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# Ultrasound-Guided Recruitment Maneuver versus Individualized Positive End Expiratory Pressure in Pediatric Patients Undergoing Laparoscopic Abdominal Surgery: Review Article

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## ABSTRACT
**Background:** Atelectasis is a prevalent postoperative complication, particularly in children due to their unique respiratory physiology and increased susceptibility to hypoxemia. Ultrasound-guided recruitment maneuver (US-RMs) and individualized positive end-expiratory pressure (PEEP) strategies were assessed for their impact on oxygenation, respiratory mechanics, and the prevention of postoperative respiratory complications (PRCs). Ultrasound offers a non-invasive, radiation-free method to guide these interventions, providing real-time imaging of lung dynamics. Key findings indicate that US-RMs effectively reopen collapsed alveoli and enhance respiratory compliance, while individualized PEEP minimizes ventilator-induced lung injury by optimizing transpulmonary pressure. Both techniques demonstrate significant reductions in PRCs, though their efficacy depends on precise monitoring and titration tailored to patient-specific factors. The study emphasized the critical role of lung-protective strategies in pediatric anesthesia, highlighting the potential of ultrasound to refine respiratory management in this vulnerable population.
**Objective:** This article aimed to highlight the effect of ultrasound-guided recruitment maneuvers against individualized PEEP on oxygenation and the prevention of respiratory complications in kids having laparoscopic abdominal operations.
**Methods:** We searched PubMed, Google Scholar, and Science Direct for Pediatric anesthesia**,** Lung ultrasound**,** Atelectasis management and Recruitment maneuvers. Only the most recent or thorough investigation, from 1995 to 2022, was taken into account. The writers evaluated relevant literature references as well. Documents written in languages other than English have been ignored. Papers that were not regarded as significant scientific research included dissertations, oral presentations, conference abstracts, and unpublished manuscripts were excluded.
**Conclusion:** Both individualized PEEP and US guided RM improved oxygenation and lung mechanics more than fixed PEEP with comparable hemodynamic profile and postoperative pulmonary complications**.**
**Keywords:** Pediatric anesthesia**,** Lung ultrasound**,** Atelectasis management**,** Recruitment maneuvers.

## INTRODUCTION
Atelectasis is one of the most prevalent postoperative pulmonary complications (PPCs) associated with general anesthesia, occurring in sixty-eight percent to one hundred percent of pediatric cases. Atelectasis prevents gas exchange, resulting in hypoxemia and various respiratory illnesses, including pneumonia and acute lung injury. Kids are susceptible to hypoxemia because of their reduced functional residual capacity and higher metabolic demands in comparison with adults [(1)].

Pneumoperitoneum is an additional risk factor for atelectasis prior to the operation. It raises the diaphragm and intra-abdominal pressure. As a consequence, the thoracic cavity is compressed, which decreases the efficient ventilation volume as well as raises the possibility of desaturation following extubation and lung complications following the operation [(2)].

To avoid atelectasis, the application of alveolar recruitment maneuver (RM) or a positive end-expiratory pressure (PEEP) has demonstrated beneficial outcomes**.** PEEP and RM reduce the frequency of anesthesia-induced atelectasis in kids.

The recruitment maneuver temporarily elevates airway pressure to open collapsed alveoli, while the use of PEEP assists in keeping the alveoli open [(3, 4)].

PEEP individualization during the operation, rather than a fixed PEEP may optimize respiratory mechanics prior to the operation**.** Lung ultrasound (US) is a radiation-free, noninvasive, reproducible, and convenient bedside imaging technique for assessing anesthesia-induced atelectasis in kids [(5, 6)].

This research aimed to compare the effect of ultrasound-guided recruitment maneuvers against individualized PEEP on oxygenation and the prevention of respiratory complications in kids having laparoscopic abdominal operations.

## PEDIATRIC RESPIRATORY PHYSIOLOGY
Significant variances in respiratory physiology among babies & adults clarify the increased susceptibility of the baby respiratory system to failure and decompensation. The primary assessment of breathing effectiveness is based on the effort required to breathe each tidal breath and the amount of gas exchange that occurs. Many factors make the baby's



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respiratory system less effective, and various counteractive mechanisms are present to compensate for the respiratory instability [7]. Unsurprisingly, young age is an important risk factor, raising the odds ratio of critical incidents in newborns under one year by a factor of four relative to older kids [8].

**DEVELOPMENTAL ASPECTS OF BREATHING CONTROL (Table 1):**

The stability of breathing is affected by the protective reflexes & immaturity of respiratory cycling. Immature respiratory control presents as apneas, occurring either as single events or in series known as periodic breathing, mainly regarded as a physiological phenomenon that will stabilize with maturity [9].

Breathing control is susceptible to perioperative disturbances in all cases receiving anesthesia, regardless of the anesthetic method utilized. Among kids, clinically relevant disturbances are more common among young kids [10].

The prevention and management of apnea following the operation in former preterm babies continues to be a subject of constant debate [11].

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**Table (1):** Possible implications of the developmental respiratory physiology for anesthesia in babies and toddlers [12]

| Physiological characteristics | Consequences for anesthesia in babies and toddlers |
|---|---|
| **Immaturity of breathing control & reflex control** | Take into account the probability of apnea postoperatively up to twelve hours post-intervention in neonates & premature babies (up to sixty post-conceptional weeks). |
| | Predict bradycardia and apnea from forceful face mask utilization in preterm born infants (TCR). |
| | Predict bradycardia and hypoxic respiratory depression. Predict a temporarily elevated possibility of laryngospasm in preschool-aged kids. |
| **Small anatomical dimensions of the laryngeal and tracheal airway** | Elevated risk of possible airway damage. |
| | Choice of laryngeal mask airways and endotracheal tubes based on size and age appropriateness. |
| | Higher susceptibility to upper airway obstruction following extubation. |
| **Elevated upper air way resistance and collapsibility** | Predict airway obstruction due to inadequate head position or inexpert execution of airway opening techniques throughout anesthesia. |
| | Predict more quick gastric inflation. |
| | Elevated probability of anesthetic complications with infections of the upper respiratory tract. |
| **Greater chest wall compliance** | Expecting quick lung de-recruitment and atelectasis during anesthesia, especially with neuromuscular blockade. |
| | Utilization of assisted ventilation and PEEP promptly following induction |
| **Reduced number of alveoli and lack of collateral ventilation** | Reduced respiratory reserve and elevated possibility for atelectasis. |
| | Take into account utilizing low FiO2 (≤ 0.8 throughout induction) to avoid absorption atelectasis development and pulmonary shunt. |
| **Elevated lower airway resistance and collapsibility** | Elevated possibility for anesthetic complications throughout infections of the lower respiratory tract. |
| | Elevated possibility for airway collapse throughout agitation. |
| | Predict less effect of inhaled bronchodilators specifically in babies. |
| **Higher metabolism** | Predict more quick oxygen desaturation with alveolar hypoventilation. |
| | Predict quicker hypercapnia because of elevated production of $CO_2$. |

**Perioperative lung collapse in pediatrics**

Pulmonary atelectasis frequently occurs in surgical cases, impairing gas exchange and respiratory mechanics, which may result in respiratory insufficiency and acute respiratory distress syndrome (ARDS), or pneumonia following the operation. The clinical presentation varies from the absence of sequelae to hypoxemia needing endotracheal intubation and ventilation (13).

**Risk factors: Patient-related risk factors:**

**Obesity:** Larger atelectatic areas in obese patients result from increased thoracic and abdominal adipose tissue compressive forces, leading to an elevated possibility of perioperative pulmonary atelectasis (14).

**Age:** Atelectasis area increases with age, peaking at 50 years, and decreases thereafter. Anesthesia-induced atelectasis is particularly significant in children under 3 years old (15).

**Diaphragmatic dysfunction:** Perioperative diaphragmatic dysfunction significantly raises atelectasis risk, with preoperative diaphragmatic thickening and reduced postoperative excursion associated with worse outcomes (15).

**Increased intra-abdominal pressure:** Conditions such as ileus, ascites, and tumors elevate pleural pressure, reducing transpulmonary pressure and promoting atelectasis, especially in the supine position (16).

**Surgery-related risk factors**

**Body position:** The supine position decreases functional residual capacity (FRC) by 27% compared to the sitting position, and the Trendelenburg position additionally compresses the dorso-caudal lung (17).

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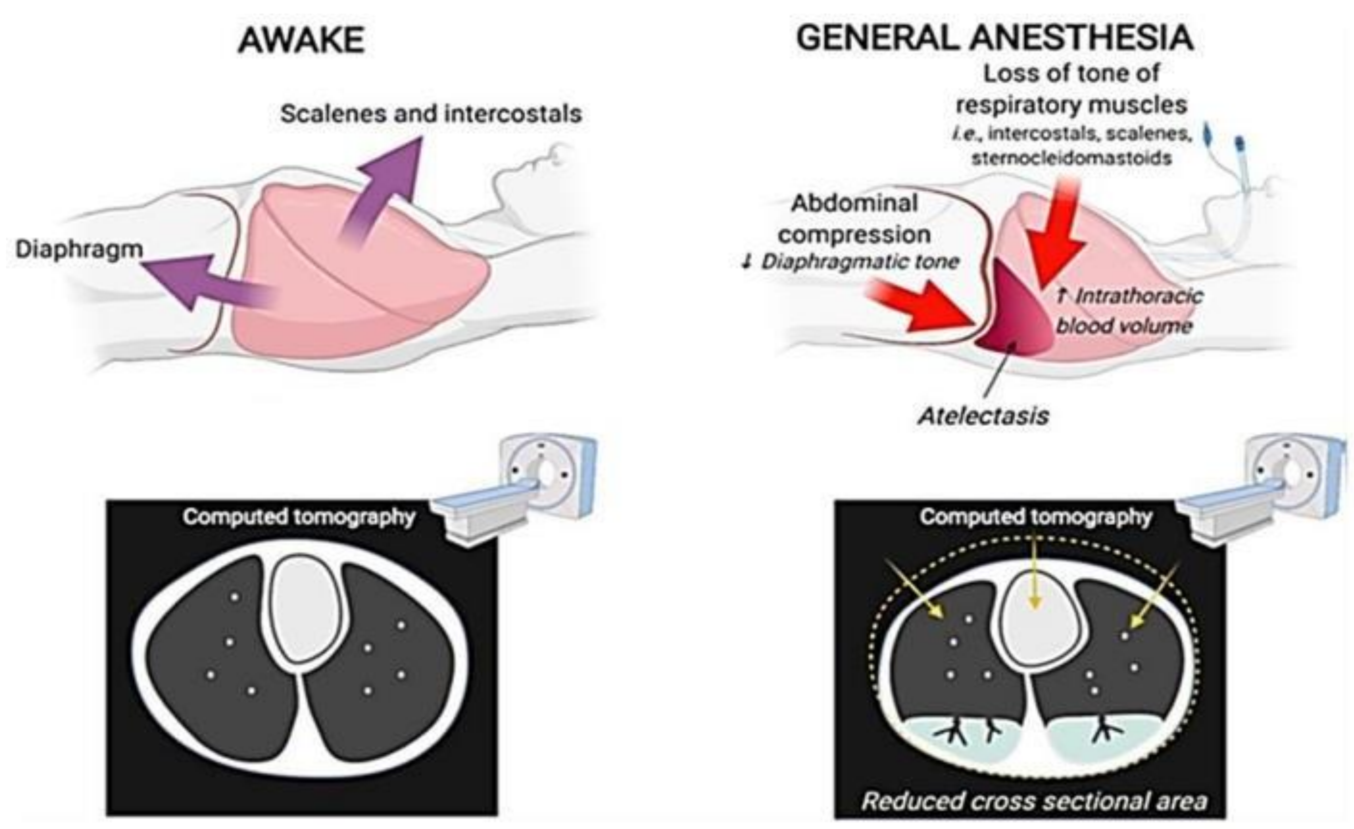


**Figure (1):** Effect of supine position. Throughout spontaneous breathing while awake, the contraction of the diaphragm and accessory respiratory muscles sustains the expansion of the lungs. Loss of muscular tone throughout anesthesia is related to cephalad movement of the dependent diaphragm, decreased cross-sectional chest area, and generation of nongravitational compressive forces (i.e., cephalocaudal gradients). In conjunction with gravity forces and a potential rise in intrathoracic blood volume, these factors can lead to a loss in lung volume and pulmonary collapse, especially in the dorsal and basal areas of the lungs (14).

**Prone positioning:** The prone position diminishes the gravity effect on the dependent lung mass, modifies the matching of chest and lung wall shapes, and alleviates lung compression from abdominal and cardiac structures. This leads to the spatial homogeneity of lung aeration and a reduced decline in regional strain and lung expansion over time, attributable to both non-gravitational and gravitational mechanisms [18].

**Lateral decubitus:** Atelectasis is predominantly in the dependent lung, resulting from compression through the weight of the mediastinum, nondependent lung, and abdominal organs, as identified using computed tomography in anesthetized cases [19].

**Pneumoperitoneum:** Pneumoperitoneum compresses juxta-diaphragmatic lung areas by raising the pressure inside the abdomen, promoting diaphragm dislocation. It reduces end-expiratory lung volume, respiratory compliance, and transpulmonary pressure, substantially increasing atelectasis volume in the dependent lung. Combination with steep Trendelenburg position, as in robotic operation, significantly heightens atelectasis risk and may need particular lung recruitment strategies [20].

**Surgery duration:** Pulmonary atelectasis appears within minutes after loss of consciousness during general anesthesia. Progressive collapse over prolonged anesthesia can exacerbate postoperative pulmonary complications, emphasizing the need to minimize duration and optimize ventilation strategies [21].

## LUNG PROTECTIVE STRATEGIES

**Postoperative respiratory complications (PRCs):** PRCs, including atelectasis, respiratory failure, pleural effusion, pneumothorax, infections, aspiration pneumonitis, and bronchospasm, occur in 11–59% of surgical patients and are related to worse outcomes. Intraoperative lung-protective ventilation (LPV) strategies, including low tidal volume (six to eight $mL \cdot kg^{-1}$ PBW), pulmonary recruitment maneuvers, and sufficient PEEP, reduce PRC risk by avoiding trauma and atelectrauma. During general anesthesia, collapsed and overdistended lung areas may coexist, potentially leading to tissue damage from mechanical stress and biomechanical processes [22].

### PRC-related factors in pediatrics

**Patient-related factors:** Pediatric patients are more susceptible to perioperative lung injury due to low functional residual capacity and high airway closure volume, resulting in a higher incidence of PRCs compared to adults [23].

**Anesthesia-related factors:** Mechanical ventilation during anesthesia can cause pulmonary injury through repetitive alveolar closing and opening, potentially damaging the alveolar-capillary barrier and contributing to pneumonia, atelectasis, and respiratory failure [23].

**Surgery-related factors:** Surgery lasting over three hours is related to an elevated possibility of PRCs highlighting the impact of procedure duration and type [23].

### Pathophysiology of ventilator-induced lung injury (VILI)

**Barotrauma:** The term "barotrauma" refers to pulmonary injury resulting from high airway pressures during mechanical ventilation. Excessive distension of alveoli can rupture the junction of the vascular sheath and alveolar wall, causing air leaks like pneumothorax, pneumomediastinum, interstitial emphysema, and pneumopericardium. The risk of injury is based not only on the magnitude of pressure but additionally on its duration and the presence of atelectasis, which influences pressure distribution [24].

**Volutrauma:** Animal studies introduced the term "volutrauma" to describe VILI caused by repetitive alveolar stretching. The amplitude and frequency of stretch have been shown to proportionally injure alveolar epithelial cells, indicating that volume overload rather than pressure is a key factor in VILI [24].

**Atelectrauma:** "Atelectrauma" indicates injury resulting from the recurrent opening and collapse of distal lung units caused by inadequate end-expiratory lung volume explaining pulmonary injury in conditions like infant respiratory distress syndrome [24].

**Biotrauma:** Slutsky coined the term "biotrauma" to describe pulmonary injury resulting from the release of inflammatory mediators during injurious mechanical ventilation. Factors like underlying pulmonary illness, systemic inflammation, surfactant dysfunction, and uneven pulmonary ventilation raise susceptibility to biotrauma [24].

**Ergotrauma:** "ergotrauma" as a unifying concept encompassing mechanical factors associated with VILI. They derived a mechanical power equation that includes tidal volume, driving pressure, inspiratory flow, PEEP and ventilatory rate, providing a framework to estimate ventilator-related lung injury risks [24].

### Components of protective lung ventilation

**Low TV Combined with PEEP:** High tidal volume (TV) ventilation can lead to pulmonary edema, the production of inflammatory mediators, and alveolar damage. The standard for TV is six to eight $mL \cdot kg^{-1}$ PBW, limiting lung overdistension. To counter the risk of atelectasis caused by low TV, PEEP is applied to enhance lung compliance and preserve alveolar distention. PEEP at 5 $cmH_2O$ is effective in preventing atelectasis in healthy pediatric lungs, but excessive PEEP can raise pulmonary vascular resistance and intracranial pressure, leading to hemodynamic fluctuations [25].

**Positive end-expiratory pressure titration**

The optimal PEEP level varies by patient and condition. Several methods for PEEP titration include

**A) Oxygenation:** PEEP/$FiO_2$ tables, though widely used, are criticized for being based on oxygenation rather than lung mechanics [26].

**C) Compliance:** Incremental/decremental PEEP titration to attain maximum static compliance (Crs) results in minimal dead space and optimal oxygen transport [26].

**D) Driving pressure:** A reduction in driving pressure with increased positive end-expiratory pressure suggests alveolar recruitment, whereas a rise indicates overdistension, making driving pressure a key parameter to minimize ventilator-induced lung injury [26].

**E) Stress index:** This index evaluates changes in pressure-time slopes during inspiration. Optimal PEEP achieves a linear increase in pressure, with upward or downward concavity indicating overdistension or potential recruitment, respectively [26].

**Lung recruitment maneuvers (RMs)**

RMs address injuries from recurrent alveolar closing and opening, effectively preventing postoperative complications. Common strategies involve ventilator- and manual-driven recruitment [26].

**$FiO_2$:** While perioperative oxygenation is essential, high oxygen concentrations can lead to resorption atelectasis, resulting from the constant absorption of oxygen into lung capillaries beyond closed airways [27].

**Other perioperative lung protection measures**

**Postoperative pain management:** Effective postoperative pain management reduces the risk of respiratory complications like pneumonia and atelectasis, shortening hospital stays and improving recovery outcomes. Combining analgesic techniques, such as neuraxial analgesia with general anesthesia, is considered an efficient strategy to balance pain relief and minimize respiratory failure risk [28].

**Lung recruitment maneuvers**

**Positive pressure mechanical ventilation and recruitment maneuvers**

**Impact of positive pressure ventilation:** Positive pressure ventilation, while lifesaving, can lead to varying degrees of airway or acinus collapse, resulting in gas exchange deterioration, lung mechanics impairment, and increased risk of inflammatory lung responses [29].

**Recruitment maneuvers (RMs):** RMs involve a temporary rise in transpulmonary pressure to reopen poorly aerated or non-aerated alveoli, improving oxygenation and respiratory compliance. They are particularly effective as rescue treatment for severe hypoxemia refractory to protective ventilation strategies and prone positioning [29].

**Methods of recruitment maneuvers**

**Ventilator-driven RMs**

**CPAP maneuver:** CPAP of 30–40 $cmH_2O$ applied for five to ten seconds until no lung collapse is observed [30].

**PCV maneuver:** PEEP incrementally elevated every $3^{rd}$ breath, maintaining recruitment pressure for ten breaths [30].

**Cycling maneuver:** Tidal volume not more than eight $mL \cdot kg^{-1}$ with PEEP increased in steps from 5 to 20 $cmH_2O$ and then decreased to baseline. Common in adults, its pediatric application requires further study [5].

**Adverse effects of RMs [13]:**

**Cardiovascular complications:** Hypotension and reduced cardiac output due to transient intrathoracic pressure increases, especially in cases with poor chest wall compliance.

**Central nervous system complications:** Reduced cerebral perfusion pressure, contraindicating RMs in head-injured patients.

**Pulmonary complications:** Risks include barotrauma (e.g., pneumothorax) and bacterial translocation due to altered alveolar-capillary membrane integrity.

**Cytokine release syndrome:** Inadequate or repeated derecruitment may aggravate cytokine production increasing inflammation. Careful monitoring and pressure limitation strategies are essential to minimize harm while implementing RMs [13].

**Laparoscopic surgery**

**Laparoscopic surgery overview:** Laparoscopic surgery offers advantages over exploratory laparotomy, including reduced pain, hemorrhage, and recovery time. The key tool is a laparoscope, allowing visualization via small incisions [31].

**Choice of insufflated gas:** Carbon dioxide is the primary insufflation gas due to its rapid clearance and minimal combustion risk. However, its absorption across the peritoneum can cause hypercapnia, necessitating careful ventilation to mitigate acidosis and arrhythmias [32].

**Effects of carbon dioxide absorption:** Hypercapnia from carbon dioxide insufflation increases minute ventilation and activates the sympathetic nervous system, raising heart rate, blood pressure, and myocardial contractility. Insufficient pulmonary ventilation can lead to myocardial depression and arrhythmias [33].

**Creation of the pneumoperitoneum:** A pneumoperitoneum is created with 2.5–5.0 L of insufflated carbon dioxide, maintaining intraabdominal pressure (IAP) up to six millimeters of mercury in babies and twelve millimeters of mercury in older kids for adequate visualization. Raised IAP can affect cardiovascular, respiratory, and neurological systems [34].

**Cardiovascular effects:** Major changes include hypotension, arrhythmias, and cardiac arrest due to factors such as vasovagal reflexes, reduced venous return, and hypercapnia. Patients with cardiovascular conditions require close monitoring, and IAP should be limited to 6–12 mmHg [35].

**Respiratory effects:** Increased IAP and diaphragm displacement reduce compliance, functional residual capacity and ventilation, causing V/Q mismatch, hypercapnia, and hypoxemia. Patients with pulmonary dysfunction may need preoperative testing and adjustments in IAP to avoid complications. Positioning affects respiratory function, the reverse Trendelenburg position improves it, whereas the Trendelenburg position worsens it [22]**.**

**Ultrasound probes and their applications**

**Linear probe (eight to twelve megahertz):** High resolution for superficial structures like the pleura and lung sliding, but poor penetration for deeper structures [23].

**Curvilinear probe (three to five megahertz):** The best all-around probe for LUS, providing excellent visualization of effusions, consolidated diaphragm, and lung due to large sector width and good penetration [15].

**Phased array probe (3–4.5 megahertz):** Advantageous for imaging among ribs with all LUS signs visible, though image clarity is less than other probes [13].

**Examination method (Figure 2):**

A simple 3-point examination of each lung offers high diagnostic accuracy and is a good starting point for novices [34]:

**Upper anterior point:** Base of the middle and ring fingers on the upper hand, over the upper lobe.

**Lower anterior point:** Palm of the lower hand near the nipple, over the middle or lingular lobe.

**Postero-lateral point:** Lateral and posterior placement behind the posterior axillary line, over the lower lobe. Rotating the probe between ribs minimizes rib shadows [34].

**Figure (2):** Probe positioning [34].

**ANOTHER METHOD**

**Complete lung ultrasound (LUS) method**

**Examining zones:** Each hemithorax is assessed in lateral, anterior, and posterior zones in transverse and longitudinal orientations to avoid missed abnormalities. Imaging can be done in supine and upright positions [35].

**Proper technique:** The probe must be perpendicular to the skin to generate accurate pleural artifacts. Larger body habitus may limit visualization of deeper structures, and probe selection depends on age and examination indication [35].

**Key LUS signs**

**Pleural line & A lines**

**Lung sliding**

**Diaphragm**

**Ultrasound findings in pulmonary diseases**

**Interstitial syndrome:** Pulmonary edema, interstitial pneumonia, pneumonitis, and lung fibrosis are associated with interstitial syndrome. The hallmark ultrasound (US) feature is **B-lines**, vertical hyperechoic lines arising from the pleural line that move with lung sliding, erase A-lines, and continue to the image's depth. Up to two B-lines per rib space are normal, three or more indicate pathology. Severe edema can cause a confluent "white lung" pattern [35].

**Pneumothorax (Figure 3):** US is nearly as effective as CT for pneumothorax diagnosis, taking less than a minute. Key findings include abolished sliding, absence of B-lines and lung pulse, and the presence of a **lung point**—the transition between normal and pneumothorax sonographic patterns. The lung point moves with respiration and is sought laterally with increasing pneumothorax size. If the lung point cannot be found, **lung pulse**, visible as "T-lines" in M-mode, can confirm adjacent pleural layers [34].

**Alveolar syndrome:** Includes alveolar atelectasis and consolidation. Consolidations appear as echo-poor areas under the pleura, sometimes with indistinct margins (**shred sign**) or tissue resembling the liver (**tissue-like sign**).

**Dynamic air bronchograms**, which move with respiration, are specific to pneumonia, while static bronchograms suggest atelectasis. Atelectasis often occurs with large pleural effusions, and differentiation requires effusion drainage to observe lung re-aeration [35].

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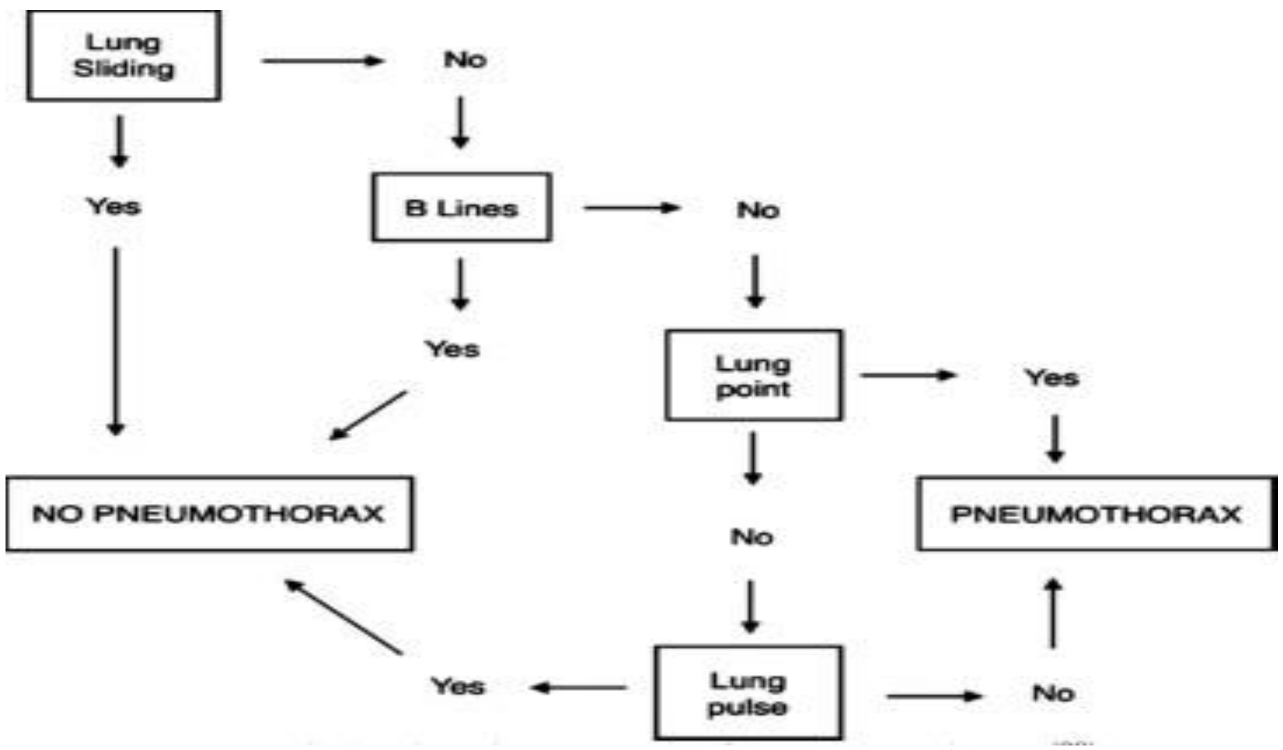


**Figure (3):** Flowchart to assess for a pneumothorax [13].

## CONCLUSION

Both individualized PEEP and US guided RM improved oxygenation and lung mechanics more than fixed PEEP with comparable hemodynamic profile and postoperative pulmonary complications.

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