to anesthetic management is required. We review a case of a patient with severely impaired biventricular function who presented for elective pulmonary lobectomy in an attempt to effect a curative resection of lung cancer and present a discussion of physiologic and pathophysiologic considerations for clinical management.

CASE PRESENTATION

The patient was a 61 year old male with a medical history notable for reactive airway disease, benign prostatic hypertrophy, alcoholism, tobacco abuse, and a dilated cardiomyopathy characterized by severe biventricular dysfunction with a history of congestive heart failure. He had recently undergone a nuclear stress imaging study which revealed a left ventricular ejection fraction (LVEF) of 8%. Cardiac catheterization demonstrated normal coronary perfusion with an LVEF of 10%. At the time of his cardiac evaluation, he was severely symptomatic, able to ambulate only 15 meters on a level surface and experienced moderately severe dependent edema. Medical therapy for heart failure included carvedilol, lisinopril, digoxin, and furosemide and these had produced significant improvement in signs and symptoms of CHF. Additional medications included aspirin and albuterol.
The patient was admitted on the morning of surgery for a scheduled bronchoscopy, mediastinoscopy, and thoracoscopic right upper lobectomy for lung mass thought to be a bronchogenic carcinoma. Results of pulmonary function testing was as follows: FEV₁ 101% predicted; FEV1/FVC 83%, DLCO 88% predicted. On admission, his vital signs were as follows: BP 110/82 P 98 SpO₂ 95% on room air; weight was 82 kg and BMI 22. Laboratory studies were significant only for hemoglobin 12.1 g/dl. He appeared comfortable seated in an upright position and denied recent dyspnea or orthopnea but he remained very sedentary. On examination, auscultation revealed distant breath sounds, mild bibasilar crackles but no murmurs, rubs, or gallops were appreciated.

QUESTIONS

1. What are your specific cardiovascular concerns for this patient given his presentation for elective resection of a probable lung cancer?
2. How would you respond to the patient’s questions regarding the risks of serious perioperative cardiovascular morbidity and mortality?
3. If you decide to proceed with this elective procedure, what is your initial approach to anesthetic induction, anesthetic maintenance, monitoring, mechanical ventilation, and lung isolation?
4. What specific pain control modalities, if any, are indicated or necessary for this thoracoscopic lobectomy?
5. What preparations should be made to prevent or treat hypotension or decreased cardiac output upon induction or thereafter?
6. What are the likely effects of mechanical positive pressure ventilation on cardiac function in a patient with normal contractile function? A patient with severe biventricular dysfunction?

CASE CONTINUATION

A frank discussion with both the patient and attending surgeon regarding the risks and benefits of surgery and anesthesia revealed that the patient
understood and accepted these risks and wished very much to proceed with elective surgery with a curative intent.

In the operating room, the patient was lightly sedated with 2 mg IV midazolam and left radial artery cannulation was performed under local anesthesia with a 20 gauge catheter. After preoxygenation, intravenous induction of general anesthesia was accomplished with 10 mg etomidate, 50 mg rocuronium, and 100 mcg sufentanil. The trachea was easily intubated with a 39 French left double lumen endotracheal tube under direct laryngoscopy and position confirmed by fiberoptic bronchoscopy. Moderate hypotension ensued with BP 80’s/50’s.

QUESTIONS

1. What are the likely causes of hypotension in this patient at this time and what treatments should be considered?
2. What specific therapies should be considered to optimize LV and RV function in the context of pulmonary resection surgery and anticipated OLV in this patient?

CASE CONTINUATION

Hypotension was initially treated by infusion of epinephrine at 2 to 6 mcg/min. Additional inotropic support was achieved by intravenous infusion of milrinone (0.25 -0.5 mcg/kg/min). Inhalational delivery of epoprostenol (Flolan) was initiated at 50 ng/kg/min to promote pulmonary vasodilatation and right ventricular afterload reduction. After the induction of anesthesia, a central venous catheter was placed in the right internal jugular vein under ultrasound guidance and a transesophageal echocardiography probe was placed for continuous echocardiographic monitoring of cardiac function. Intraoperative echocardiographic examination revealed severely impaired biventricular function, severely dilated left ventricle, moderately dilated right ventricle, moderate mitral regurgitation and mild tricuspid regurgitation. A small but observable improvement in biventricular systolic function was observed with the initiation of
inotropic therapy (epinephrine and milrinone) and inhaled pulmonary vasodilator therapy. General anesthesia was maintained with 0.7-1.9% sevoflurane and midazolam.

QUESTIONS
1. What effects, if any, do the initiation of OLV and hemithoracic insufflation have on the normally contractile heart? The severely hypocontractile heart?
2. At this time the patient is stable with optimized biventricular function. In the anticipation of one lung ventilation, thoracoscopy, and hemithoracic insufflation, do you have concerns for deterioration of cardiovascular function and what, if any, additional preparations should be made? Which ventricle is most likely to be adversely affected by these procedures and processes?
3. Are there any specific concerns for the management of OLV in this patient which would mandate a particular ventilatory approach?

CASE CONTINUATION
One lung ventilation was easily achieved via the endobronchial lumen of the double lumen endotracheal tube and operating conditions were deemed to be excellent. Efforts were made to minimize pleural insufflation pressure. Delivered tidal volumes during OLV were approximately 5 cc/kg and peak pressures were below 30 cm H$_2$O throughout. PEEP (5 cm H$_2$O) was applied throughout the OLV period.

QUESTIONS
1. As hypoxemia may result from an increase in intrapulmonary shunt and venous admixture during OLV, what preparations, if any should be made to prevent and treat this problem?
2. Are there any other specific concerns regarding the management of OLV in this patient?
3. Are recruitment maneuvers for the ventilated dependent lung contraindicated in this patient? Is CPAP for the nondependent lung a more favorable option?

4. Given that this patient does not have a thoracic epidural catheter in situ, what plans should be made for pain management postoperatively?

CASE CONTINUATION

SpO₂ values ranged from 92 to 100% during one lung ventilation. Lobectomy proceeded via a thoracoscopic approach and was concluded without complication. The non-dependent lung was reinflated gently with continuous positive airway pressure at the conclusion of surgery and two lung ventilation resumed at that time. After confirmation of neuromuscular recovery, the patient was emerged and extubated. Transport was to an intensive care unit dedicated to the care of surgical patients after cardiothoracic surgery. His recovery was complicated only by moderate postoperative hypercarbia treated with BiPAP and left basilar atelectasis which responded to pulmonary toilet therapies. On postoperative day 3, he was transferred to a step down unit and was discharged home without additional complication on postoperative day 4.

DISCUSSION

Cardio-respiratory Interaction

Spontaneous ventilation affects the physiology of the cardiovascular system largely through phasic changes in intrathoracic pressure and lung volume due to diaphragmatic motion and can be understood based on the effects of these pressure/volume changes on venous return, ventricular interdependence, and ventricular loading phenomena. In general, negative intrathoracic pressure promotes an increase in venous return to the right heart which elevates right ventricular (RV) end diastolic volume. Through ventricular interdependence phenomena, left ventricular (LV) filling and LV stroke volume may be limited. Under normal conditions, augmented venous return leading to improved LV stroke volume is likely to be the net result of these changes.
Positive pressure ventilation (PPV) has effects on LV afterload that are generally the inverse of those associated with spontaneous ventilation. An increase in intrathoracic pressure with a positive pressure breath decreases transmural aortic root pressure, decreasing LV afterload. Unloading the LV favors LV ejection in patients with ventricular dysfunction.

RV afterload tends to increase at higher lung volumes. The degree to which positive pressure ventilation in general and PEEP in particular lead to elevated PVR and RV afterload augmentation depends upon whether the primary effect is to recruit atelectatic alveoli or to overdistend those alveoli which are adequately ventilated. At lung volumes below FRC, PVR is elevated due to compression of alveolar vessels. If PEEP is applied under these conditions, resolution of atelectasis and an increase in lung volume towards FRC would be expected to diminish PVR and RV afterload, potentially augmenting RV performance.

**Cardiorespiratory Interaction in Patients with Cardiomyopathy**

Under normal cardiovascular conditions, the increase in intrathoracic pressure from PPV limits cardiac preload via decreased venous return, resulting in decrements in cardiac output via the Frank Starling mechanism. Thus the normal heart is said to be “preload dependent.” However, if cardiac contractile function is profoundly compromised, effects on ventricular afterloading may predominate, particularly since patients with severe biventricular dysfunction are often hypervolemic.

**One Lung Ventilation - Effect on Cardiac Function**

The initiation of OLV has been correlated with an increase, decrease, and no change in cardiac output in patients undergoing OLV. The selective application of PPV to one lung is likely to result in reduction in LV afterload to the extent that intrathoracic pressure is increased. During thoracoscopic surgery, pressure within the operative hemithorax is also affected by pleural insufflation pressure. Evidence from experimental studies support a pressure related
reduction of cardiac output and increased pulmonary arterial pressure from
insufflation. The exacerbation of RV afterload and deterioration of RV function in
this context is a distinct possibility.

OLV affects LV preload via decrements in filling through direct effects on
venous return as well as phasic and steady state ventricular interdependence
phenomena just as in two lung ventilation. More dramatic increases in lung
volume and intrathoracic pressure associated with recruitment maneuvers and
higher levels of PEEP and CPAP during OLV are associated with a decrement in
cardiac output.

OLV results in alveolar hypoxia in the non ventilated lung. Hypoxic
pulmonary vasoconstriction (HPV) involving an entire unventilated lung reduces
intrapulmonary shunt but may also increase pulmonary vascular resistance
(PVR). Within the normal lung, the low pressure, high capacitance vasculature is
well known to buffer changes in blood volume. Despite buffering effects,
increases in PVR and PAP can occur with the onset of OLV, creating conditions
of increased afterload for the RV.

One Lung Ventilation – Effect on Cardiac Function in Patients with
Cardiomyopathy

The clinical effects of OLV in human patients with systolic ventricular
dysfunction has not been studied systematically and the scant available
information in the English language literature comes from case reports. The
limited available information suggests that OLV per se does not greatly perturb
hemodynamic function in the adequately preloaded heart under optimal
conditions of inotropic and pulmonary vasodilator support. Nevertheless, care
should be taken to avoid iatrogenic pulmonary hyperinflation, atelectasis,
hypercarbia, and of course, hypoxemia, all of which could further exacerbate
increases in PVR and RV afterload.

Contraction of the Pulmonary Vascular Bed

Loss of pulmonary parenchyma inevitably reduces pulmonary vascular
bed volume. PVR typically normalizes postoperatively while right ventricular ejection fraction decreases over several days. Compensatory right ventricular dilatation may preserve RV stroke volume after major lung resection despite a reduced RVEF. In the absence of relevant data, it is reasonable to conclude that preoperative severe biventricular dysfunction would reduce compensatory adaptation of the RV.

**Anesthetic Management**

The goals of anesthetic management in patients with cardiomyopathy include maintenance of normovolemia, avoiding medications which cause myocardial depression, and prevention of increased ventricular afterload. Managing OLV in this patient population during may be challenging and requires maintaining a balance between optimal ventilation strategies (optimal minute ventilation, avoidance of barotrauma, minimizing pulmonary vascular resistance, optimal lung isolation, and appropriate oxygenation) and support of ventricular function (inotropic intervention, afterload reduction, and maintenance of coronary perfusion). In patients with low-output states with or without congestive symptoms, inotropic agents, vasodilators and diuretics can be used to facilitate a more desirable physiologic state on the Frank-Starling curve.

**Postoperative Pain Control**

Thoracic epidural analgesia (TEA) represents the “gold standard’ for post-operative pain management in thoracic surgery. TEA can provide excellent analgesia, attenuate the postoperative stress response and associated sympathetic activity, and improve pulmonary function. There is evidence to support the use of TEA in improving heart function in patients with heart failure secondary to ischemic cardiomyopathy and in minimizing adverse perioperative cardiac events. If TEA or other neuraxial technique is used for pain management in this patient population, dosing with local anesthetic should be performed slowly and under continuous monitoring with attention to the aforementioned hemodynamic goals. Opioids (fentanyl, sufentanil, morphine, or
hydromorphone) can be used adjunctively in the neuraxis to reduce the required dose and concentration of local anesthetic (0.0625% bupivacaine, 0.1% ropivacaine), which in turn minimizes the degree of TEA-related sympathectomy.

**Anesthetic Agents**

Inhaled volatile anesthetics may worsen ventricular function by reducing preload, afterload and contractility. Right ventricular failure can occur due to acute elevations in PVR caused by hypoxia, hypoventilation, atelectasis and high ventilating pressures. It appears that halothane, isoflurane, and sevoflurane do not affect PVR unfavorably. However, PVR can be increased by both desflurane and nitrous oxide; thus these agents should be avoided in patients at risk of RV failure, i.e. those with preexisting RV dysfunction and severe pulmonary hypertension.

Fentanyl and sufentanil are commonly used in thoracic surgery and have minor effects on pulmonary hemodynamics. Remifentanil may cause a reduction in pulmonary vascular tone through histamine and opioid receptor pathways.

Etomidate is known for its stable hemodynamic profile, and is often advocated as the induction agent of choice in patients with depressed cardiac function. However, etomidate is known to cause adrenal insufficiency and its use in critically ill patients is controversial. Though arterial pressure is maintained during etomidate anesthesia, there is concern for augmented left ventricular (LV) afterload which could potentially adversely affect myocardial function in patients with pre-existing systolic dysfunction.

Thiopental can reduce RV contractility and SVR, but does not affect PVR. Ketamine, shown to have a safer hemodynamic profile than etomidate in critically ill patients, can increase PVR and myocardial work. Propofol is known to reduce ventricular filling pressure and contractility but these effects can be reversed with inotropic support.

**Inotrope and Vasopressor Therapies**

Optimal use of inotropes during cardiac dysfunction and congestive heart
failure (CHF) remains controversial. Nevertheless, they are used for improving cardiac output by augmenting contractility, decreasing SVR, and enhancing diuresis through increased renal blood flow. Dobutamine, dopamine and epinephrine all improve stroke volume (SV), increase heart rate (HR) and decrease filling pressure. However, they increase myocardial stroke work and oxygen consumption. Additionally, β-adrenergic receptor responses may be blunted in CHF, leading to a low efficacy of these agents. Milrinone, a phosphodiesterase inhibitor, acts through a non-β-adrenergic pathway, and does not exhibit a diminished efficacy or tolerance. It produces less tachycardia than the adrenergic agonists, decreases filling pressure and SVR, and increases SV. It causes relatively more RV afterload reduction through pulmonary vasodilation and less direct inotropy, resulting in lower cardiac oxygen consumption.

Norepinephrine, phenylephrine and vasopressin are all used to stimulate vasoconstriction to increase mean arterial pressure. If this response increases coronary blood flow, improved ventricular function with an increase in LV and RV output is the likely result. Norepinephrine, a potent α1-adrenergic agonist primarily increases systolic, diastolic and pulse pressures. It can increase coronary perfusion but may be cardiotoxic if used for a prolonged period. Phenylephrine, an α-agonist, is often used in bolus form for correction of sudden severe hypotension and may worsen RV function in patients with chronic pulmonary hypertension. Vasopressin can produce potent systemic vasoconstriction and pulmonary vasodilation through stimulation of nitric oxide (NO) from the pulmonary endothelium.

**Pulmonary Vasodilators**

Right ventricular failure is typically related to an elevation in PVR, which may represent the primary cause of RV failure or a contributing factor in patients with established ventricular dysfunction from other causes. Reduction of PVR is therefore a primary focus of treatment for prevention of ventricular failure in these patients. Pulmonary vasodilating agents may be administered enterally (phosphodiesterase inhibitors (sildenafil) and bosentan), intravenously (calcium
channel blockers, adenosine, magnesium, nitroglycerin, phosphodiesterase inhibitors, and prostanoids), or inhalationally (nitric oxide (iNO), prostacyclin, iloprost, nitroprusside, nitroglycerine, milrinone). The inhalational delivery of vasodilators produces predominantly or exclusively pulmonary vasodilatation depending upon the pharmacokinetic and pharmacodynamic properties. iNO and prostacyclin both produce selective pulmonary vasodilation, decreasing PVR, and improving oxygenation with minimal systemic hemodynamic effects. They are effective in treating pulmonary hypertension due to vascular disease, ARDS, acute lung injury, and RV failure complicating cardiac surgery. Inhaled prostacyclin, Flolan™, works through a receptor mediated increase in cyclic AMP causing vasodilation and inhibiting smooth muscle cell proliferation and platelet aggregation. Because prostacyclin is much less expensive than iNO and more easily administered, it has found utility in cardiothoracic surgery and is widely used in this context.

**FURTHER READING**


