Extrapleural Pneumonectomy

36

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Key Points

- Extrapleural pneumonectomy is a formidable surgical procedure performed on patients with limited life expectancy. Anesthetic management may contribute to containment of perioperative morbidity and mortality through the control of intraoperative physiologic disruptions and postoperative pain and an appreciation of the associated postoperative complications to affect early intervention.
- Beyond standard anesthetic management issues for pneumonectomy, there exist a number of important "EPP-specific" anesthetic concerns. These include significantly greater blood loss, more delicate management of intravascular fluid and blood components, greater operative impairment of venous return, high probability of dysrhythmias, and greater potential for hemodynamic instability related to pericardial window and its patch.
- Common causes of hypotension during EPP include compression of the heart or great vessels by tumor or surgical pressure/retraction, blood loss and/or inadequate fluid resuscitation, and thoracic epidural sympathetic blockade.
- No single anesthetic recipe is of proven superiority for either EPP or lung resection surgery in general. The priority for early extubation favors the use of short-acting modern inhalational and intravenous agents, with limited use of traditional parenteral narcotics. Thoracic epidural analgesia is widely employed intraoperatively to facilitate extubation at the conclusion of surgery by providing dense analgesia without depression of sensorium or respiratory drive.
- Fluid management remains a challenge due to the increased blood loss in EPP, hemodynamic instability, renal toxicity of chemotherapy agents, and the potential for exacerbation of acute lung injury.

Introduction

Extrapleural pneumonectomy (EPP), the en bloc resection of the lung, parietal and visceral pleurae, pericardium, and diaphragm, is a formidable surgical procedure. First described for the treatment of tuberculous empyema, it is currently typically performed for local control of malignant pleural mesothelioma (MPM). It may also be applied to other malignancies or infections involving or obliterating the pleural space, including thymoma and non-small cell lung cancer (NSCLC) [1]. Although there has been a dramatic reduction in perioperative mortality from 31% reported in the 1970s [2] to a recent systematic review demonstrating mortality ranging from 0% to 11.8% [3], postoperative major morbidity remains high (12.5–48%). Higher center volume may be associated with decreased mortality and morbidity after surgery for MPM [4]. Currently, EPP and the lung-sparing alternative, pleurectomy/decortication (P/D), are considered by many to have a critical role in the multimodality treatment of MPM [4–9]. This chapter will discuss the important "EPP-specific" anesthesia concerns [10, 11], including intraoperative intracavitary hyperthermic chemotherapy (IOHC), which is being applied in a few centers for better control of local disease in MPM.

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Malignant Pleural Mesothelioma and Pleural Dissemination of Malignancy

MPM arises on the pleural surface of the chest wall, lung, pericardium, or diaphragm, tends to spread or recur locoregionally, and is generally fatal within a year of diagnosis [12]. Its etiologic link to asbestos exposure has been established [13], but not all patients with mesothelioma have a history of asbestos exposure, and other etiologies have been postulated [14]. The annual incidence of mesothelioma in the United States is estimated to be approximately 3300 cases per year [15]; this incidence of mesothelioma peaked around the year 2000 and is now declining, secondary to control of exposure to asbestos. No single modality of treatment significantly improves median survival beyond 12 months. EPP offers the most complete cytoreduction, but recurrence occurs locoregionally. Multimodality approaches, combining cytoreduction by P/D or EPP, with chemotherapy, radiotherapy, or photodynamic therapy have been evaluated in various combinations recently, with reported improved survival statistics [3–8]. The control of locally advanced disease in thymoma, sarcoma, and NSCLC has been reported with variable success. EPP in Stage IVa thymoma or Stage IV NSCLC (often combining induction chemotherapy and/or adjuvant radiation) has a 5-year survival of 53–78% and 24–55%, respectively [1]. But reports are sparse with mainly small cohorts of patients. With the exception of IOHC, these multimodality treatment therapies generally do not greatly impact anesthetic management of EPP.

Intraoperative Intracavitary Heated Chemotherapy

The intraoperative application of chemotherapy (usually cisplatin) to address microscopic disease remaining in the empty hemithorax prior to closure has important implications on anesthetic management. Intracavitary application targets the chemotherapy directly at the sites of recurrence (including the abdomen), with higher doses than would be tolerated systemically. Heating the chemotherapy agent increases tumoricidal activity by increasing the permeability and metabolic activity of the cells [16].

Surgical Considerations

The *technique* of *EPP* [17] consists of several basic steps:

1. *Incision and exposure of the parietal pleura*
   An extended posterolateral thoracotomy with resection of the 6th rib is the most common approach.

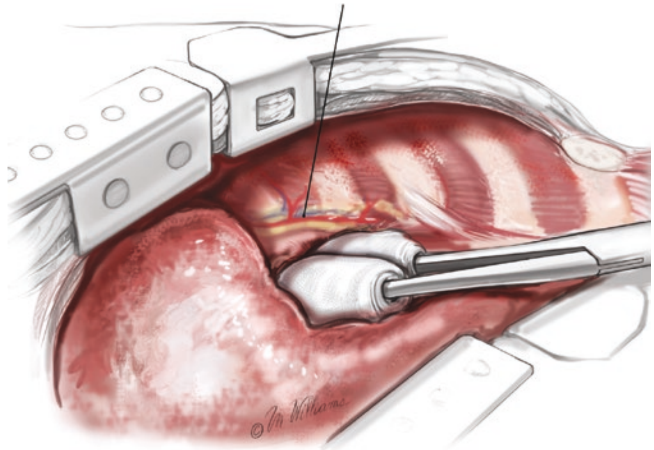

Fig. 36.1 Blunt anterior parietal dissection with identification of the internal mammary vessels. (Reprinted with permission from Marcia Williams Medical and Scientific Illustration [17])

2. *Extrapleural dissection to separate the tumor from the chest wall*
3. *En bloc resection of the lung, pleura, pericardium, and diaphragm with division of the hilar structures*
   A combination of blunt and sharp extrapleural dissection is initiated anterolaterally and advanced to and over the apex, to bring the tumor down from the posterior and superior mediastinum (Fig. 36.1).
   - Beware of injury to the internal mammary vessels/grafts and subclavian vessels during dissection anteriorly and at the apex, respectively, as well as traction injury to the azygous vein and superior vena cava in the superior mediastinum.
   - In addition, during left EPP, injury may occur to the intercostal arteries, thoracic duct, and recurrent laryngeal nerve.

   Posterior dissection is then performed and the esophagus dissected away from the tumor. The diaphragm is avulsed circumferentially (Fig. 36.2) and dissected bluntly from the underlying peritoneum (Fig. 36.3), and the pericardium is opened.
   - During division of the medial aspect of the diaphragm, the inferior vena cava may be injured or torsed.

   The main pulmonary artery (PA) and pulmonary veins are then dissected, isolated, and stapled extra- or intrapericardially. After the main bronchus is dissected as far as the carina, the bronchial stapler is fired under direct visualization with the fiber-optic video bronchoscope to assure a short bronchial stump. Bleeding from numerous exposed vessels on the inner thoracic cavity is temporized by packing, but definitive hemostasis is not sought until the specimen is removed.
4. *Radical lymph node dissection*
   Radical mediastinal lymph node dissection is performed, followed by reinforcement of the bronchial stump. The

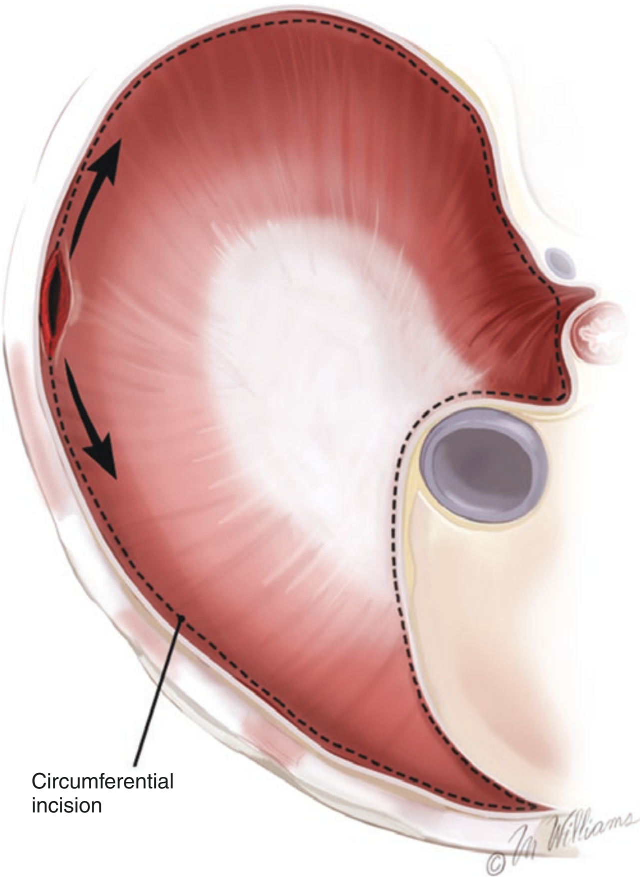

Fig. 36.2 The diaphragm is incised circumferentially. (Reprinted with permission from Marcia Williams Medical and Scientific Illustration [17])

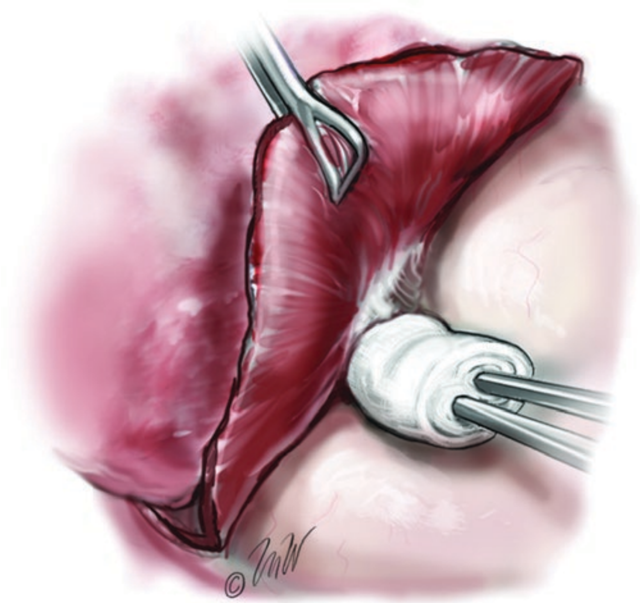

Fig. 36.3 The diaphragm is dissected bluntly from the underlying peritoneum. (Reprinted with permission from Marcia Williams Medical and Scientific Illustration [17])

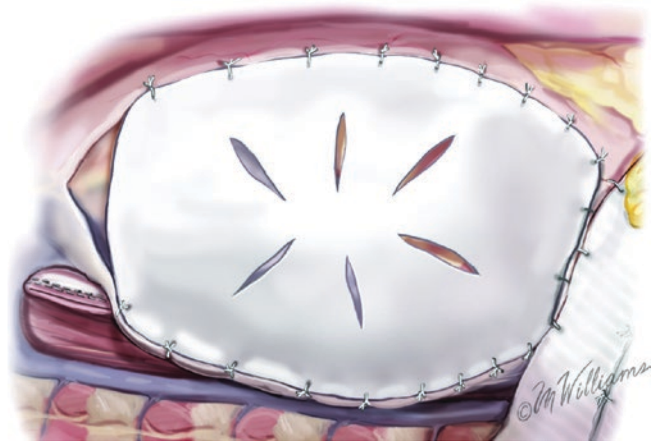

Fig. 36.4 Reconstruction with diaphragmatic and fenestrated pericardial patches which prevent herniation. (Reprinted with permission from Marcia Williams Medical and Scientific Illustration [17])

hemithorax is then irrigated with warm saline and water (wash phase) to remove and osmotically lyse residual microscopic tumor.

4. *Optional administration of IOHC*
5. *Reconstruction of the diaphragm and pericardium* (Fig. 36.4)
   The last step is reconstruction of the diaphragm and pericardium using a prosthetic such as Gore-Tex DualMesh (W.L. Gore and Associates, Inc., Flagstaff, Arizona). These patches prevent subsequent herniation of abdominal contents and cardiac herniation into the empty hemithorax.

Technique of IOHC

Two perfusion cannulae (inflow and outflow) are placed within the open hemithorax after tumor resection and hemostasis. Chemotherapy in dialysate maintained at 42 °C is circulated via a pump for 60 min. The volume of perfusate is adjusted to keep the hemithorax full, which maximizes surface area contact between residual microscopic tumor cells and a high local concentration of cisplatin. Systemic administration of cytoprotectants is performed either before or after the chemotherapy administration depending on the agent used (Table 36.1); the timing is important to maximize tumorigenicity while sparing renal function [7]. Sodium thiosulfate covalently binds and inactivates cisplatin in the blood. Amifostine (Ethyol, Alza Pharmaceuticals – USA), which exhibits 100-fold preferential uptake by normal cells and salvages intracellular free radicals, has also been used. Amifostine may cause hypotension with rapid administration.

Table 36.1 Renal protective strategies for EPP with intraoperative intracavitary hyperthermic chemotherapy (IOHC) with cisplatin (Brigham and Women's Hospital Protocol)

Admission day before surgery for intravenous hydration
7-day hold of nonsteroidal anti-inflammatory drugs
Pretreatment with intravenous amifostine (30 mins prior to IOHC) and 2nd dose 2 h later (910 mg/m^2 and 500 mg/m^2)
Intravenous sodium thiosulfate following IOHC (4 g/m^2 bolus, 12 g/m^2 over 6 h)
Liberalized IV hydration and assiduous avoidance of systemic hypotension during and after IOHC
Urine alkalinization ($NaHCO_3$ 45 mEq/h × 2 h, 22.5 mEq/h)

Table 36.2 Suggested exclusion criteria for EPP

Karnofsky performance status <70%
Abnormal creatinine
Abnormal liver function tests
Evidence of unresectability by CT, MRI, echocardiogram
Room air $PaCO_2$ > 45 mmHg
Room air PaO_2 < 65 mmHg
Left ventricular ejection fraction <45%
Predicted postoperative FEV_1 < 1 L[a]

Karnofsky score 70 – Care for self: unable to carry on normal activity or do active work

CT computed tomography, *MRI* magnetic resonance imaging, *FEV_1* forced expiratory volume in 1 s

[a]Patients with predicted postoperative FEV_1 < 2 L are recommended to undergo quantitative radionuclide ventilation-perfusion scanning

Patient Selection

Critical to risk reduction, general exclusion criteria utilized by the surgical group with the most favorable published survival statistics [5] are listed in Table 36.2. Patients with a predicted postoperative forced expiratory volume in 1 s ($ppoFEV_1$) or less than 0.8 L are considered for P/D, rather than EPP.

Preoperative Patient Preparation

An awareness of the perceived cardiopulmonary reserve, the anatomical extent and impact of the tumor, and coexisting disease states allows the anesthesiologist to tailor invasive monitors, lines, and anesthetic plan to preempt or efficiently respond to problems. If IOHC is planned, renal protection strategies begin preoperatively with hydration and the withholding of nonsteroidal anti-inflammatory medications (Table 36.1).

Cardiopulmonary Risk Assessment

The assessment of cardiopulmonary reserve is especially difficult. Measurements traditionally employed to predict post-thoracotomy pulmonary complications include $ppoFEV_1$, maximal oxygen consumption (VO_2max), and diffusing capacity for carbon monoxide (DL_{CO}) [18]. Preoperative transthoracic echocardiograms are routine, and cardiac stress and right heart catheterization are utilized if there is evidence of ventricular dysfunction or pulmonary hypertension, respectively. History, physical examination, and echocardiography will reflect cardiac functional status but may not predict the response to the stress of pneumonectomy in the setting of major fluid shifts [19]. Patients with a history of recent myocardial infarction in the last 3 months or life-threatening arrhythmias would be considered for P/D rather than EPP.

Radiologic Studies

Computed tomography and magnetic resonance imaging (MRI) of the chest play an important role in assessing tumor invasion of the chest wall, vertebrae, diaphragm, and mediastinal structures. They are used for staging and/or to assess tumor resectability [20]. The anesthetic implications include safe placement of epidural catheters at the thoracic region, level and site of intravenous access, quantity of blood and blood products available, and the potential necessity for cardiopulmonary bypass during resection.

Anesthetic Considerations

Specific Anesthetic Issues for EPP

Beyond the standard management issues for pneumonectomy [21], important "EPP-specific" anesthesia concerns are shown in Table 36.3.

Table 36.3 Anesthetic issues for extrapleural pneumonectomy

Significantly greater blood loss compared to pneumonectomy
More delicate management of intravascular fluid and blood components
Greater operative impairment of venous return
Greater danger of surgical disruption of major vascular structures
More complex and variable physiology of the nonoperative lung (restrictive and obstructive)
High probability for disruption of internal mammary artery coronary grafts (if present)
High probability of dysrhythmias
Frequent "pseudo-ischemic" ST changes on EKG during wash phase
Greater potential for hemodynamic instability related to pericardial window and its patch
Greater postoperative pain and pulmonary dysfunction related to the larger incision

Lines and Monitors

Generous intravenous access is paramount, and blood should be available in the operating room. If the superior vena cava is in jeopardy, lower extremity intravenous access is mandatory. A nasogastric tube aids posterior esophageal dissection intraoperatively and gastric decompression (and the prevention of gastric acid aspiration) postoperatively. Invasive monitors (arterial and central venous lines) are routine. The site of central venous access is important, as the potential for causing a pneumothorax in the nonoperative lung has to be weighed against injury to the subclavian vein during surgical dissection on the operative side.

Although pulmonary artery (PA) catheters have potential interpretation pitfalls during pneumonectomy [22, 23], they may be useful for postoperative fluid and right heart management issues. Transesophageal echocardiography (TEE) is a more powerful and reliable monitor of right and left ventricular filling and function and is a more sensitive monitor of myocardial ischemia, particularly during left EPP when the surgical incision precludes appropriate EKG lead placement. However, there is no direct evidence of improved outcome, and the cost and need of technical expertise make this tool worthwhile only in selected cases.

Choice of Anesthesia

No single anesthetic recipe is of proven superiority for either EPP or lung resection surgery in general. The priority for early extubation favors the use of short-acting modern inhalational and intravenous agents, with limited use of traditional parenteral narcotics.

Thoracic Epidural Analgesia

Despite emerging promising regional techniques for post-thoracotomy analgesia, thoracic epidural analgesia (TEA) remains the technique of choice for EPP. TEA reduces perioperative pulmonary [24] and cardiac complications [25, 26], including pulmonary infections, atelectasis, myocardial infarction, and the incidence of supraventricular tachyarrhythmias post-thoracotomy. TEA is widely employed intra- and postoperatively for EPP. It also facilitates extubation at the conclusion of surgery by providing dense analgesia without depression of sensorium or respiratory drive.

The sympatholytic effects of TEA may complicate hemodynamic management if dense blockade is imposed during or prior to the dissection phase of EPP. It is therefore common to initiate bolus dosing of the epidural catheter later in the surgery. Ultimately, solutions and infusion rates are individualized to address catheter insertion site, hypotension, pruritus, nausea, opioid tolerance, sedation, or other side effects.

One-Lung Anesthesia

Lung Isolation Techniques

Lung isolation to facilitate surgical exposure may be achieved using either a double-lumen endotracheal tube (DLT) or a bronchial blocker. For EPP, DLTs allow rapid ventilation or collapse of either lung, effective suctioning, and uninterrupted lung isolation at the time of surgical cross clamp. We favor a left-sided DLT is for a right EPP (and vice versa). There is no hardware present in the operative bronchus, and compared to a bronchial blocker, a left-sided DLT is less likely to be dislodged with surgical manipulation. Although right-sided DLTs have a smaller margin of safety (due to short right upper lobe anatomy), this is rarely an impediment to their effective use. When an anomalously high right upper lobe precludes an effective air seal at the bronchial cuff, this is easily remedied by passing a blocker down the tracheal lumen [27]. Blockers are principally used for left-sided EPP in patients with difficult airway anatomy and withdrawn prior to stapling the bronchus in order to avoid accidental inclusion into the suture line.

Optimizing Oxygenation During One-Lung Ventilation (OLV)

"Lung-protective" (low tidal volume 5–6 ml/kg, limiting peak airway pressure <35 cmH_2O, and dependent lung positive end-expiratory pressure (PEEP)) ventilation with the intention of limiting dependent lung volutrauma and atelectasis is important [28]. Recruitment maneuvers (RM) and reducing $FiO_2 < 1.0$ when tolerated may be employed.

EPP patients, during OLV in the lateral decubitus position, often exhibit an element of restrictive physiology in the dependent lung imposed by the weight of the tumor and surgical pressure during dissection. Frequent large changes in compliance require vigilance to prevent high airway pressures or volumes (depending on the mode of ventilation). During intracavitary lavage, where a perfusate of cisplatin exerts weight on the mediastinum, both RM and PEEP are important to prevent atelectasis. In addition, dependent lung pneumothorax may easily occur during dissection of large tumors and will require surgical decompression. The IOHC fluid may accumulate in the dependent thorax if the pleural defect is not adequately repaired.

Despite a greater propensity for dependent lung atelectasis and possibly increased nondependent lung shunt (inhibition of hypoxic pulmonary vasoconstriction due to more vigorous surgical manipulation), hypoxemia during OLV for EPP is unusual. This is because the best predictor of oxygen desaturation during OLV is increased (>55% of cardiac output) blood flow to the operative lung, which is seldom the case in MPM [29].

Hemodynamic Management

Hypertension

Hypertension should be avoided during the dissection phase, as it will greatly exacerbate bleeding from the innumerable avulsed chest wall veins. It may also be an issue when the specimen is removed and venous return to the heart is suddenly unimpeded.

Hypotension

This is more frequent, and its treatment should reflect its etiology whenever possible (Table 36.4). Reduced venous return is the most common mechanism, caused by mechanical pressure on the mediastinum during dissection or torsion of great vessels. Critical phases of surgery when venous return is most threatened include the induction, dissection, and terminal repositioning phases. Vasodilation from hyperthermia during IOHC may occur as core temperatures not uncommonly exceed 38 °C.

Induction

Preemptive vasoconstricting agents and judicious selection of induction agents/doses are particularly indicated for patients with large tumor burdens, large effusions, or radiographic evidence of cardiac or major vessel impingement. Often, the thoracic epidural test-dose effect is still peaking at the time of induction, potentially further increasing compensatory vasoconstrictor requirements.

Dissection Phase

Venous return is impeded by blood loss, insensible losses, and variable degrees of compression from the tumor, retractors, and blunt dissection pressure. The temptation to correct venous return by enthusiastic crystalloid volume expansion is to be resisted. Judicious use of vasopressors, together with blood products when appropriate, will temporize until the specimen is removed. Communication with the surgeon during this phase is paramount, and a coordinated effort is necessary to maintain forward progress with acceptable hemodynamics. A low threshold for administration of blood during this phase often proves strategic. When the specimen is removed, venous return, hemodynamics, and respiratory compliance should normalize. Persistent hypotension at this stage suggests hypovolemia.

Repositioning and Emergence

Herniation of the heart (particularly with right EPP), with torsion of great vessels and circulatory arrest, may abruptly occur upon resumption of the supine position at the end of surgery. Immediate return to the lateral position is the appropriate reflex response. This usually improves hemodynamic parameters, while preparation for reoperation is made if necessary.

The diagnosis is less obvious when only moderate hypotension occurs at this juncture. Culprits include partial cardiac herniation (loose or partially ruptured pericardial patch), tamponade (tight pericardial patch or retained pericardial effusion), inferior vena cava impingement (tight right diaphragmatic patch), hypovolemia, and deviated mediastinum, among others.

Reduced venous return is the common mechanistic denominator. A sluggish response to fluid boluses and vasopressors suggests that mechanical impediments to venous return should be ruled out before leaving the operating room. Aggressive bolus dosing of the epidural in anticipation of emergence may contribute to diagnostic confusion. A portable chest radiograph is usually helpful in ruling out partial cardiac herniation or guiding medialization of the mediastinum by withdrawal of air from the chest drain. TEE may assist in the diagnosis.

Table 36.4 Causes of hypotension during EPP

Common	Compression of the heart or great vessels by tumor or surgical pressure/retraction
	Blood loss/inadequate fluid resuscitation
	Thoracic epidural sympathetic blockade
Uncommon	Air-trapping (“auto-PEEP”)
	Tension pneumothorax
	Drugs (vasodilators/negative inotropes)
	Right heart dysfunction/failure
	Cardiac herniation
	Tight pericardial patch
	Shifted mediastinum following closure
	Myocardial ischemia
	Dysrhythmias
	Embolic events
	Transfusion reactions
	Drug reactions
	Sepsis

Fluid Management

Average estimated intraoperative blood loss during EPP in the best of surgical hands is approximately 0.5–1.5 L. Most of this occurs in a gradual, continuous fashion during the processes of blunt separation of the parietal pleura from the chest wall, although catastrophic bleeding can occur from major vessels during dissection of the hilum or at the apex. Monitoring of the extent of blood loss requires vigilance and communication with the surgeons.

Antifibrinolytics have not been shown to reduce packed red blood cell requirements in EPP surgery [30]. As with any pneumonectomy, excessive crystalloid is to be avoided as it may exacerbate the pulmonary edema of post-lung resection acute lung injury. Fluid management thus becomes a balancing act in the setting of significant hemodynamic swings with intermittently moderate-to-major episodes of blood loss. This balance shifts in favor of more liberal fluid administration in patients receiving IOHC, out of concern for nephrotoxicity.

Central venous pressure measurements, PA occlusion pressures, or observance of respiratory variation on arterial line tracings may be unreliable indicators of intravascular volume during manipulation of weighty tumors, with the chest open to atmosphere. Attention to the surgical field (including the fullness of the heart), urine output, blood gas and hematocrit results, and occasionally TEE are helpful guides.

Postpneumonectomy Pulmonary Edema (PPE)

An emphasis is made on discriminating between hypovolemia and impairments of venous return out of concerns that unnecessary volume resuscitation may contribute to PPE. Pulmonary edema of the remaining lung following pneumonectomy occurs in 2–4% of patients and carries mortality in excess of 50% [31]. The incidence in EPP may be as high as 5–8% [32, 33], which may be in part due to the greater fluid shifts associated with EPP. It is apparent that in the presence of the increased pulmonary capillary permeability in acute lung injury, unnecessary crystalloid or colloid administration will exacerbate the degree of edema and hypoxemia. This is the basis for the widely adhered to practice of conservative (restrictive) fluid management for pneumonectomy patients [21] and highlights the importance of close attention to the matching of fluid administration to blood loss in EPP patients.

Cardiovascular Considerations

Dysrhythmias

The incidence of supraventricular dysrhythmias (SVD) after EPP is higher (21–44%) [4, 5, 7, 32, 34, 35] than for standard pneumonectomy (13–20%) [35, 36]. Thoracic epidural blockade with bupivacaine has been shown to reduce the incidence of perioperative SVD compared to equianalgesic epidural narcotics [26], and there is increasing evidence that medical prophylaxis (amiodarone, beta-blockers, magnesium and calcium channel blockers) is effective in preventing postoperative atrial fibrillation after general thoracic surgery [37]. Although there may be currently inadequate evidence to recommend routine prophylaxis against AF for all patients undergoing lung surgery, it is reasonable to administer diltiazem to those patients with preserved cardiac function not taking beta-blockers preoperatively in intermediate to high-risk patients [37].

It is uncommon for routine prophylaxis against SVD for EPP but important to avoid withdrawal of beta-adrenergic blocking drugs, if they are in use. Intraoperative dysrhythmias are generally triggered by mechanical irritation and do not appear to predict postoperative SVD. EKG leads should be attached to a ready defibrillator to provide the capability of synchronized electrical cardioversion intraoperatively.

Myocardial Ischemia

Myocardial ischemia may be difficult to detect during EPP as alterations in the position of the heart relative to the surface EKG lead positions would be expected to alter their sensitivity. During left-sided thoracotomies, it is not practical to monitor lead V-5. When myocardial ischemia is suspected, TEE should be employed.

Dramatic ST segment elevations may occur during the wash phase. These tend to occur with irrigation, correct promptly with cessation, and are not associated with other hemodynamic alterations suggestive of myocardial ischemia (Fig. 36.5), most likely representing nonischemic electrophysiologic changes related to focal myocardial warming or surface electrolyte changes [38]. No treatment is necessary unless they persist, produce hemodynamic instability, or are confirmed to be associated with wall motion abnormalities by TEE.

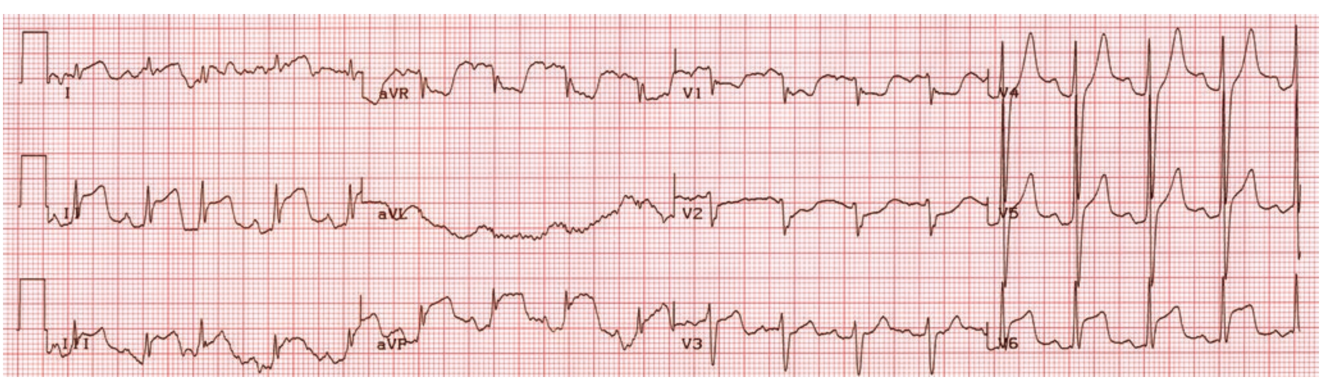

Fig. 36.5 The EKG obtained during wash phase with warm water, following removal of the specimen (including pericardium). Concurrent TEE revealed no global or regional wall motion abnormalities. The EKG rapidly normalized following termination of irrigation

Perioperative Pain Management

There is increasing evidence that TEA with local anesthetics and opioids is superior in the control of dynamic pain, plays a key role in early extubation and mobilization, reduces postoperative pulmonary complications, and has the potential to decrease the incidence of post-thoracotomy pain syndrome. For EPP, although a bolus dose of local anesthetic may be administered prior to surgical incision, the risk of hemodynamic instability usually precludes continuous intraoperative dense neuraxial blockade. Nonetheless, it is vital to aggressively control acute postoperative pain [39, 40].

Preexisting pain related to mesothelioma is not uncommon and frequently treated with opioids. Tolerance may occur after 1–2 weeks of treatment, and such patients present a challenge in terms of postoperative pain control and physiologic withdrawal. Patients on chronic opioids presenting for EPP would generally receive an opioid-free epidural infusion, with additional patient-controlled systemic opioids prescribed to minimize the occurrence of withdrawal. Ketamine may be a useful adjunct [41].

Early Postoperative Considerations

Depending on center experience, majority of patients may be weaned and extubated in the operating room. This minimizes duration of positive pressure on the bronchial stump and avoids the potential problems of ventilator-associated alveolar barotrauma and infection. Prudence is advised in difficult or complicated EPP with increased transfusion requirement or excessive fluid administration in the IOHC cases.

Management of the Ipsilateral Thoracic Space

In addition to the potential for cardiac herniation and its hemodynamic consequences (described earlier), rapid filling of the empty hemithorax with fluid, blood, or abdominal contents from a ruptured diaphragmatic patch can also compromise cardiorespiratory function. Air/fluid is removed from the chest drain at the end of surgery in an attempt to medialize the mediastinum. This is an imprecise process, and a chest radiograph is obtained on arrival in the ICU to assess mediastinal position. Intrathoracic pressure monitoring may guide intermittent fluid evacuation of the pneumonectomy space [42]. This prevents rapid accumulation resulting in respiratory compromise while avoiding contralateral lung hyperexpansion, compromised venous return, and hypotension with excessive and/or rapid removal.

Other Issues Specific to EPP

- Patients who have undergone IOHC receive liberal fluids for the initial 24 h as part of the renal protection strategy (Table 36.1).
- Standard chest compression is ineffective in EPP patients because the mediastinum is dynamic and shifts to the empty hemithorax.

Conclusion

EPP is a radical and aggressive surgery, which presents a great challenge to the thoracic anesthesiologist. Besides standard anesthesia concepts for pneumonectomy, management involves an understanding of the technique of EPP, common intraoperative physiologic disruptions, and anticipated complications. Emerging multimodality treatments for MPM have additional anesthetic implications. One of those, IOHC, is discussed in the context of general EPP-specific anesthetic issues.

Clinical Case Discussion

Case

A 50 year-old male is scheduled for right extrapleural pneumonectomy. The diagnosis of mesothelioma was made on pleural biopsy, and he has completed six cycles of chemotherapy. He is a nonsmoker, and apart from well-controlled hypertension, he has no other significant comorbidities.

Questions

1. *Apart from routine preoperative assessment for pulmonary resection:*
   (a) Are any specialized cardiac and pulmonary function tests indicated?
   - Echocardiography commonly used to assess cardiac function.
   - Stress test only when history, examination, and echocardiography suggest significant cardiac disease.
   - FEV_1, DL_{CO}, and exercise capacity routinely assessed.
   - Ventilation/perfusion scans recommended if $FEV_1 < 2$ L.
   - Predicted postoperative $FEV_1 < 1$ L may preclude EPP.

   (b) What is the importance of radiologic investigations?
   - Surgical staging and tumor resectability.
   - Anesthetic implications include safe placement of epidural catheters at the thoracic region, level of intravenous access, quantity of blood and blood products available, and the potential necessity for cardiopulmonary bypass during resection.

Table 36.5 Hypotension during critical phases of surgery

Phase	Mechanism(s)	Management strategy
Induction	Reduced venous return Vasodilation (induction agents, epidural) Exacerbation of tumor compressive effects by the decrease in FRC Loss of "thoracic pump" of spontaneous ventilation Positive pressure ventilation	Preemptive vasoconstricting agents and judicious selection of induction agents/doses are particularly indicated for patients with large tumor burdens, large effusions, or radiographic evidence of cardiac or major vessel impingement
Dissection	Blood loss Insensible losses Variable degrees of compression from the tumor, retractors, and blunt dissection pressure	Communication with the surgeon is paramount Judicious use of vasopressors A low threshold for administration of blood and products when appropriate
Repositioning and emergence	Circulatory arrest Herniation of the heart (particularly with right EPP), with torsion of the SVC and IVC Moderate hypotension Partial cardiac herniation (loose or partially ruptured pericardial patch) Tamponade (tight pericardial patch) Hypovolemia Deviated mediastinum Aggressive bolus dosing of the epidural in anticipation of emergence	Immediate return to the lateral position A sluggish response to fluid boluses and vasopressors suggests that mechanical impediments to venous return should be ruled out A portable chest radiograph is usually helpful in ruling out partial cardiac herniation or guiding medialization of the mediastinum

2. *How is an extrapleural pneumonectomy different from pneumonectomy?*
   - See Table 36.3.
3. *What are the common causes of hypotension and the management strategies?* (Table 36.5)
4. *How would the application of intraoperative intracavitary heated chemotherapy affect the anesthetic management?*
   - Renal protective strategies should be employed (Table 36.1).
   - Restrictive physiology exhibited by EPP patients during one-lung ventilation is exacerbated by the weight of the perfusate, and positive end-expiratory pressure is especially important to prevent atelectasis.
   - Fluid management is delicate balance between renal protection and the potential for exacerbation of acute lung injury in fluid overload.

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