Diaphragmatic ultrasonography and inspiratory muscle training in patients undergoing mechanical ventilation: A scoping review

Abstract

Introduction

Mechanical ventilation-induced diaphragm dysfunction is a common complication in patients receiving invasive mechanical ventilation (IMV). Although inspiratory muscle training (IMT) and diaphragmatic ultrasonography (US) have independently demonstrated value for respiratory rehabilitation and diaphragm function assessment, respectively, their integration has been scarcely investigated. This scoping review aimed to map the available evidence on the use of diaphragmatic US in the context of IMT before, during, or after IMV and to identify the main knowledge gaps in this field.

Methods

This scoping review was conducted according to the PRISMA-ScR guidelines. Electronic searches were performed in PubMed/MEDLINE, Embase, Web of Science, and LILACS to identify studies published within the last 10 years evaluating diaphragmatic US in the context of IMT before, during, or after IMV. The authors independently screened eligible studies, extracted the data, and performed a narrative synthesis to map current applications of diaphragmatic US in IMT and identify existing knowledge gaps.

Results

Five studies, reported in six publications between 2022 and 2025, met the inclusion criteria. Diaphragmatic excursion (DE) was the most frequently assessed ultrasound parameter and was reported to improve or be preserved following IMT across the included reports. In contrast, findings for diaphragm thickness (DT) and thickening fraction (DTF) were inconsistent. IMT protocols and US applications were highly heterogeneous, and no study used diaphragmatic US to guide patient selection, individualize training intensity, or adjust training progression.

Conclusion

Diaphragmatic US appears to be a promising tool for assessing functional changes associated with IMT, particularly DE. However, evidence remains insufficient to establish its role in patient selection, training individualization, or longitudinal monitoring, underscoring the need for standardized ultrasound-based approaches to IMT in future clinical trials.

Keywords: Breathing Exercises, Diaphragm, Respiratory Muscles, Ultrasonography, Mechanical Ventilation

Introduction

Respiratory muscle weakness is a common complication among patients receiving IMV and is recognized as an important contributing factor to difficult weaning, extubation failure, prol onged stay in the intensive care unit (ICU), and worse clinical outcomes. Among the respiratory muscles, the diaphragm is particularly vulnerable to inactivity induced by IMV, leading to rapid atrophy and contractile dysfunction that can be observed within the first 24 to 48 hours of ventilatory support. This phenomenon is known as ventilator-induced diaphragm dysfunction (VIDD).[1-3]

Based on these observations, IMT has emerged as a rehabilitation strategy aimed at restoring respiratory muscle function in patients receiving IMV. IMT protocols described in the literature range from relatively low loads, typically between 20% and 30% of maximal inspiratory pressure (MIP),[4] to higher-load protocols grounded in muscle training principles suggesting the need to exceed 50% of MIP to induce significant physiological adaptations in inspiratory muscle strength and endurance.[5-7] Both approaches have reported favorable safety and feasibility profiles, as well as improvements in parameters such as MIP, maximal expiratory pressure (MEP), the rapid shallow breathing index (RSBI), duration of weaning, and ventilator-free days.[5-8]

In parallel, diaphragmatic ultrasound (US) has gained widespread acceptance as a bedside tool for the assessment of respiratory muscle structure and function.[9,10] Ultrasound enables non-invasive evaluation of DE, DT, and DTF, providing real-time information on diaphragmatic performance during spontaneous breathing and weaning trials.[9-11] Several

studies have described associations between these sonographic parameters and inspiratory muscle strength, extubation success, and clinical outcomes in patients receiving IMV.[10-13]

Despite the growing body of evidence supporting both IMT and diaphragmatic ultrasound, these two areas have largely evolved independently. Most IMT studies have used MIP as the primary outcome measure of inspiratory muscle function, whereas diaphragmatic US has been predominantly investigated as a diagnostic and predictive tool for weaning success. Consequently, the potential of diaphragmatic US to monitor or assess response to IMT in mechanically ventilated patients remains insufficiently explored.

Therefore, this scoping review aimed to map the available evidence on the role of diaphragmatic US in the context of IMT in patients before, during, or after IMV. The guiding research question was: What evidence exists regarding the use of diaphragmatic US in the context of IMT in patients undergoing or candidates for IMV, particularly in relation to monitoring training response, assessing outcomes, and identifying knowledge gaps in these settings?

Methods

This scoping review was conducted in accordance with the PRISMA-ScR guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) and methodological recommendations for scoping reviews.[14,15] The PRISMA-ScR checklist will be completed and reported as supplementary material (Supplementary Material 1). A review protocol was developed before the review was conducted and specified the search strategy, eligibility criteria, and search period. The

literature search covered the period from January 2016 to January 30, 2026. The protocol was subsequently registered in the Open Science Framework (OSF) in June 2026 (https://osf.io/3es5g), and the review was conducted according to the predefined protocol.

Selection Criteria

The selection criteria were structured according to the PCC framework (Population, Concept, Context). Studies were included if the population comprised adult patients who were candidates for IMV, undergoing IMV, in the weaning process, or in the post-IMV rehabilitation phase. The concept was the use of diaphragmatic US in the context of IMT, including monitoring of training response and assessment of outcomes. The context included respiratory rehabilitation and recovery of inspiratory muscle function following IMV.

Prospective and retrospective observational studies, randomized controlled trials (RCTs), and quasi-experimental studies published within the last 10 years were considered eligible, provided they reported clinically relevant outcomes such as DT, DE, DTF, diaphragmatic contraction velocity (PCV), and diaphragmatic relaxation velocity (PRV) following IMT implementation. Studies published in English or Spanish were included. Animal studies, narrative reviews, editorials, expert opinions, letters to the editor, and publications lacking sufficient clinical data for extraction were excluded.

Search strategy

A structured literature search was conducted in PubMed/MEDLINE, Web of Science, Embase, and LILACS from January 2016 to January 30, 2026, to identify potentially eligible

studies. The search strategy combined controlled vocabulary terms (MeSH, Emtree, DeCS, and database-specific equivalents) and free-text terms related to the target population ("Critical Illness", "Intensive Care Units", "Mechanical Ventilation", "Ventilator Weaning", and "Airway Extubation"), diaphragmatic ultrasound ("Diaphragm", "Diaphragm Ultrasonography", "Diaphragm Ultrasound", "Ultrasonography", "Diagnostic Imaging", "Diaphragm Thickening Fraction", "Diaphragmatic Excursion", and "Diaphragmatic Dysfunction"), and inspiratory muscle training ("Inspiratory Muscle Training", "Inspiratory Muscle Strength Training", "Respiratory Muscle Training", "Inspiratory Muscles", "Respiratory Muscles", "Breathing Exercises", "Maximal Inspiratory Pressure", and "MIP").

The complete search strategy is provided in Supplementary Material 2. Additionally, a manual search of the reference lists of all included studies was performed to identify potentially relevant publications not retrieved through the initial database search.

Study selection

Retrieved records were exported to a reference management software to identify and remove duplicates. Subsequently, study selection was conducted in two stages: (1) screening of titles and abstracts according to previously defined eligibility criteria, and (2) full-text assessment of potentially relevant studies. Both stages were performed independently by the authors, and disagreements were resolved through consensus.

Studies were included if they explicitly addressed the role of diaphragmatic US in the context of IMT, considering any of the scenarios defined for evidence mapping, including its use for monitoring training response and assessing outcomes before, during, or after IMV.

Data extraction and evidence synthesis

Data extraction was performed independently by the authors. Extracted variables included author and year of publication, country where the study was conducted, methodological design, sample size, clinical setting, characteristics of the IMT protocol used, and diaphragmatic US findings. The application of diaphragmatic US was also recorded in relation to the predefined evidence-mapping scenarios, including monitoring of training response and outcome assessment before, during, or after IMV.

Extracted data were organized into evidence tables and subsequently synthesized using a descriptive and narrative approach. In addition, a thematic synthesis was conducted based on the application of diaphragmatic US in the context of IMT, aiming to identify common patterns, describe key methodological characteristics, and summarize the reported findings across the relevant scenarios. Results were reviewed and discussed by the authors until consensus was reached regarding study classification, interpretation of the available evidence, and identification of major knowledge gaps.

In accordance with the Joanna Briggs Institute methodology for scoping reviews and the PRISMA-ScR guidance, no formal methodological quality assessment or risk-of-bias evaluation of the included studies was performed. The primary objective of this review was to map the extent and characteristics of the available evidence, identify how diaphragmatic ultrasonography has been applied in the context of inspiratory muscle training, and highlight existing knowledge gaps rather than evaluate intervention effectiveness or formulate evidence-based clinical recommendations.

Results

The electronic search yielded 429 records. After duplicate removal and title/abstract screening, potentially relevant reports were retrieved and assessed for eligibility. Following the eligibility assessment, five reports from the database search met the inclusion criteria. An additional report was identified through citation searching. Overall, six reports corresponding to five underlying studies were included in the review (Figure 1).

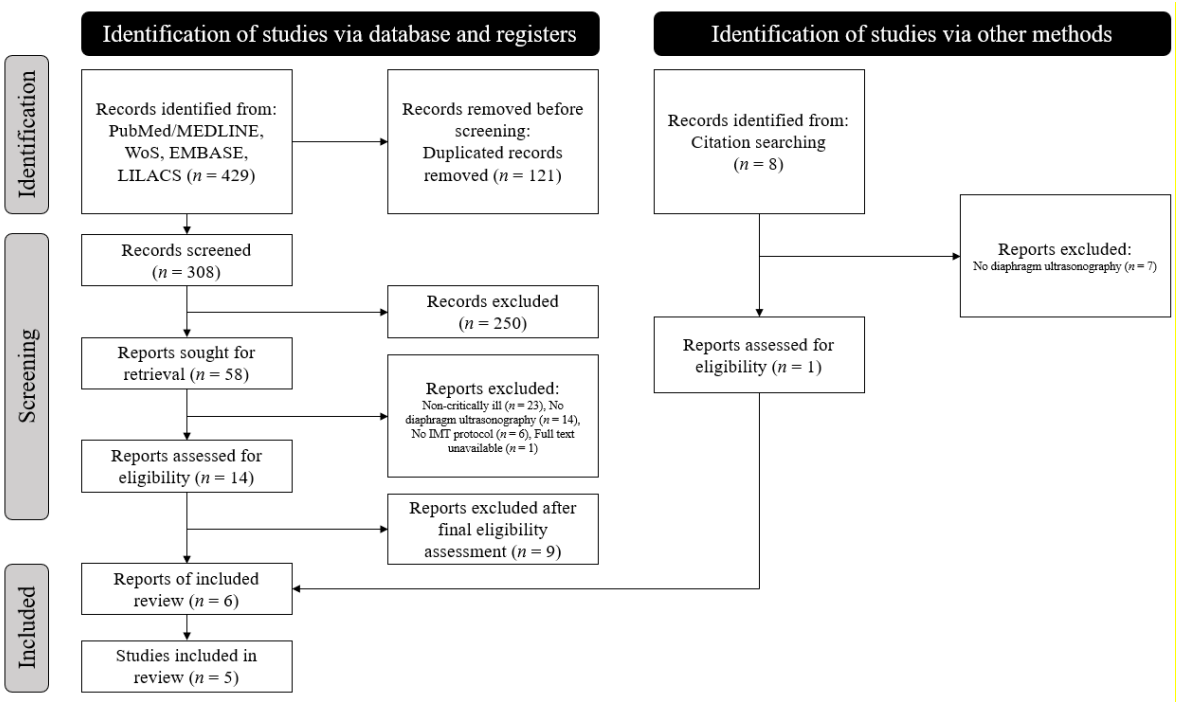


Figure 1: PRISMA-ScR flow diagram.

Note: MEDLINE: Medical Literature Analysis and Retrieval System Online; WoS: Web of Science; EMBASE: Excerpta Medica Database; LILACS: Literatura Latinoamericana y del Caribe en Ciencias de la Salud; IMT: Inspiratory Muscle Training; *n*: number of records/studies.

Characteristics of the included studies

The five included studies were published between 2022 and 2025 and reported in six publications. One study was conducted in Japan and reported in two publications, while the

remaining studies originated from Taiwan, Turkey, Colombia, and China. Four studies were RCTs, including one single-blind RCT, and one was a case series. The 2025 publication by Mizusawa et al. was a longitudinal follow-up/secondary report of the same RCT published in 2024 and was therefore not considered an independent trial. The clinical settings covered different stages of IMV, including patients receiving IMV in the intensive care unit, patients undergoing ventilator weaning or post-extubation rehabilitation, and patients undergoing major surgery who received pre- and postoperative IMT in the context of perioperative IMV. Table 1 summarizes the main characteristics and objectives of the included studies.

Table 1: General characteristics of the included studies

Author	Year	Country	IMV context	Objective
Huang et al.[16]	2022	Taiwan	Before and after IMV associated with upper abdominal surgery	To determine the effect of preoperative and postoperative IMT in patients undergoing upper abdominal surgery
Benli et al.[17]	2024	Turkey	Patients in the respiratory ICU after extubation (IMV >2 days)	To evaluate the effect of IMT on diaphragm thickness and diaphragmatic function in patients who received invasive mechanical ventilation
Mizusawa et al.[18,19]	2024 - 2025	Japan	Before and after IMV associated with major thoracoabdominal surgery to prevent prolonged ventilatory support (>48 h)	To evaluate the effect of preoperative IMT on diaphragmatic excursion in patients with esophageal cancer
Wilches-Luna et al.[20]	2025	Colombia	ICU patients receiving IMV for more than 72 hours	To describe changes in inspiratory muscle strength and diaphragmatic function after seven days of IMT in patients receiving IMV
Liu et al.[21]	2025	China	Older adults (≥65 years) with COPD receiving IMV for >48 hours	To evaluate the effectiveness of diaphragm ultrasound monitoring combined with IMT in facilitating weaning from invasive mechanical ventilation in older adults with COPD

Note. COPD = chronic obstructive pulmonary disease; ICU = intensive care unit; IMT = inspiratory muscle training; IMV = invasive mechanical ventilation

IMT Protocols used

The sample size of the included studies ranged from 5 to 96 participants. Most studies evaluated widely used threshold IMT devices, primarily PowerBreathe® or Threshold IMT®. Training loads ranged from 30% to 50% of MIP, and most protocols began at low-to-moderate intensity, with some incorporating progressive weekly increases in load. One study implemented a multimodal respiratory training strategy combining diaphragmatic breathing exercises, IMT, and accessory muscle training.

The duration of the interventions varied considerably across studies, ranging from short protocols of 5 days in critically ill or post-extubation patients to several weeks in perioperative populations, including both preoperative and postoperative training phases. Despite this heterogeneity, most interventions consisted of two daily training sessions, with repetition schemes generally ranging from 6 to 10 breaths per set and multiple sets per session, reflecting a structured approach to inspiratory muscle strength and endurance training.

The timing of IMT protocol implementation was heterogeneous, encompassing pre-ventilatory, peri-ventilatory, and post-ventilatory phases according to the clinical context of each study. Nevertheless, all studies shared common methodological principles based on threshold loading and repeated daily training exposure (Table 2), although the specific training prescriptions varied across studies.

Diaphragmatic US outcomes and response patterns

Diaphragmatic US findings were heterogeneous across the included studies, as detailed in Table 2. DE was the most consistently reported parameter across the included evidence. Most reports described improvements or preservation of DE following IMT, whereas one primarily reported attenuation of the expected postoperative decline.

In perioperative populations, IMT was associated with significantly higher DE compared with control groups. In surgical patients receiving IMV, IMT maintained significantly higher DE values compared with controls, who exhibited a marked reduction in diaphragmatic mobility after the intervention (5.29 ± 1.82 cm in the IMT group versus a deterioration of 2.53 ± 0.88 cm in the control group; $p = 0.012$)[16]. Other findings in patients undergoing thoracic surgery reported increases in DE from 5.57 ± 1.42 cm to 6.56 ± 1.46 cm ($p < 0.01$) following preoperative training, with a smaller loss of mobility at three-month follow-up (−0.13 ± 1.12 cm in the IMT group vs. −1.81 ± 1.45 cm in controls; $p < 0.01$)[19].

In the ICU setting and during ventilator weaning, IMT also demonstrated benefits on diaphragmatic dynamics. A RCT in elderly patients with COPD reported significantly higher DE values in the intervention group (2.40 ± 0.46 cm) compared with the control group (2.06 ± 0.46 cm; $p < 0.001$)[21]. Similarly, in post-extubation patients, IMT assessed by diaphragmatic US was associated with a significant increase in DE after five days of intervention ($p = 0.005$). These findings suggest a potential improvement in diaphragmatic function following IMT in patients recovering from prolonged mechanical ventilation.[17]

Regarding structural changes, DTF was assessed in four of the included studies. In a case series of critically ill patients, variable increases in DTF were observed, ranging from baseline values of 21–47% to post-intervention values of 19–56%[20]. However, other RCTs did not find statistically significant differences between groups for this parameter ($p > 0.05$),

which may be related to intrinsic patient variability or the impact of airway resistance in conditions such as COPD[16,17].

With respect to DT, baseline values ranged from 0.20 to 0.35 cm, with minimal changes and no statistically significant differences following training. Additionally, advanced contractile dynamics were assessed by analyzing PCV and PRV. The results showed significant increases after IMT: PCV increased from 9.09 ± 2.21 cm/s to 10.02 ± 2.60 cm/s ($p = 0.028$), while PRV increased from 11.30 ± 3.67 cm/s to 12.90 ± 3.43 cm/s ($p = 0.029$)[17]. These findings suggest that IMT enhances strength and displacement and improves the efficiency of diaphragmatic contractile dynamics.

Table 2: IMT protocols and diaphragmatic US outcomes in the intervention groups

Author	Design	*n*	IMT protocol	IMT device	Diaphragmatic US findings in the intervention group				
					DT	DE	DTF	PCV	PRV
Huang et al.[16]	RCT	28 patients (13 IMT, 15 control)	Start at 50% of MIP, with weekly increases of 5–10%. 3 weeks preoperative and 4 weeks postoperative	Threshold IMT trainer (Dofin™, Breathing Strength Builder, Taiwan)	Not reported	↑	o	Not reported	Not reported
Benli et al.[17]	Single-blind RCT	20 patients (10 IMT, 10 conventional physiotherapy) + 10 healthy controls	30% of MIP, twice daily for 5 days. 4 sets of 6–8 breaths	Threshold-loaded PowerBreathe Medic Plus (PowerBreathe International Ltd., Southam, UK)	o	↑	o	↑	↑
Mizusawa et al.[18,19]	RCT	40 analyzed at post-intervention T1 (20 IMT, 20 IS)[18]; 32 analyzed in longitudinal follow-up (15 IMT, 17 IS)[19]	30% of MIP during the first week, then 50% of MIP; ≥2 sessions/day, 30 breaths/session, ≥4 days/week during the preoperative period	PowerBreathe Medic (PowerBreathe International Ltd., Northfield Road, Southam, Warwickshire, UK)	Not reported	↑	Not reported	Not reported	Not reported
Wilches-Luna et al.[20]	Case series	5 patients	Initial load at 50% of MIP, twice daily for 7 days. 3 sets of 10 repetitions	Threshold IMT (Philips Respironics, Koninklijke Philips N.V.)	o	↑	↑	Not reported	Not reported

Author	Design	*n*	IMT protocol	IMT device	Diaphragmatic US findings in the intervention group				
					DT	DE	DTF	PCV	PRV
Liu et al.[21]	RCT	96 patients (48 intervention, 48 control)	Sequential training: diaphragmatic breathing exercises, IMT at 30% of MIP, and accessory muscle training	Threshold-based device	Not reported	↑	↑	↑	Not reported

Note. ↑ = increase in the measured parameter; o = no change or no statistically significant change; Not reported = data not available in the original study. IMT = inspiratory muscle training; IS = incentive spirometry; US = ultrasound; DT = diaphragm thickness; DE = diaphragmatic excursion; DTF = diaphragm thickening fraction; PCV = peak contraction velocity; PRV = peak relaxation velocity; RCT = randomized controlled trial; MIP = maximal inspiratory pressure

Discussion

This review identified a limited number of studies that combined diaphragmatic US with IMT in patients undergoing IMV or in perioperative settings associated with IMV. Although the available evidence was scarce and methodologically heterogeneous the included studies generally reported a similar pattern: diaphragmatic US was primarily used as a tool to monitor training response, whereas its potential to guide indication, individualization, or progression of IMT remains largely unexplored (Figure 2).

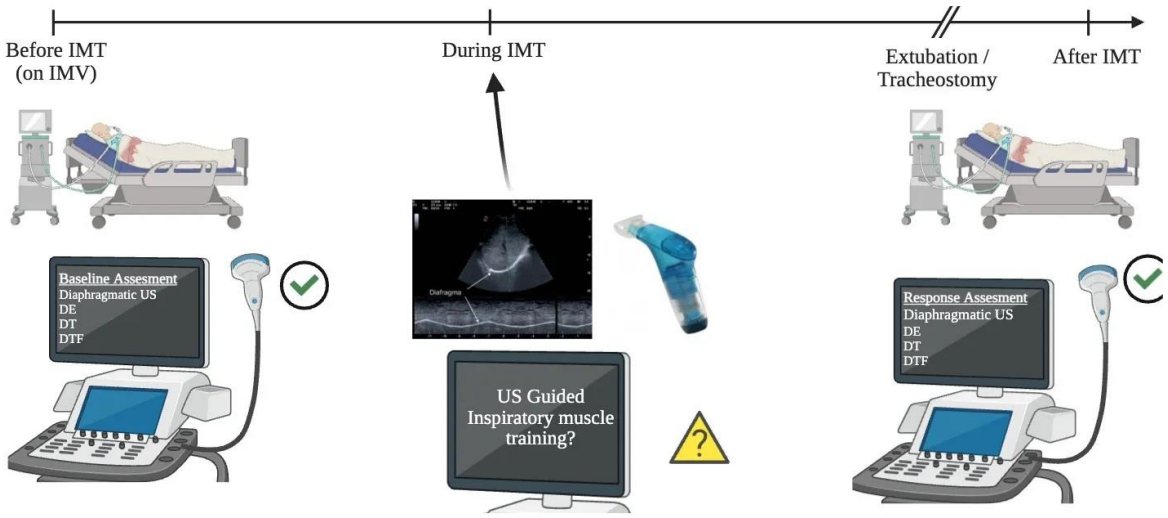


Figure 2: Current application of diaphragmatic US during IMT. Current evidence shows that diaphragmatic US is mainly performed before and after IMT to assess treatment response. No included study used serial ultrasound measurements during training to guide patient selection, adjust training intensity, or individualize progression, highlighting an important knowledge gap for future ultrasound-guided respiratory rehabilitation strategies.

Note: IMV = invasive mechanical ventilation; IMT = inspiratory muscle training; US = ultrasonography; DE = diaphragmatic excursion; DT = diaphragm thickness; DTF = diaphragm thickening fraction.

DE was the most frequently assessed US parameter and the one with the most consistent findings[16–21]. In most studies, IMT was associated with better preservation or increases in DE compared with conventional care, particularly in patients undergoing IMV for major surgery and in those undergoing ventilator weaning. These findings are physiologically plausible, as DE reflects the diaphragm's capacity to generate inspiratory displacement and has been previously associated with inspiratory muscle strength and successful weaning from mechanical ventilation[13,22–24]. However, substantial variability in protocols, populations, and assessment time points precludes determining the magnitude and consistency of the observed changes in DE.

Evidence was less consistent for DT and DTF. While some studies reported stability or increases following training, others found no statistically significant differences. This discrepancy likely reflects the physiological differences between the US-derived parameters. DT is primarily a structural marker that may change more slowly, whereas DTF is a functional index influenced by inspiratory effort, loading conditions, and the level of ventilatory support during measurement[25–27]. Consequently, these parameters may exhibit greater biological and methodological variability than DE.

Another relevant finding was the marked heterogeneity of IMT protocols. Studies implemented training across pre-ventilatory, peri-ventilatory, and post-ventilatory phases using threshold-loading devices with intensities between 30% and 50% of MIP. However, important variations were observed in intervention duration, session frequency, load progression schemes, and number of breaths per session. This variability is consistent with the literature, where methodological heterogeneity limits comparability across studies and

hinders the identification of specific training components responsible for observed ultrasound changes[28,29].

The application of diaphragmatic US was also heterogeneous. In most studies, it was used exclusively as an outcome measure before and after the intervention, without being incorporated into the prescription or adjustment of training. No study used US-derived parameters to select candidates for IMT, individualize training intensity, or dynamically modify load during the intervention. This represents one of the main knowledge gaps identified in this review and highlights an opportunity to develop more personalized respiratory rehabilitation strategies, positioning diaphragmatic US as a potential tool for individualizing IMT.

Currently, MIP remains the standard method for IMT load prescription despite being a volitional test dependent on patient cooperation, potentially yielding false-negative results due to suboptimal effort and not exclusively reflecting diaphragmatic strength[29-31]. The integration of non-volitional parameters such as US represents a critical opportunity to improve assessment and monitoring in patients undergoing IMT.

The limitations of this review should be considered when interpreting the findings. The small number of included studies, limited sample sizes in several investigations, heterogeneity of clinical populations, and variability in IMT protocols and US techniques restrict comparability across studies and preclude quantitative synthesis. Furthermore, although a structured search strategy was applied across indexed databases and complemented with manual searching, the possibility of missing relevant literature cannot be excluded, particularly from non-indexed sources or grey literature.

Conclusion

The available evidence suggests that diaphragmatic US is a promising tool for assessing functional changes associated with IMT in patients before, during, or after IMV. However, there are still insufficient data to define its role as a marker for patient selection, longitudinal response monitoring, or individualization of training programs. Future clinical trials should incorporate standardized US protocols, simultaneously assess both structural and functional diaphragmatic parameters, and investigate US-guided IMT strategies in order to determine whether this approach can optimize respiratory rehabilitation and improve clinical outcomes in patients undergoing IMV.

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