Review

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Lung re-aeration assessment by ultrasound during mechanical ventilation: Current knowledge of literature review

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ABSTRACT

Lung collapse, commonly associated with conditions such as atelectasis, pneumonia, and acute respiratory distress syndrome, significantly impairs gas exchange and respiratory function. Monitoring lung re-aeration is therefore crucial in evaluating the effectiveness of therapeutic interventions, including non-invasive ventilation, invasive mechanical ventilation, and physiotherapy, which aim to restore lung volume and improve respiratory efficiency. Lung re-aeration involves two key physiological processes such as recruitment and inflation. Both mechanisms improve lung compliance and optimize ventilation-perfusion matching, improving overall respiratory function. LUS has emerged as a promising alternative for assessing lung aeration, supporting its feasibility in detecting and tracking lung re-aeration across various clinical scenarios, and providing real-time insights into lung recruitment and inflation. This review integrates current evidence on the physiological mechanisms of lung collapse and the clinical applications of ultrasound as a tool for monitoring lung re-aeration, highlighting its potential to optimize respiratory management in critically ill patients.

Key words: Lung recruitment; lung ultrasound, lung consolidation; mechanical ventilation.

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Introduction

Lung collapse, often associated with conditions like atelectasis, pneumonia, and more severe forms of acute respiratory distress syndrome (ARDS), can significantly impair gas exchange and respiratory function [1]. This collapse leads to a reduction in the lung's ability to oxygenate blood and remove carbon dioxide, which can result in severe respiratory distress [2]. Assessing lung re-aeration is therefore crucial for monitoring the effectiveness of therapeutic interventions such as non-invasive positive ventilation (NIV), invasive mechanical ventilation (MV), and physiotherapy. These interventions aim to restore lung volume, improve gas exchange, and reduce the workload on the respiratory muscles. Recruitment describes the aeration of previously gasless lung regions-areas where alveolar units have collapsed or become unventilated [3]. Physiologically, it refers to increasing lung volume at the same pressure [4]. Inflation, on the other hand, involves the further aeration of lung regions that are already inflated, thereby increasing the volume within these aerated areas [5]. This process leads to the expansion of alveoli, improving lung compliance and optimizing the matching between ventilation and blood perfusion within the lungs.

By maximizing alveolar expansion in well-aerated regions, inflation improves overall lung efficiency, which is essential in cases where certain lung regions are damaged or collapsed [6]. The effectiveness of recruitment is often influenced by different ventilatory conditions, such as variations in positive end-expiratory pressure (PEEP) and tidal volume (Vt), which affect the gas distribution within the lungs [7]. This process can be quantified by measuring the reduction in nonaerated lung tissue, often expressed in grams, under varying ventilation strategies [8].

Traditionally, computed tomography (CT) has been the gold standard for evaluating lung aeration, providing detailed images that allow clinicians to assess the extent of lung collapse, recruitment, and inflation [9]. CT scans enable precise quantification of aerated and nonaerated lung tissue, offering insights into the effectiveness of interventions aimed at improving lung function [10,11]. However, CT is limited by its accessibility, high cost, exposure to ionizing radiation, and lack of real-time feedback, making it less suitable for frequent or bedside assessments. Lung ultrasound (LUS) has emerged as a promising alternative to CT in the evaluation of lung aeration [12,13]. Unlike CT, LU is non-invasive, widely accessible, portable, and safe for repeated use, as it does not expose patients to radiation. It provides real-time feedback, making it highly suitable for continuous monitoring in critical care settings. Recent studies have shown that LUS is feasible for detecting and monitoring lung re-aeration, including recruitment and inflation, across various clinical scenarios [1,14–16]. This review integrates recent findings on the applications of LU in clinical settings, particularly its effectiveness in detecting and tracking lung re-aeration.

Physiological features of lung collapse and lung re-aeration

Atelectasis can be classified into obstructive and non-obstructive types [17]. The primary mechanisms involved include increased pleural pressure, decreased alveolar pressure, and surfactant dysfunction. Obstructive atelectasis occurs when airway obstruction prevents air from reaching the alveoli, leading to distal air reabsorption and lung collapse [18]. Common causes include tumours, mucus plugs, and foreign bodies. High FiO_2 can also contribute to absorption atelectasis by accelerating oxygen absorption and destabilizing alveoli [19]. Non-obstructive atelectasis results from external compression, as seen in pleural effusions, pneumothorax, or abdominal distension [20]. Postoperative atelectasis, frequently occurring within 72 hours of surgery, involves both obstructive and non-obstructive mechanisms [21,22]. Treatment aims at lung re-aeration through various strategies [23]. Pneumonia-induced consolidation makes affected regions non-recruitable, while ventilatable areas remain inflamed [24]. Gravity, sedation-related muscle inactivity, and chest wall load contribute to dependent atelectasis. Recruitment manoeuvres, prone positioning, and higher PEEP can help reopen collapsed lung regions. ARDS, a severe inflammatory condition, leads to alveolar-capillary barrier dysfunction, impaired gas exchange, and lung heterogeneity [25]. Atelectasis plays a key role in ARDS management, as its resolution helps optimize ventilation while preventing further lung injury [26–28]. The degree of lung recruitment, correlating with responses to PEEP and prone positioning, is crucial for tailoring ventilation strategies and minimizing VILI [29].

Mechanical ventilation and re-aeration

Invasive MV plays a critical role in managing patients with respiratory failure. With a target to re-aeration, RM and optimal PEEP levels are used to counteract atelectasis, particularly in inhomogeneous lungs prone to collapse. However, lung structural variability affects re-aeration efficacy, with aggressive recruitment risking overdistension in some areas while leaving others unaffected [27]. Invasive MV is crucial in managing respiratory failure, aiming to reaerate collapsed lung regions through RM and optimal PEEP. Cressoni et al. [30] found that lung recruitability is higher in severe ARDS and depends on lung morphology rather than disease origin. In a study on early ARDS, non-focal morphology showed greater lung recruitment (417 ± 293 mL) than focal morphology (48 ± 66 mL), with focal ARDS exhibiting higher alveolar hyperinflation (23% ± 14% vs. 8% ± 9%, p = .007) [31]. Thus, recruitment manoeuvres may be more beneficial in non-focal ARDS. While MV supports ARDS patients, it can also cause VILI [32]. Key ventilatory parameters, including plateau and driving pressures, PEEP, tidal volume, and dynamic factors like respiratory rate, contribute to lung injury risk [33]. The extent of damage depends on lung tissue vulnerability, applied mechanical power, and exposure duration [34]. Protective ventilation strategies focus on low tidal volumes and optimal PEEP to prevent alveolar collapse while minimizing overdistension [35]. Over time, the approach has shifted from "open the lung and keep it open" [36] to "do no further harm," reflecting the limitations of ventilation in addressing lung inhomogeneity [37].

NIV is still a first step treatment in selected acute respiratory failure, significantly increasing both the range of treatable conditions and the settings in which it is applied [38]. Once limited to specialized units, NIV is now widely used in emergency departments, ICUs, and general wards, especially following the COVID-19 pandemic [39]. Its versatility and efficacy make it valuable for managing conditions like COPD exacerbations, cardiogenic pulmonary oedema, and select cases of hypoxemic respiratory failure [40]. NIV reduces the need for artificial airways, lowering ventilator-associated pneumonia risk, minimizing sedation, and preserving airway defences [41]. It mimics key effects of invasive ventilation, enhancing minute ventilation, reducing respiratory muscle workload, and improving alveolar recruitment with PEEP [41]. Additionally, NIV impacts cardiac function, offering benefits in heart failure or fluid overload while potentially influencing cardiac output and ventricular afterload [43]. However, NIV carries risks such as ventilator-induced lung injury (VILI), auto-PEEP, and patient discomfort due to poor synchronization [44–46]. A related concept, patient self-inflicted lung injury (P-SILI), describes lung damage caused by excessive respiratory muscle activity, particularly in severe ARDS patients, whether breathing spontaneously or under NIV [47]. P-SILI results from intense inspiratory efforts that generate large pleural pressure swings, leading to overdistension, pendelluft effects, pulmonary oedema, and regional injury [48]. This mechanism disrupts tidal volume distribution, exacerbating inhomogeneity and increasing local stress in atelectatic lung areas, even without large tidal volumes [49].

How to perform lung recruitment

Alveolar recruitment can occur progressively as collapsed lung regions reopen, mimicking the healing process in cases of inflammatory consolidation and often signaling a favorable response to therapy. Otherwise, it can be achieved through static or dynamic ventilatory maneuvers during mechanical ventilation. A recruitment maneuver typically involves a transient increase in airway pressure to reopen alveoli, followed by the application of adequate PEEP to maintain lung expansion [50]. However, recruitment can also occur through non-ventilatory means, such as clearing airway obstructions or adjusting patient positioning. Despite its widespread use, recruitment remains a non-standardized intervention. One of the earliest approaches, the sigh maneuver, involves temporarily increasing tidal volume or PEEP, leading to improved oxygenation and lung compliance [51]. A commonly studied method is sustained inflation, where the lungs are held at high pressure (e.g., 30-45 cmH_2O) for a short duration. While this can enhance lung aeration and gas exchange, its effects are often transient, reversing within minutes [50]. Similarly, CPAP-based maneuvers (e.g., 35 cmH_2O for 20-30 seconds) have been shown to improve oxygenation, but studies report variable and short-lived benefits [52–54]. A more individualized approach involves performing a decremental PEEP trial after recruitment, allowing identification of the optimal level to prevent alveolar collapse [55]. However, excessive pressures or frequent maneuvers may lead to overdistension and potential lung injury, highlighting the need for careful patient selection. In the context of NIV, traditional recruitment strategies are less effective due to the inability to directly control airway pressures [56]. Instead, techniques such as prone positioning, postural adjustments, and bronchoscopy-assisted clearance can enhance lung expansion and improve oxygenation. Prone positioning, in particular, has demonstrated benefits in certain populations by optimizing ventilation-perfusion matching and reducing the risk of ventilator-induced lung injury [57]. When combined with NIV, these strategies may provide a non-invasive means of improving gas exchange in selected patients [58]. Finally, lung recruitment should be tailored to the individual, balancing potential benefits with the risks of lung overdistension and hemodynamic compromise [59].

How to measure lung recruitment and re-aeration

Lung recruitment can be assessed using indirect methods, such as gas exchange and lung mechanics, which infer recruitment based on increased alveolar participation in tidal ventilation. However, measuring "functional" recruitment remains challenging, as improvements in oxygenation and lung mechanics may also result from reduced cardiac output and changes in intrapulmonary shunting rather than true alveolar recruitment [60]. Indeed, studies have shown only a weak correlation between oxygenation improvement and recruitment assessed via CT scan, with cardiac and vascular factors also influencing shunting. Changes in elastance at higher pressures can reflect both alveolar recruitment and improved lung compliance, but in some cases, increasing PEEP may lead to overdistension despite recruitment [61]. Direct methods include CT scans, pressure–volume (PV) curves, electrical impedance tomography (EIT), and the recruitment-to-inflation (R/I) ratio. CT scans quantify lung recruitment by assessing tissue re-aeration at different pressure levels [62]. While CT remains the gold standard for lung morphology assessment, its clinical utility is enhanced when recruitment strategies are tailored to lung morphology. A multicenter randomized controlled trial in France involving 420 ARDS patients compared a standard low-PEEP strategy with a personalized approach based on CT morphology. In the personalized group, focal ARDS patients received 8 mL/kg tidal volume with low PEEP and prone positioning, while non-focal ARDS patients received 6 mL/kg tidal volume, high PEEP, and recruitment maneuvers. However, 21% of patients were misclassified as focal or non-focal, with a higher mortality rate observed in misclassified patients within the personalized group [63]. More recently, Protti et al. found that significant tissue recruitment, as measured by CT, was not consistently associated with compliance improvements, and an absence of recruitment could not be inferred from stable or reduced compliance [64]. PV curves assess recruitment by analyzing hysteresis and volume shifts at different PEEP levels. Demoroy et al. [65] demonstrated a correlation between lung hysteresis, calculated via PV curves, and volume increases during recruitment maneuvers. However, PV-derived recruitment does not always correlate with CT-based assessments, as it primarily reflects gas volume changes rather than true tissue recruitment. EIT and the R/I ratio offer non-invasive, real-time monitoring of lung recruitment [66,67]. However, monitoring lung recruitment during NIV remains particularly challenging due to limitations in interface stability and air leaks that affect pressure control and compliance measurements [68,69]. While CT and PV curves are difficult to apply reliably in NIV, EIT and the R/I ratio may provide valuable insights but require adaptation to mitigate artifacts. These challenges underscore the need for tailored monitoring strategies in NIV to optimize recruitment and patient outcomes.

Lung ultrasound in pulmonary consolidation

The consolidated lung appears as a real anatomical image rather than an artifact showing an hypoechoic parenchymal texture similar to that of the liver, along with blood vessels that can be identified using Doppler imaging [70]. Despite consolidation, residual air may still be present within the affected lung regions, which appears as bright, hyperechoic spots on ultrasound, representing air trapped within the peripheral airways [71]. These spots are artifacts generated by the interaction between ultrasound waves and air and are commonly referred to as "air bronchograms" [72]. In cases where air is still dynamically shifting, it is referred to as a dynamic air bronchogram, a feature that can help differentiate consolidation from obstructive atelectasis [73]. Conversely, a static air bronchogram, where air remains immobile within the affected bronchi, is often associated with airway obstruction. Obstructive atelectasis typically presents with static bronchograms arranged in a horizontal or parallel pattern due to parenchymal collapse and volume reduction [74]. Another useful sign in LUS is the "pulse sign," which occurs in cases of atelectasis [75]. It refers to the transmission of cardiac pulsations through dense, non-compliant, air-deprived lung tissue, causing visible rhythmic movement. Distinguishing atelectasis from consolidation requires significant expertise, and LUS findings should always be interpreted within the clinical context. In inflammatory consolidations, denser pre-consolidated lung parenchyma often surrounds the affected areas. This altered lung architecture appears on ultrasound as a mix of artifacts, including vertical reverberation artifacts of varying lengths and intensity [76]. When these artifacts originate from the edges of a consolidation, they are referred to as "C-lines", while those arising from deep irregular borders of consolidations are described as "shred signs"[77]. In addition, pleural irregularities and vertical artifacts emerging from the pleural line near the consolidation have been associated with focal interstitial syndrome [78]. The ultrasound appearance of these findings varies depending on multiple factors, including the stage of disease progression (Figure 1).

Clinical assessment

Various studies have explored LUS to assess alveolar recruitment using different strategies and protocols (Table 1). In a case report, LUS identified lung consolidation consistent with pneumonia [79]. During a recruitment maneuver, increasing PEEP led to the transition from consolidation to vertical B-lines, indicating re-aeration. Similar findings were reported by Gardelli et al. [80] and Santuz et al. [81], though without quantitative assessment of re-aeration. Stefanidis et al. [82] conducted a pilot study on 10 patients with lung consolidation, using LUS before and after a recruitment maneuver (PEEP from 5 to 15 cm H_2O), showing a correlation between ultrasound changes and blood gas improvements. Bouhemad et al. [83] developed a scoring system to quantify LUS changes, correlating well with recruitment effectiveness. Their study also demonstrated that LUS could accurately monitor pneumonia resolution, with strong agreement between CT-based aeration changes and LUS re-aeration scores. In ARDS patients, they found a significant correlation between PEEP-induced recruitment measured by P-V curves and LUS-based

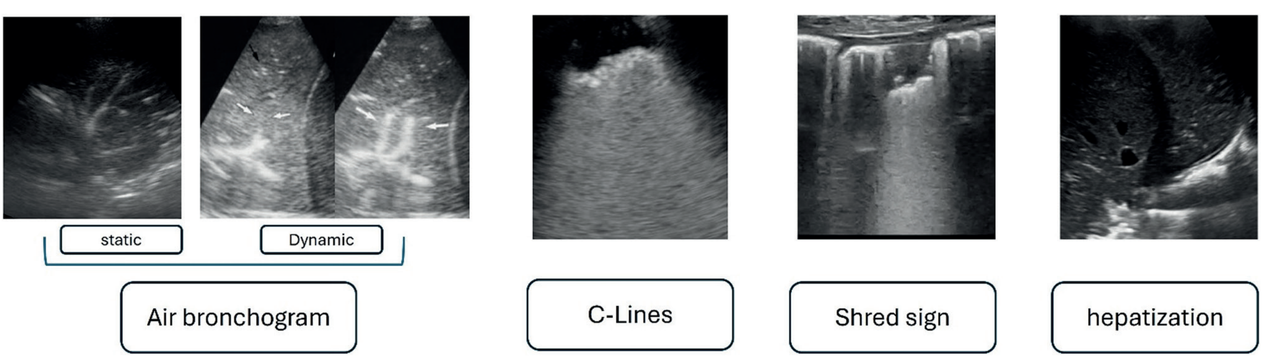

Figure 1. Ultrasound features of lung consolidation and atelectasis. Lung ultrasound in consolidation reveals a hypoechoic, liver-like texture with visible blood vessels. Air bronchograms appear as hyperechoic spots, with dynamic bronchograms indicating consolidation and static ones suggesting obstructive atelectasis. The "pulse sign" reflects cardiac pulsations in dense lung tissue. Additional LUS features include C-lines, shred signs, and pleural irregularities, varying with disease progression.

Table 1. Summary of key ultrasound studies on lung recruitment.

Study	Type of study	Primary focus	Outcome
Pelosi et al. **[91]**	Prospective, interventional 10 patients	Test if the sighs recruit the lung, prevent reabsorption atelectasis, and whether these effects differ between pulmonary and extrapulmonary ARDS due to variations in chest wall elastance.	Sigh recruitment maneuvers improved oxygenation and lung aeration; benefits reversed within 30 minutes.
Lapinski et al. **[53]**	Prospective 14 patients	Sustained inflation for alveolar recruitment in respiratory failure	CPAP at 30-45 cmH_2O for 20 seconds improved oxygenation within 10 minutes; effects lasted at least 4 hours.
Villagrà et al. **[92]**	Observational 17 patients	Recruitment maneuvers during lung protective ventilation in ARDS	Significant increases in lung gas volume observed only in early ARDS; arterial oxygenation unaffected.
Gardelli et al. **[80]**	Case report 1o patients	Sonographic assessment of lung recruitment in ARDS	Lung re-expansion using ultrasound after recruitment maneuvers.
Constantin et al. **[63]**	Observational 19 patients	Lung morphology predicts response to recruitment maneuvers in ARDS	Recruited lung volume was significantly higher in patients with non-focal ARDS compared to focal ARDS.
Xi et al. **[93]**	Randomized controlled trial 110 patients	Recruitment maneuver in ARDS patients using low tidal volume ventilation	In the RM group the PaO_2/FiO_2 was significantly increased compared to baseline at 120 minutes after RM on day one and day two (P=0.007 and P=0.001) but no significant difference in hospital mortality.
Bouhemad et al. **[83]**	Observational 30 patients	Compare lung re-aeration measured by bedside chest radiography, lung computed tomography, and lung ultrasound in patients with ventilator-associated pneumonia treated by antibiotics.	Bedside lung ultrasound can estimate lung re-aeration in patients with ventilator-associated pneumonia treated by antibiotics and can also detect the failure of antibiotics to reaerate the lung.
Cressoni et al. **[30]**	Prospective 33 patients	ARDS patients	PEEP up to 15 cmH_2O and plateau pressure up to 30 cmH_2O are insufficient for an open lung strategy; higher pressures are needed, balancing atelectrauma and volutrauma risks.
Tusman et al. **[85]**	Observational 83 patients	Postural recruitment maneuvers in mechanically ventilated children	Changes in body position during ventilation at 10 cmH_2O PEEP reduced atelectasis without increasing airway pressures, while LUS can guide personalized P-RM settings.
Wu et al. **[88]**	Randomized double blind 74 patients	Effects of ultrasound-guided alveolar recruitment maneuvers on atelectasis in laparoscopic surgery	Ultrasound-guided recruitment maneuvers reduce perioperative aeration loss and improve oxygenation, with better effects on atelectasis than sustained inflation maneuvers.
Liu et al. **[89]**	Randomized controlled trial 105 patients	Recruitment maneuvers under LUS guidance in upper abdominal surgery	Lower incidence of atelectasis and postoperative hypoxemia in the recruitment plus PEEP group compared to control and PEEP-only groups.

re-aeration scores [84]. Tusman et al. [85] highlighted the role of LUS in guiding ventilatory adjustments, confirming atelectasis resolution after a stepwise increase in airway pressure. After recruitment, a PEEP of 10 cm H_2O maintained lung aeration, achieving a plateau pressure of 25 cm H_2O and SpO_2 of 99% with an FIO_2 of 0.3. Similarly, in a pediatric ARDS case on ECMO, LUS initially showed severe lung aeration loss with dynamic air bronchograms and multiple coalescent B-lines. Increasing PEEP to 30 mm H_2O resulted in the appearance of A-lines, indicating successful re-aeration [86]. Another study explored positional maneuvers for recruitment [87]. In three anesthetized children, a PEEP trial failed to resolve atelectasis in the supine position, but lateral positioning led to its disappearance in the non-dependent lung. Both lungs remained aerated after returning to supine. In a randomized trial comparing LUS-guided alveolar recruitment to sustained inflation in laparoscopic gynecological surgery, the LUS-guided group showed significantly lower post-surgical LUS scores [88] Another randomized study on 122 abdominal surgery patients found a lower incidence of atelectasis in the recruitment + PEEP group (17.5%) compared to control and PEEP-only groups (52.4% and 50.0%). Postoperative hypoxemia was also lower in the recruitment + PEEP group (5%) compared to the control and PEEP groups (27.5% and 15%) [89]. Figure 2 depicts an example of lung recruitment described by LU.

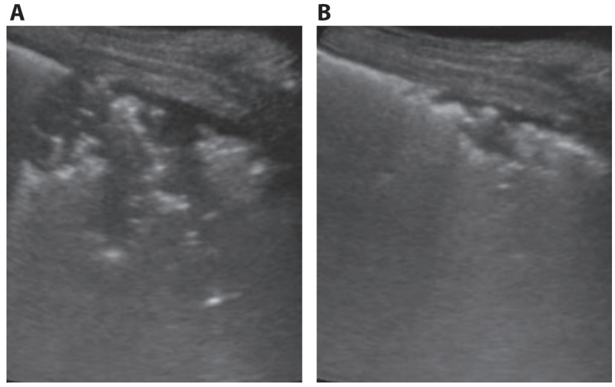

Figure 2. Consolidated recruited lung. The figures illustrate atelectasis and tidal recruitment in the posterior regions. Pulmonary consolidation or atelectasis appears as a hypoechoic area interspersed with air bronchograms. The presence of tidal recruitment is identified by visual differences in lung aeration and the extent of atelectasis between end-expiration and end-inspiration. Images A and B were captured following a lung recruitment maneuver.

Practical approach

We suggest a flowchart for a systematic approach in the assessment and monitoring of lung collapse and alveolar recruitment, integrating LUS into various patient conditions (intubated, spontaneous breathing, or NIV) (Figure 3). The decision-making process adapts based on ultrasound responses during treatment, optimizing therapeutic management. The approach to monitoring and managing lung collapse and alveolar recruitment using LU can be tailored based on the patient's condition. For intubated patients, the initial ultrasound examination (T0) focuses on identifying consolidation or atelectasis, typically characterized by B-lines, consolidation, or air bronchograms (Figure 3). If atelectasis is detected, a recruitment maneuver, such as increasing PEEP or performing sustained inflation, is initiated. Post-maneuver ultrasound (T1) is then used to assess re-aeration, with a transition from consolidation to vertical B-lines indicating successful recruitment. If re-aeration is insufficient, additional measures, such as positional changes or further increases in PEEP, may be applied. The PEEP selection should be guided by applying a step-wise increment in airway pressure to detect the plateau opening pressure [90]. Ultrasound is subsequently performed 30 minutes after the procedure (T2) to confirm whether the re-aeration persists. Ongoing monitoring is conducted every 6-12 hours to detect the reappearance of atelectasis and guide further interventions. In spontaneous breathing patients, the initial ultrasound examination (T0) identifies the presence of atelectasis or consolidation (Figure 4). If no atelectasis is found, periodic ultrasound checks are performed to monitor any changes in lung aeration. In cases where atelectasis is observed, non-invasive recruitment maneuvers, such as adjusting PEEP or utilizing positional changes, are considered. After the maneuver, post-recruitment ultrasound (T1) is conducted to assess the resolution of atelectasis. Again, a follow-up ultrasound is done 30 minutes later (T2) to ensure the lung remains aerated. Regular monitoring helps prevent the

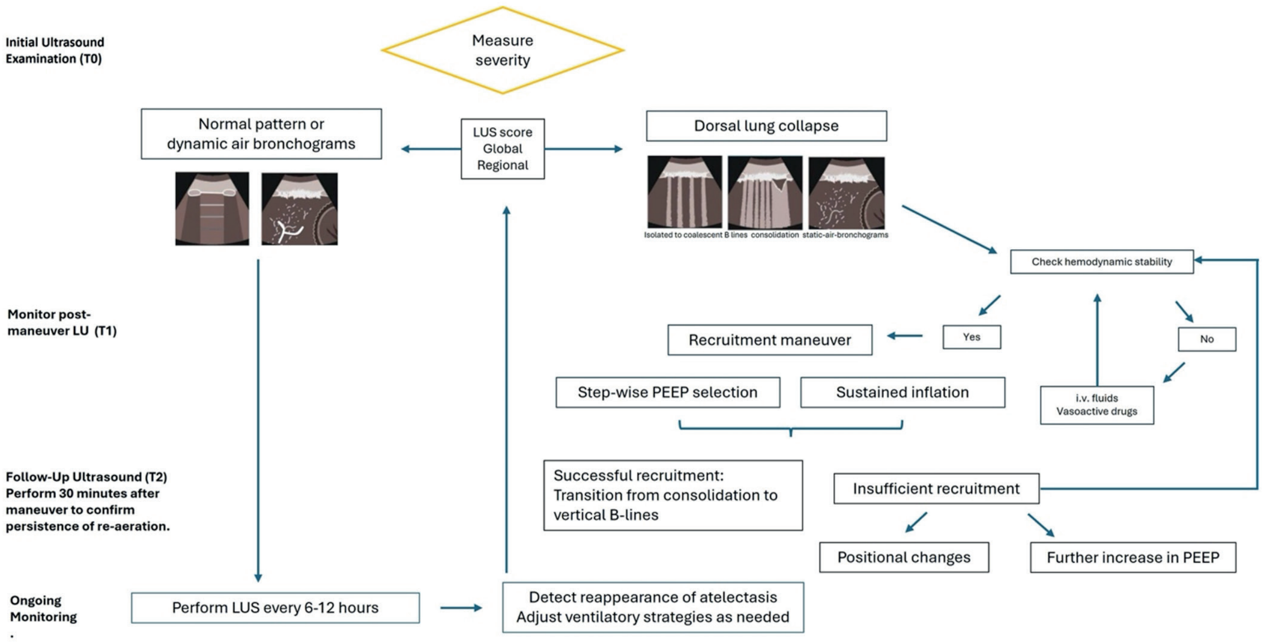

Figure 3. Ultrasound-Guided assessment and management of atelectasis in intubated patients. Ultrasound assessment in intubated patients: T0 identifies atelectasis (B-lines, consolidation, air bronchograms). If present, recruitment maneuvers are applied. T1 evaluates re-aeration, with B-lines replacing consolidation indicating success. T2 (30 min post-maneuver) confirms persistence. Monitoring continues every 6-12 hours.

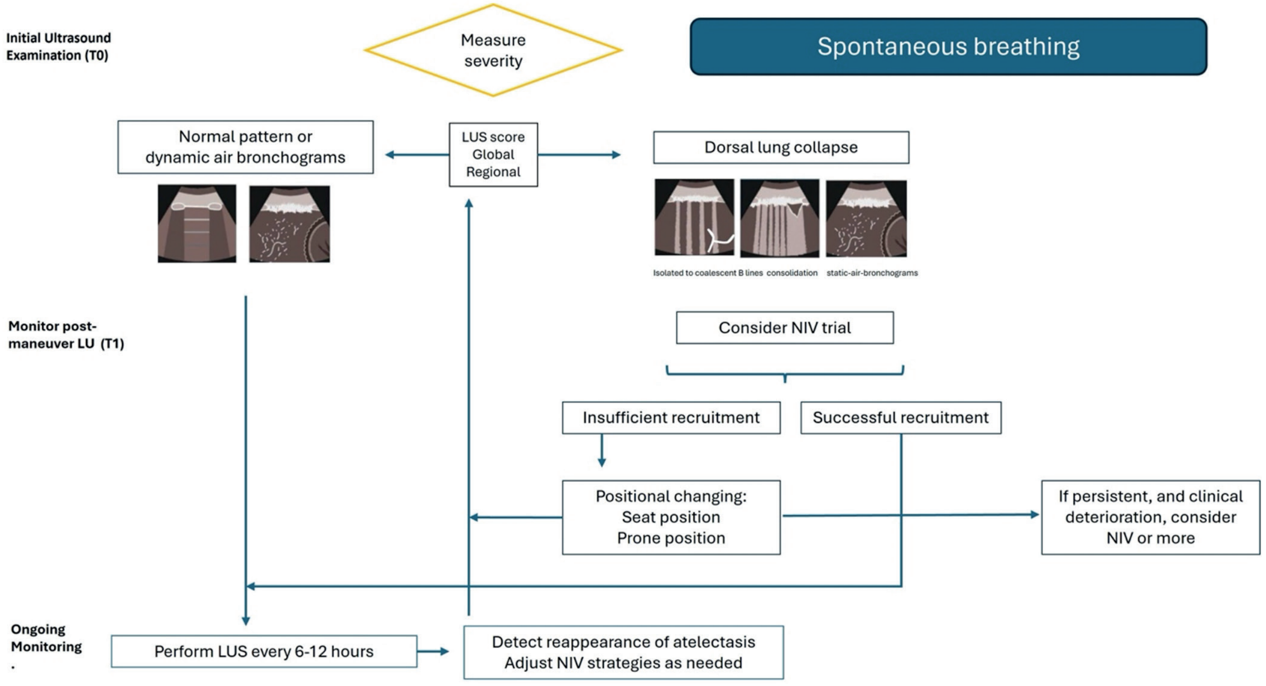

Figure 4. Ultrasound Monitoring and Non-Invasive recruitment in spontaneous breathing patients. Ultrasound assessment in spontaneous breathing patients: T0 identifies atelectasis or consolidation. If absent, periodic monitoring is performed. If present, non-invasive maneuvers (e.g., PEEP adjustment, positional changes) are applied. T1 evaluates re-aeration, with T2 (30 min later) confirming persistence. Ongoing monitoring helps prevent recurrence.

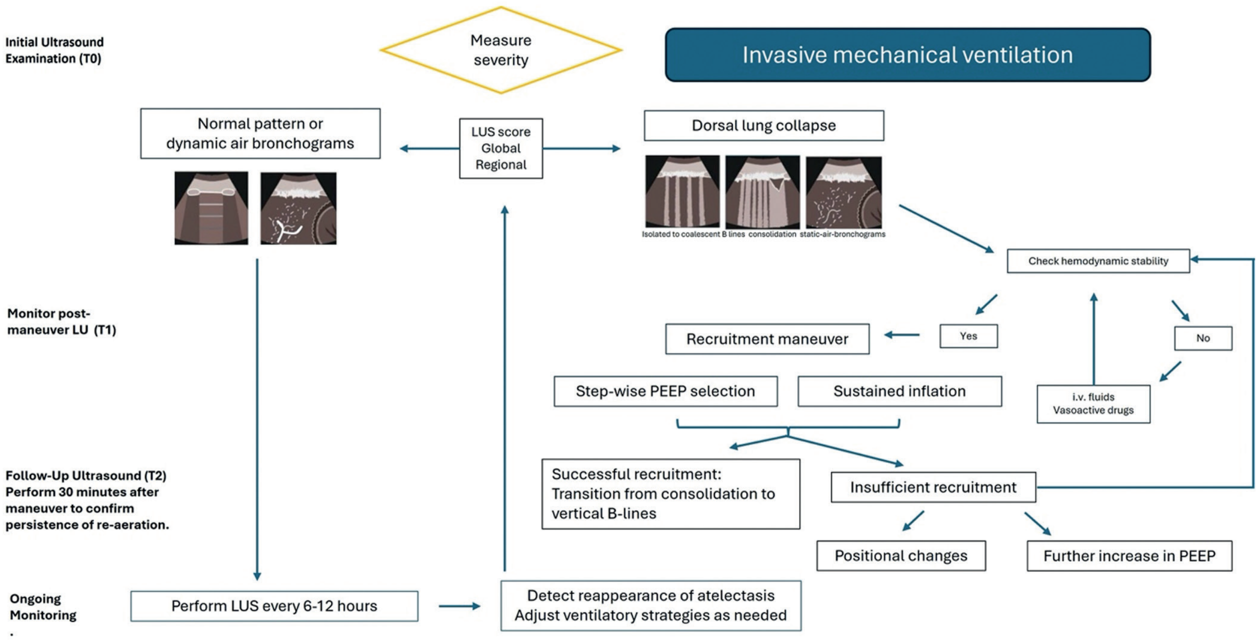

Figure 5. Ultrasound-Guided monitoring and NIV adjustments for atelectasis management. Ultrasound assessment in NIV patients: T0 identifies consolidation and poorly aerated regions. If consolidation is present, NIV settings (e.g., PEEP) are adjusted to improve aeration. T1 evaluates the response, with A-lines replacing B-lines indicating improvement. Long-term monitoring (every 6-12 hours) ensures persistent aeration and guides further NIV adjustments to prevent or manage atelectasis.

recurrence of atelectasis. For NIV patients, the initial ultrasound examination (T0) focuses on identifying consolidation and poorly aerated regions (Figure 5). If consolidation is detected, adjustments to the NIV settings, such as increasing PEEP, are considered to enhance aeration. Post-treatment ultrasound (T1) evaluates the response, with the goal of transitioning from B-lines to A-lines, indicating improved aeration. If the response is inadequate, further adjustments to NIV support are made. In all patient groups, long-term monitoring with periodic ultrasound (every 6-12 hours) is essential to ensure persistent aeration and to detect any new occurrences of atelectasis or complications. Depending on ultrasound findings, ventilatory strategies are adjusted to either prevent or address atelectasis, ensuring optimal lung protection and recovery.

Conclusion

Ultrasound is an increasing tool in the assessment of lung re-aeration, offering numerous advantages in terms of accessibility, safety, and real-time feedback. As research continues to validate its role and as technology advances, ultrasound will likely play a central role in the management of patients with lung collapse and respiratory failure, offering clinicians a reliable, non-invasive method for monitoring and optimizing treatment strategies.

Abbreviation: NIV= non-invasive ventilation; MV= mechanical ventilation; ARDS= acute respiratory distress syndrome; PEEP= positive end expiratory pressure; VT= tidal volume; RM= recruitment maneuver; CT= computed tomography; LU= lung ultrasound.

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