Extra-pleural pneumonectomy: How I teach it

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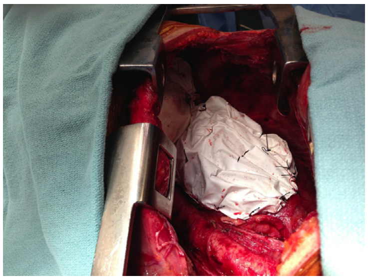

Reconstructed diaphragm after extrapleural pneumonectomy for mesothelioma.

CENTRAL MESSAGE

Extrapleural pneumonectomy is an option for some patients with mesothelioma as part of a multimodality treatment plan with the hope of long-term remission.

Video clip is available online.

Extrapleural pneumonectomy (EPP) is a complex procedure used to treat malignant pleural mesothelioma (MPM). Despite advances in therapy, MPM continues to have a very poor prognosis. Currently, nonsurgical management with combinations of chemotherapy and immunotherapy provide overall survival of about 18 months.[1,2] EPP is the most extensive surgical option for MPM, involving the en bloc resection of the lung, parietal and visceral pleura, diaphragm, and pericardium, and is commonly used as a component of multimodal therapy to provide an aggressive treatment option with the hope of long-term remission. Although EPP is perceived as a high-risk intervention, it presents with a potential for optimal macroscopic complete resection and can be done with limited risk in expert centers. MPM is an increasing health issue worldwide, with thousands of new cases documented each year. The incidence of this disease is steadily increasing and will likely continue to increase over the next century as asbestos exposure manifests.[3] The rising incidence of MPM calls for EPP-trained surgeons around the world. The purpose of this article is to report our technique of EPP.

PREOPERATIVE EVALUATION/PATIENT SELECTION

Preoperative evaluation of a patient who may be a candidate for EPP is extensive due to the nature of the surgery proposed. Thorough staging workup and physiologic investigations should be performed before EPP (Table 1). Our selection process for Surgery for Mesothelioma After Radiotherapy (SMART) is guided by the histologic type of mesothelioma, staging, local extent of disease, and physiologic workup.

Patients are staged with a computed tomography (CT) scan of the chest, abdomen and pelvis, and positron-emission tomography-CT scan. Mediastinal and hilar lymph node staging is then performed with endobronchial ultrasound for patients with clinically positive nodes on CT scan or positron-emission tomography-CT scan or with bulky disease. All imaging is performed within 6 weeks of the start of radiation. Opioid-dependent chest pain is a worrisome sign for the ability to perform an EPP due to chest wall invasion and is generally a contraindication to SMART, particularly in the context of biphasic disease. All of our patients have *BRCA-1* associated protein 1 loss tested by immunohistochemistry and p16 homozygous deletion tested by fluorescence in situ hybridization because we are investigating the value of these genetic alterations to determine the response to radiation. *BRCA-1* associated protein 1 loss and p16 homozygous deletion positivity are also helpful to confirm the diagnosis of mesothelioma.[4]

The feasibility of EPP is then decided based on the CT scan. All intrathoracic structures are reviewed in detail to ensure that the tumor will be fully resectable. The overall bulk of disease is also assessed because it has been found that total tumor thickness is a good correlate to tumor volume and an independent predictor of survival.[5] Local chest wall invasion is not necessarily a contraindication to SMART because the chest wall can be resected en bloc with the EPP specimen.

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TABLE 1. Preoperative investigations

Staging	Physiologic testing
CT Scan of the chest, abdomen, and pelvis	History of chest wall pain
PET-CT	Echocardiography
Brain MRI	Exercise study (history of coronary disease or angina)
Invasive mediastinal staging with EBUS for hilar and mediastinal node biopsy	
Biopsy of tumor	
p16 and BAP-1 testing	

CT, Computed tomography; *PET-CT*, positron emission tomography-computed tomography; *MRI*, magnetic resonance imaging; *EBUS*, endobronchial ultrasound; *BAP-1*, *BRCA-1* associated protein 1.

Cardiac workup is performed for all patients being considered for EPP. Echocardiography is always done to rule out pulmonary hypertension, left ventricular dysfunction, and valvular abnormalities. The echocardiogram also allows us to rule out pericardial effusion and intrapericardial extension of the tumor. We also perform an exercise study in patients who have an abnormal echocardiogram or a history of coronary artery disease or angina.

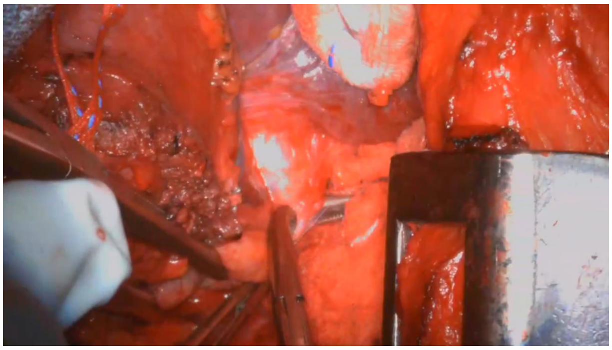
SMART PROTOCOL

The SMART protocol includes a short course of hypofractionated radiation (25-30 Gy) delivered in 5 daily fractions over 1 week followed by surgery a week later. The short time frame between radiation and surgery was chosen to limit the risk of radiation-induced pneumonitis. The goal of the radiation is to sterilize the tumor edges and prevent seeding to the peritoneal, pericardial, and contralateral pleural cavities.

The short duration of the SMART treatment provides benefit in patients traveling long distances. We currently have treated more than 120 patients with this protocol. The 30- and 90- day mortality rates were 0.9% and 3.6%, respectively, with a median survival of 42.8 months for patients with epithelioid mesothelioma.[6]

HOW I TEACH IT

EPP is performed on average 5 days after the end of radiation (range, 2-12 days).[6] The patient is first placed in a lateral decubitus and a posterolateral incision is performed (Video 1). The latissimus muscle is transected and the serratus anterior is preserved. The sixth rib is removed to facilitate access to the extrapleural plane. The periosteum is first incised along the sixth rib with cautery. The periosteum is then elevated and preserved to facilitate closure at the end of the surgery. It is important to note that resection of the fifth rib provides better access to the apex of the pleural cavity and is selected when difficult dissection around the thoracic inlet is anticipated.



VIDEO 1. Extrapleural pneumonectomy. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00267-0/fulltext.

After the rib is cleared and sectioned, the intercostal muscles are separated from the parietal pleura and the extrapleural plane is exposed. The pleura is taken down the chest wall toward the spine and the apex of the chest. Dental pledget and Yankauer suction are used for the dissection to bluntly dissect, suction, and facilitate exposure of the reflection line. The pleura is further taken down to the azygos vein on the right side, or the aorta on the left side. The azygos vein is then sharply dissected and its junction with the superior vena cava (SVC) dissected. The phrenic nerve is clipped and divided. The esophagus is then identified and the tumor is sharply dissected off of the esophagus. A nastogastric tube is used to facilitate the localization of the esophagus. The dissection is extended anteriorly to the internal thoracic vessels, which are preserved if possible. The thoracic vessels are then dissected toward the apex of the chest.

Once the hilum is free, the pericardium is exposed anteriorly and opened anterior to the SVC with sharp dissection. This allows a complete resection of the involved ipsilateral pericardium. The pericardial division is continued up to the reflection on the SVC superiorly and inferiorly to the diaphragm, taking care to have adequate margin. The pericardial fat pad is removed with the tumor to expose the diaphragm.

The hilar vessels are dissected for later division after the diaphragm is resected. The superior pulmonary vein is then dissected intrapericardially and an umbilical tape is placed to aid with future division of the vein. The pulmonary artery is dissected and encircled proximally.

The posterior pericardium is then opened behind the inferior pulmonary vein. On the right side, the pericardial reflection between the inferior pulmonary vein and the inferior vena cava (IVC) is then dissected inside the pericardium to free the posterior pericardium. The inferior pulmonary vein is encircled intrapericardially and an umbilical tape is placed.

We then perform a second thoracotomy in the eighth intercostal space to provide the exposure necessary to fully resect the hemidiaphragm, especially posteriorly along the chest wall and in the area of the ipsilateral crus. The lower thoracotomy also allows improved visualization for sharp dissection of the diaphragm along the IVC on the right side and the esophagus on the left side. The anterior part of the diaphragm muscle is divided with cautery at the insertion sites with the chest wall after reflecting the tumor and pleura away. The peritoneum is also opened and the abdominal organs are exposed. The diaphragm is retracted with a long Kocher to aid with exposure.

On the right side, the hepatic ligaments are divided to free the diaphragm from the liver. The diaphragm is fully resected to the hepative veins. The diaphragmatic vessels are ligated or clipped during this part of the dissection, taking care to identify all small vessels because these veins drain directly into the infradiaphragmatic IVC. The IVC is then sharply dissected, taking care to avoid injury to the hepatic veins, and the phrenic veins ligated. These veins are variable in number and position and can easily be torn.

The diaphragm is then freed from its IVC attachment and attention is again turned to the anterior dissection. The junction of the pericardium and diaphragm is divided, taking care to leave enough length on the pericardium for reconstruction. The pericardium and the diaphragm are then dissected toward the IVC away from the tumor.

After the diaphragm is fully resected, the pneumonectomy is performed. The veins and artery are divided with vascular staplers. The bronchus is then dissected. The bronchial arteries are ligated and the bronchus is sharply dissected to preserve the vascularization of the stump. The main bronchus is encircled and divided with a TA-30 (Medtronic) green stapler load after checking bronchoscopically to ensure an adequately short stump of about 1 cm. The thoracic-abdominal stapler is used because it provides the best angle for the bronchial stump. The bronchus is divided and the lung, pleura, diaphragm, and pericardium are removed en bloc. We do not routinely ligate the thoracic duct on the right side. The cavity is irrigated with water and hemostasis is ensured.

The diaphragm is then reconstructed using 2 1-mm expanded polytetrafluoroethylene meshes, stapled together in the middle to allow adequate length for the diaphragm. Interrupted double-armed 2-0 Prolene sutures are used at 3- to 4-cm intervals to attach the mesh circumferentially. The sutures are placed on the pericardium medially from superior to inferior and through the cartilage anteriorly by taking bites with each needle from superior to inferior. Next, along the ninth interspace laterally each needle of the double-armed suture is used to take a bite from external to internal. Posteriorly, at least 1 stitch is placed through the periosteum of the vertebral body to anchor the mesh. A number of sutures are placed with the mesh extracorporeally to allow for adequate visualization. The mesh is then brought into the chest and the remaining sutures are placed along the edges of the mesh, taking care to ensure that the mesh is taught with no large gaps. Care is taken to avoid impingement on the IVC on the right side and the esophagus and aorta on the left side. It is important to make sure that the mesh is very loose around the IVC to avoid any constriction.

Next, the bronchial stump is covered with the posterior pericardium. The posterior pericardium is dissected off of the pulmonary artery and the superior pulmonary vein along the oblique sinus on the right side to gain some length. Coverage of the stump is then performed by suturing the pericardium to the vagus nerve and surrounding tissue behind the bronchial stump using interrupted 4-0 polydioxanone sutures.[7] In our experience, the posterior pericardium could be used to cover the bronchial stump more than 90% of the time. The stitches are progressively tied.

Finally, the pericardium on the right side is reconstructed with 0.1-mm expanded polytetrafluoroethylene mesh using interrupted 2-0 silk sutures. The pericardium on the left is not reconstructed due to negligible risk of cardiac herniation, and a higher risk of creating restrictive pericarditis due to the extent of the pericardial resection on the left side. The sutures are placed every 1 cm on the pericardium and 1.5 cm on the mesh to allow adequate space around the heart. It is vital that the mesh is kept very loose to avoid any constriction postoperatively. Once secured, several incisions are made in the pericardial mesh to avoid postoperative tamponade.

After ensuring hemostasis, a single 28 Fr curved chest tube is placed and loosely secured to the diaphragm with a 5-0 Prolene suture to prevent movement of the tube. The chest is then closed starting with the inferior thoracotomy using number 2 Vicryl figure-of-8 sutures. Number 2 Vicryl figure-of-8 pericostal sutures are then placed around the fifth and seventh ribs. Before tying these sutures, a rib approximator is used to bring the ribs together and 2-0 silk is used to close the intercostal muscles in a running fashion. The pericostal sutures are then tied down. The closure must be watertight to avoid any chest wall seroma, which presents a risk of wound infection or dehiscence particularly with the preoperative radiation.

The chest wall muscle layers are closed with number 2 Ticron, the subcuticular layer is then closed with 2-0 Ticron, and the skin with 4-0 Vicryl in a running fashion. Dressings are placed and the chest tube is connected to a pneumonectomy drainage system.

POSTOPERATIVE CARE

Postoperatively, patients are monitored in a step-down unit for 3 to 4 days after surgery. In the early postoperative period, judicious use of intravenous fluids is prescribed due to the large fluid shifts associated with the extensive dissection of this procedure. The chest tube remains in place for 3 to 4 days predominantly to observe the character of the output and monitor for bleeding. It is removed after the patient has fatty foods to ensure the absence of chyle leak. Prophylactic antibiotics are continued until the chest tube is removed. Although a nasogastric tube is frequently used intraoperatively to aid in identifying the esophagus, it is removed before the completion of the procedure. Patients remain without orally consumed food and fluid for the first 24 hours and then the diet is slowly advanced as bowel function returns. Blood work is tested twice daily for the first few days. Electrolytes are actively replaced to limit the risk of atrial fibrillation. Prophylactic anticoagulation therapy is started immediately postoperatively and maintained for 6 weeks after surgery as an outpatient after hospital discharge.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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