THORACOTOMY

Surgical Specialty:	Thoracic Anesthesia
Authors:	Jue Hou, MD, Alina Lazar, MD Ann & Robert Lurie Children's Hospital, Chicago, IL

Background:

- General Considerations
  - Surgical Indications[1-3]:
    - Congenital defects: congenital diaphragmatic hernia (CDH), tracheoesophageal fistula (TEF), esophageal atresia, congenital pulmonary airway malformations (CPAM), broncho-pulmonary sequestrations, congenital lobar emphysema (CLE), bronchogenic cysts, dermoid cysts.
    - Neoplastic or acquired conditions: tumors (lymphoma, teratoma, neuroblastoma, thymoma, mediastinal mass), infection (empyema, consolidated pneumonia/abscess), thoracic trauma.
    - Cardiac procedures: ligation of ductus arteriosus, repair of aortic coarctation, modified Blalock-Tausig shunt, vascular ring resection. In small infants, two-lung ventilation with lung retraction on the operative site is typically used, while in older kids, one-lung ventilation (OLV) is preferred for improved exposure.
    - Video-assisted thoracoscopic procedures converted to open thoracotomies
    - The incision is usually posterolateral, through the 4th or 5th intercostal space. A chest tube may be placed below the thoracotomy incision.
  - Muscle-sparing techniques and an axillary approach improve early postoperative lung function, reduce requirements for pain medications, and minimize the risk of chest wall deformities.
  - Perioperative analgesia is essential to ensure optimal postoperative respiratory mechanics.
- Patient Considerations
  - Infants and young children have a higher risk of hypoxemia and hypercarbia than older children and adults during thoracotomy for several reasons:
    - As a result of immature hypoxic pulmonary vasoconstriction, the smaller hydrostatic gradient between the lungs, and increased chest wall compliance causing compression of the dependent lung, there is a more equal distribution of blood flow to both the dependent and non-dependent (deflated) lung, which leads to shunting.[1,2].
    - Airway closure in the dependent lung and atelectasis are more likely to occur because functional residual capacity is reduced and closer to residual volume until 6-8 years of age.[2,3]

        - Metabolic rate and O_2 consumption are higher.
        - Smaller, more compressible lungs are more difficult to adequately ventilate in the lateral decubitus position.
    - Hypoxia, hypercarbia, hypothermia, acidosis, and increased intrathoracic pressure can cause increased pulmonary vascular resistance and cardiopulmonary compromise.
- Disease-related Considerations
    - Anterior mediastinal mass: Risk of cardiovascular compromise and complete airway obstruction.
    - Infection/empyema: Lung isolation is crucial to protect the less affected side; regional anesthesia may be contraindicated.
    - TEF and CDH: Gastric distension and herniated abdominal organs can cause significant respiratory complications.
    - CLE and CPAM: Risk of progressive pulmonary distention with positive pressure ventilation.
    - CDH:
        - Neonates require lower peak pressures with permissive hypercapnia to prevent pneumothorax; high-frequency oscillatory ventilation or even extracorporeal membrane oxygenation (ECMO) are needed in severe cases.
        - Pulmonary hypoplasia is often present, most severely in the lung ipsilateral to hernia.
        - In severe pulmonary hypertension, prostaglandin E1 is used to maintain the patency of the ductus arteriosus. Inhaled nitric oxide and vasoactive medications may be necessary.[2,3]
        - Abdominal closure may cause respiratory and hemodynamic compromise – a temporary closure may be required.
- Associated Comorbidities may include:
    - Pulmonary hypertension (neonates, CDH)
    - Congenital cardiac abnormalities (in CLE, TEF)

Anesthetic Planning:

- Pre-Anesthetic Evaluation
    - Identify associated congenital anomalies
    - Imaging
        - An echocardiogram may be required to rule out congenital heart disease, or cardiac impairment from large lung or mediastinal masses.
        - Chest computed tomography (CT) if indicated to evaluate the extent of airway compromise.
        - Chest X-Ray
    - Assess cardiopulmonary status and pulmonary reserve.
        - Exercise tolerance, dyspnea, baseline saturation/oxygen requirements
    - Discussions to have with surgeon/family
        - Need for OLV
        - Need to preserve spontaneous ventilation during certain portions of the procedure (e.g., CLE, TEF)
        - Anticipated need for blood transfusion
        - Postoperative analgesia, including regional analgesia
        - Postoperative need for ventilatory support

        - Patient disposition
        - Need for ECMO in severe pulmonary hypertension or large mediastinal mass
- Specific or Unique Room Set-Up Requirements
    - Airway/ventilation
        - Open thoracic surgery can be performed with a conventional endotracheal tube (ETT) in the trachea, and the operated lung collapsed by the surgeon with swabs and retractors to expose the lesion.
        - If lung isolation is selected, it is typically accomplished via selective mainstem intubation, placement of a bronchial blocker, or a double-lumen tube (DLT) (in children older than 8-10 years of age).[1,2]
            - A detailed discussion of lung isolation methods and device sizes is beyond the scope of this guide.
                - A Single-Lung Ventilation SPA Case Guide is under development at the time of this publication.
        - A flexible bronchoscope should be available to confirm airway device placement (if OLV is needed) and to troubleshoot ventilation/ oxygenation problems.
        - An ICU ventilator or high-frequency ventilatory methods may be considered electively or as rescue modes for patients with tenuous physiology (e.g., CDH)
    - Drugs/Infusion:
        - Standard
        - Vasopressor/resuscitation drugs as indicated
    - Monitors
        - Standard American Society of Anesthesiologists monitors
        - Arterial catheterization is indicated due to hemodynamic changes during lung manipulation, risk of blood loss, and monitoring of arterial blood gases during single-lung ventilation.
        - Consider central venous access (preferably on the ipsilateral side of the thoracotomy where a pneumothorax will surgically occur) for inadequate peripheral IV access and anticipated need for vasopressors.
        - $EtCO_2$ may be unreliable:
            - $EtCO_2$ can be lower than arterial CO_2 during OLV
            - Difficult to capture in uncuffed ETT, high-frequency oscillation, ECMO, non-anesthesia ventilator (e.g., Hamilton)
    - Intravenous access: 2 peripheral intravenous (IV) catheters (at least one large-bore IV), transfusion equipment (including blood warmer) readily available.
    - Blood Availability
        - Blood loss is usually minimal for most thoracic surgery, but given the proximity of the great vessels, it may occur suddenly.
        - Cross-matched blood should be readily available.
    - NICU/PICU Bed Availability
        - Indicated for postoperative ventilatory support or hemodynamic instability.
        - Neonates/infants usually require post-operative mechanical ventilation in the NICU after repair of CDH, TEF, and cardiac procedures due to decreased lung compliance and/or hemodynamic instability.[2,3]
    - Other Indicated Resources
        - ECMO in select cases (e.g., CDH, anterior mediastinal mass)

Intraoperative Considerations:

- General
    - Avoid heat loss/maintain normothermia
        - Warming mattress, radiant heat, increased ambient temperature, fluid warmer
- Surgical Considerations
    - Adequate muscle relaxation
    - Close communication between surgery and anesthesia teams regarding acute changes in hemodynamics, respiratory/ventilatory status, and adequate lung isolation.
    - A Valsalva maneuver is typically required to test the bronchial stump after lung resection.
    - The surgeon may request a brief period of sustained lung inflation to facilitate pneumothorax evacuation before finalizing chest closure if a chest tube is not inserted.
    - Recruitment breaths as needed to reduce atelectasis in the ventilated lung during OLV, and to re-recruit the operative lung at the end of surgery.
    - For TEF, bronchoscopy is often performed by the surgeon to identify the location of the fistula and to guide the placement of the ETT tip below the fistula, if possible. If the stomach is overdistended and is severely compromising ventilation and hemodynamic stability, a direct surgical gastric drain may be placed for decompression. Spontaneous ventilation may be beneficial during this portion of the procedure.
- Induction/Intubation
    - Inhalational or IV induction
    - Maintaining spontaneous ventilation during induction and intubation may be beneficial in some cases of TEF, mediastinal masses, and some congenital thoracic malformations.
    - Achieve OLV if indicated, and confirm airway device placement (fiberoptic or fluoroscopy).
- Positioning
    - Typically, lateral decubitus positioning with an axillary roll. Check pressure point and head/face padding and avoid nerve compression.
    - Recheck ETT/bronchial blocker/DLT placement after positioning (especially in OLV).
- Maintenance of Anesthesia:
    - Balanced anesthetic technique with inhaled and intravenous agents.
        - Inhaled anesthetics attenuate hypoxic pulmonary vasoconstriction.
        - IV opioids and regional anesthesia may reduce this effect by decreasing the amount of inhaled anesthetic required.
        - Minimize additional factors that decrease hypoxic pulmonary vasoconstriction[2,3]:
            - Vasodilators,
            - Alkalosis (metabolic and respiratory)
            - Hypothermia.
- Ventilation Management:
    - Lung protective strategies are recommended[5]: peak airway pressures optimally <25 cm H_2O in young children, tidal volumes of 4-7 mL/kg, positive end-expiratory pressure (PEEP) >4 cm H_2O; higher respiratory rates may be needed to compensate for lower tidal volumes, especially if OLV is used.
        - Large tidal volumes can increase shunting to the non-dependent lung.
        - Small tidal volumes increase the risk of atelectasis.

    - A higher FiO_2 may be needed to improve hypoxia caused by shunting and atelectasis.
        - However, very high concentrations of oxygen may cause oxidative injury to tissues and absorption atelectasis.
    - Permissive hypercarbia ($PaCO_2$ 50-70mmHg) is generally well tolerated.
- Hemodynamic/fluid management
    - Maintain intravascular volume and appropriate hemoglobin levels for oxygen-carrying capacity.
    - Avoid excessive fluid administration.
- Analgesia
    - Multimodal approach: at the minimum, IV opioids, acetaminophen, non-steroidal anti-inflammatory drugs (NSAIDs) (if no contraindications)
    - Ketamine or dexmedetomidine infusions and gabapentinoids may be considered in patients with preexisting chronic pain or opioid intolerance.
    - Regional anesthesia:[1,2]
        - Thoracic epidural (direct or caudal insertion) catheter
        - Paravertebral nerve block/catheters have a decreased incidence of hypotension, nausea, and vomiting compared to epidurals.[1,2]
        - Erector spinae nerve block (single shot or catheter)
        - Single shot caudal epidural with local anesthetic and/or morphine/hydromorphone
    - Intercostal nerve blocks or cryoablation by the surgeon are alternatives to regional analgesia
- Postoperative nausea and vomiting (PONV) Prophylaxis
    - Ondansetron: 0.1-0.15mg/kg q6hr (max 4mg), dexamethasone: 0.1mg/kg (max 8mg), judicious IV fluid hydration
    - For patients with a history of or high risk of PONV: may add a scopolamine patch and/or low-dose intraoperative IV propofol infusion
- Emergence/Disposition
    - Emergence Delirium Prophylaxis
        - Dexmedetomidine, propofol
        - Adequate thoracotomy pain control
        - Preoperative teaching regarding recovery/postoperative expectations
    - Uncomplicated cases are extubated and observed overnight on the floor, at minimum.
    - NICU/PICU is indicated for patients with respiratory compromise or who need postoperative respiratory or hemodynamic support.

- Post-op Care
    - Adequate analgesia without oversedation/respiratory depression can be challenging to maintain – multimodal analgesia is essential.
    - Inadequate pain control can lead to increased oxygen consumption, increased heart rate/blood pressure, splinting, poor cough efforts, and atelectasis/de-recruitment.
    - Post-thoracotomy pain syndrome may occur in 20% of children.[3]

Case-Specific Complications/Pitfalls

- Hypoxia:
    - Gradual intraoperative hypoxia may occur at the beginning of the procedure until hypoxic pulmonary vasoconstriction limits the flow to the deflated lung.
    - In addition to the obligatory shunting in the operative lung, atelectasis is the most common cause of hypoxia during the maintenance phase. It can be addressed by increasing the FiO2, and gentle re-recruitment of the dependent lung. PEEP (4-5 cm H2O) can be added to the dependent lung. If these measures are not effective, continuous posiive airway pressure (CPAP) to the non-dependent lung may be considered. Changes in the lung isolation and airway device position should be ruled out (fiberoptic or fluoroscopy). A temporary return to two-lung ventilation may be required in some cases.[4,5]
    - Acute hypoxia and increased airway pressure during OLV may signal complete airway obstruction by intrabronchial cuff migration above the carina. In this case, the cuff position should be deflated and the device repositioned.
    - Serosanguinous secretions from the operative lung or even blood clots may partially or completely obstruct the airway, particularly towards the end of surgery or when the patient is returned to the supine position. Bronchial lavage and suctioning the ETT typically relieve the obstruction, but in some cases, an ETT is dynamically obstructed via a ball-valve mechanism by a mucous plug or blood clot, in which case the ETT needs to be replaced to restore airway patency.
    - Bronchospasm may cause hypoxemia – treat with bronchodilators and steroids.
    - Postoperative hypoxia may occur as a consequence of atelectasis, de-recruitment, bronchospasm, pneumothorax, or pain-induced splinting.
- Hypotension may occur as a result of:
    - Compression or kinking of large blood vessels or mediastinum during surgical manipulation
    - Blood loss, hypovolemia (eg. especially if a large open procedure like CDH)
    - Pneumothorax due to aggressive ventilation (e.g., during CDH, bronchospasm) – consider chest tube placement for suspected pneumothorax in acute decompensation
    - Lung hyperinflation from positive pressure ventilation in certain cystic lesions (e.g., CLE)
    - Anterior mediastinal mass causing compression on the heart and great vessels.

References

1. Semmelmann A, Kaltofen H, Loop T. Anesthesia of thoracic surgery in children. Pediatr Anesth. 2018;28:326–331. PubMed Link
2. Hammer, GB. Anesthesia for thoracic surgery. In: Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 6th ed. Philadelphia, PA; Elsevier; 2019: 340-354
3. Rodriguez-Diaz, C. Anesthesia for pediatric thoracic surgery. In: Cohen E, ed. *Cohen's Comprehensive Thoracic Anesthesia*. Philadelphia, PA; Elsevier; 2021: 318-327
4. Templeton TW, Piccioni F, Chatterjee D. An Update on One-Lung Ventilation in Children. Anesth Analg. 2021:132(5):1389-1399. PubMed Link
5. Templeton TW, Miller SA, Lee LK, Kheterpal S, Mathis MR, Goenaga-Díaz EJ, Templeton LB, Saha AK. Hypoxemia in young children undergoing one-lung ventilation: a retrospective cohort study. Anesthesiology. 2021;135(5):842-853. PubMed Link

---

Created: 8/6/22; Last Revised: 6/26/23

Reviewed by:

Reviewer #1: Jennifer Lau, M.D., Children's Hospital- Los Angelas

Reviewer #2: Destiny Chau, M.D., Arkansas Children's Hospital

Reviewer #3: Bridget K. Pearce, M.D., University of Michigan