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Diaphragm ultrasound in children useful in emergency and non-emergency indications. Clinical applications: A systematic review

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ABSTRACT

M-mode ultrasonography has been used in the assessment of diaphragm kinetics. The sonographic diaphragmatic parameters can provide valuable information in the assessment and follow-up of patients with diaphragmatic dysfunction, during ventilation, and can potentially help to understand post-operative pulmonary dysfunction or weaning failure from ventilation. We conducted a systematic review of literature concerning the clinical applications of diaphragmatic ultrasound in children. The morphological and functional evaluation of the diaphragm by ultrasound technique is becoming an increasingly widespread practice in intensive, medical and surgery category. Our systematic review shows how diaphragmatic ultrasonography finds indication in different areas. It requires a standardization of parameters and normal measurement values.

1. Introduction

Ultrasound as a point of care tool (POCUS) is in increasing use not only in intensive care and emergency departments but also in routine clinical practice [1]. The application area has grown to include also the study of the diaphragm [1]. The diaphragm is the main respiratory muscle and plays a pivotal role in ventilation. There are several causes that can determine diaphragmatic dysfunction (DD) such as neuromuscular pathologies, cardiac surgery, ventilation or chronic lung diseases. The entire diaphragm or only one side may be involved. Dysfunction is defined as a loss of maximum muscle strength resulting in reduced inspiratory capacity and reduced resistance of the respiratory muscles [2,3]. There are techniques for examining diaphragmatic function in adults and not always applicable in children [4]. The gold standard is the measurement of transdiaphragmatic pressure (Pdi) [5–7]. However, it is an invasive and difficult technique to perform, therefore its use is limited both in adults and even more so in children. Various non-invasive tests have been used to study the diaphragmatic function in the clinical practice, for example, from blood pressure measurement static inspiratory maximal (MIP) and the nasal pressure generated during sniff maneuvers [8–10]. Indirect techniques to DD measurement can occur with ventilatory function tests such as a reduction in total lung capacity (CPT) and vital capacity, electromyography with stimulation of the phrenic nerve [6]. Finally, fluoroscopy is commonly used to diagnose diaphragmatic paralysis, but this method lacks specificity [11]. Recent studies have shown that ultrasound (US) allows the quantitative evaluation of diaphragmatic function. Different US techniques have been validated, however to date there is no standardization as well as for normal values of US parameters. Several reviews on the use of US, or POCUS, for the evaluation of diaphragm dysfunction in adults are described [12–15] but no reviews have been performed for children. We conducted a systematic review of literature concerning the clinical applications of diaphragmatic US in children.

1.1. Diaphragm anatomy

The diaphragm is one of the main muscles of the respiratory system. It divides the abdomen from the chest, and in its relaxed form it assumes the typical domed appearance. When contracted, the diaphragm flattens itself reducing the intrathoracic pressure and passing the air inside into the lungs. The diaphragm is able to do this for its anatomy including: the centrum tendineum (apex of the dome) that is the non-contractile and therefore non-modifiable area; the muscle fibers that depart from the centrum tendineum radially from the back to the front. These muscle fibers terminate on the posterior aspect of the T5 to T12 ribs. The

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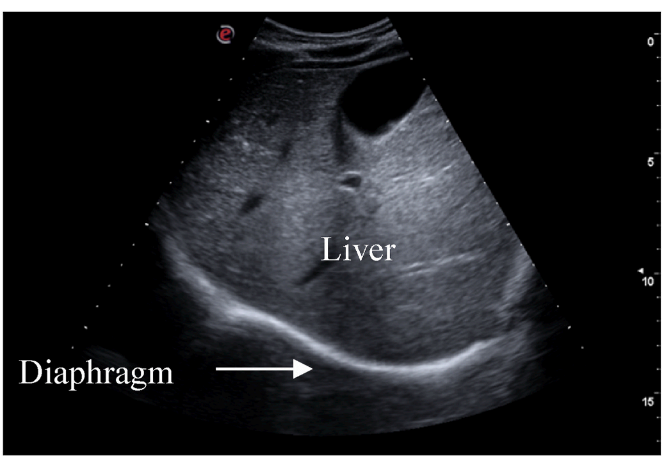
diaphragm and rib area are commonly referred to as the apposition zone (ZOA). During contraction, the change in the length of the muscle fibers leads to a change in the size of the diaphragm (thickening) in the ZOA, causing the diaphragm to move caudally during inspiration and cranially during exhalation (Figs. 1 and 2). The diaphragm is innervated by the phrenic nerve which, passing through the mediastinum, reaches the diaphragm in the abdomen. During mechanical ventilation, depending on the type of ventilation of the drugs used for sedation, the normal diaphragmatic function is either abolished.

1.2. Diaphragm ultrasound anatomy, technique and parameters

To evaluate diaphragm function are described in literature two various approach (Fig. 3).

1. A 3.5–5 MHz phased array probe is required for performing diaphragmatic ultrasound. The probe is placed under the right or left rib margin in the mid-clavicular line, or in the right or left anterior axillary line. Thus, the probe is direct medially in a long way to direct the ultrasound perpendicular to the posterior third of the semi-diaphragm. B-mode is initially used to visualize the exploration area; M-mode is used to visualize the diaphragm movement (Figs. 1–3). The liver serving as an acoustic window on the right and the spleen on the left. The acoustic window from the spleen offering is smaller, so the excursion of the left hemidiaphragm will be more difficult. For this reason, on the left, it is often necessary to resort to the approach from Le Rolle et al. [16]: the probe must be placed on



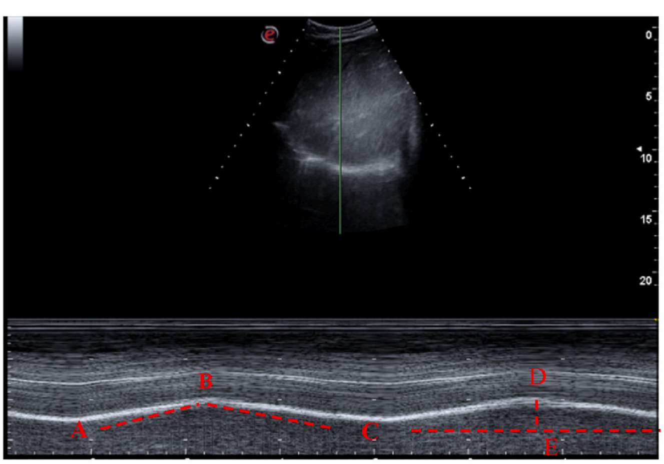


Fig. 1a. A) 6-years old with a normal diaphragm in B- and M-mode with convex probe in subcostal approach: AB: inspiratory slope; BC: expiratory slope; DE diaphragm excursion; AC: duration cycle.

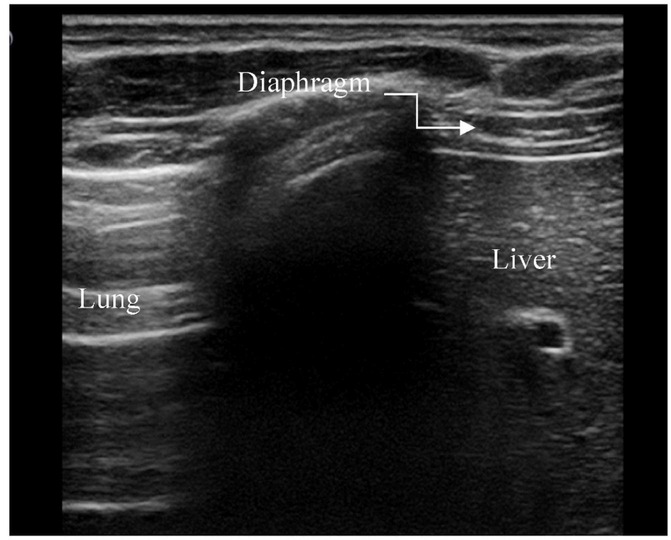
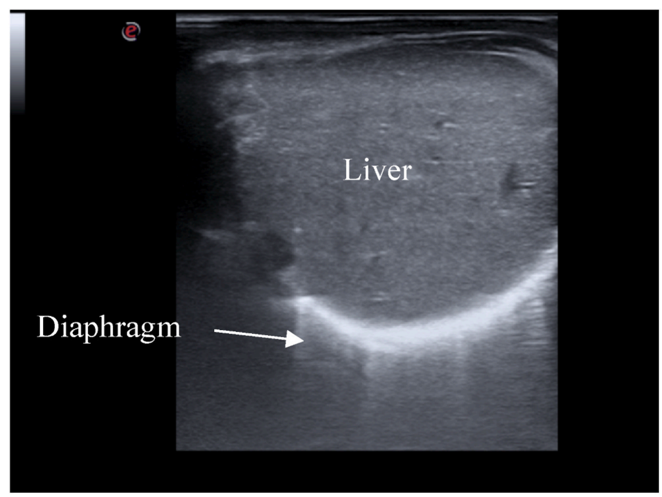


Fig. 1b. B) 6-years old with a normal diaphragm in B-Mode, with a linear probe in medium axillary line. Diaphragm thickness.



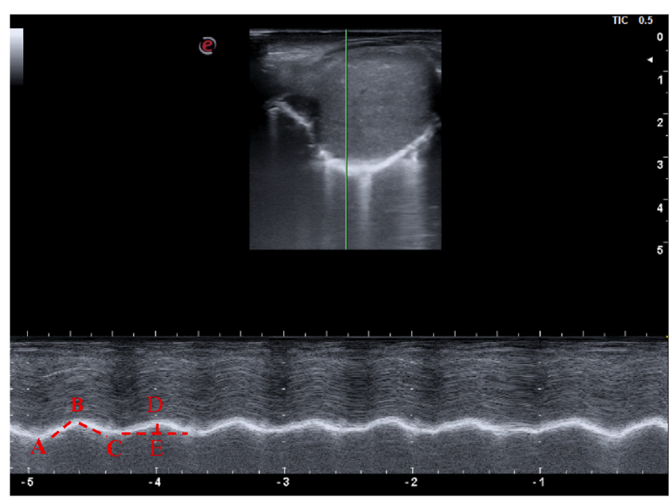


Fig. 2a. A) 34 weeks diaphragm, with respiratory distress, in Nasal intermittent positive pressure ventilation (NIPPV) in B- and M-mode, with phase-array probe in subcostal approach: AB: inspiratory slope; BC: expiratory slope; DE diaphragm excursion; AC: duration cycle.

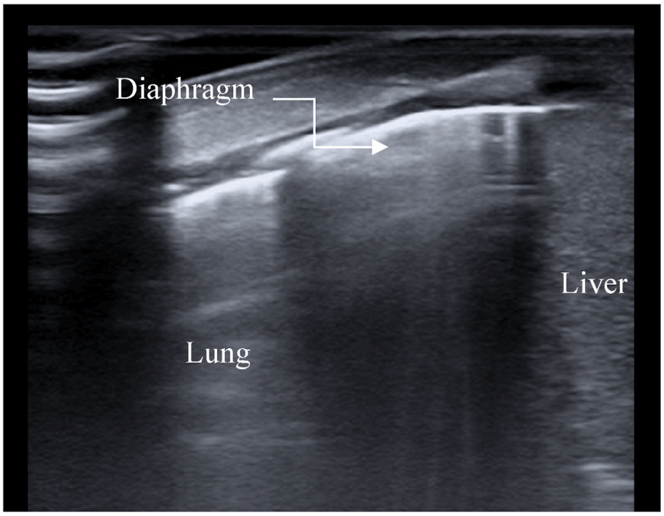


Fig. 2b. B) 34 weeks diaphragm with respiratory distress, in Nasal intermittent positive pressure ventilation (NIPPV) in B-Mode, with a linear probe in medium axillary line. Diaphragm thickness.

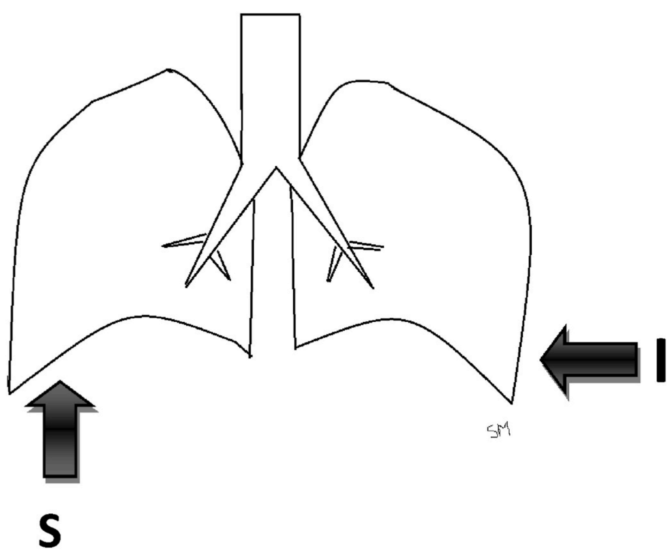


Fig. 3. Diaphragm ultrasound technique: two approach. Subcostal (S) and intercostal (I).

the longitudinal plane, in correspondence with the middle axillary line or, posteriorly, on the axillary line. Once the transducer has been positioned at this level, it must be rotatedclockwise, until the image of a hyperechoic curve is obtained which corresponds to the left hemidiaphragm. The normal inspiratory movement of the diaphragm is caudal, as the diaphragm approaches the probe; the expiratory one is cranial, the diaphragm moves away from the probe. In M-mode is possible to measure the diaphragmatic excursion (DE, cm), the diaphragmatic contraction speed (slope, cm/s), the inspiratory time (Tinsp, s) and the duration of the cycle (Ttot, s) [17].

2. With the linear probe at high frequency (>10 MHz), in M-mode, is possible to evaluate the diaphragm thickness (DT) and the thickening with inspiration (TF) (Figs. 1–2). The probe is positioned in the ZOA, between VIII and X intercostal space along the mid-axillary or antero-axillary line, 0.5–2 cm below the costophrenic sinus. In B-mode two parallel echogenic layers are identified: the closest line is the parietal pleura, the deeper one is the peritoneum. The diaphragm is the least echogenic structure between these two lines (Figs. 1–2) [18].

The ultrasound parameters evaluated are.

- *Thickness and thickening fraction:* Diaphragm thickness (DT) is measure perpendicularly between the pleural and peritoneal membrane (Figs. 1–2). The term thickening fraction (TF) refers to the percentage increase in thickness of the diaphragm that occurs at each inspiratory act as a consequence of the contraction of the muscle. The study of DF and TF must be carried out in correspondence with ZOA, displaying first B-MODE and then M-MODE. Thanks to M-MODE it is possible to evaluate how the DT varies in relation to the ventilatory phase. In the inspiratory phase the muscle thickens, reaching, at the end of a quiet inhalation, what is called maximum diaphragmatic thickness. At the relaxed end of a quiet exhalation, the muscle is thick and corresponds to the so-called minimum or expiratory diaphragmatic thickness. Therefore, TF is described by the relation TF = [(maximum thickness - minimum thickness)/minimum thickness] %. This ultrasound index constitutes a valid estimate of diaphragmatic contractility with greater accuracy than the thicknesses taken individually.
- *Diaphragm Excursion:* In M-mode is possible to measuring the diaphragm excursion. In this image the normal diaphragm is represented as a hyperechogenic line that moves during the acts of breath. During inspiration, the diaphragm moves towards probe and this is recorded as an upward motion of hyperechogenic line; during expiration, the diaphragm moves away from transducer resulting in a downward inflexion. The amplitude of excursion of the hemidiaphragm is measured on the vertical line drawn from the baseline to the point of the maximum height of the inspiration. The vertical distance represents diaphragmatic excursion. In this image is possible evaluate the speed of contraction of the diaphragm (inspiratory slope [IS]), and the duration of the cycle (Ttot) (Figs. 1–2).

2. Materials and methods

Two independent researchers performed extensive research on electronic medical databases [PubMed, Embase, Cochrane Library, Scopus and Web of Science] evaluating the published literature. References of all recovered articles were scanned for additional relevant manuscripts. The terms MeSH (Medical Subject Headings) "*diaphragm ultrasound*" AND "*diaphragm dysfunction*" AND "*ultrasound*" has been entered into the search bar. The search was developed to have the widest possible sensitivity, while specificity was ensured by scanning the retrieved results as follows: A reviewer examined the titles and abstracts resulting from the electronic search to exclude articles that were irrelevant. Others two independent reviewers reviewed the full text of the remaining studies. A sixth reviewer was employed to make the final decision when it could not be reached. All type of article were considered and were included only studies in children. Then were discussed the results. This study was conducted and reported following the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) guidelines (Flowchart 1). We then scanned all the studies documenting the use of diaphragmatic ultrasound and potential uses.

3. Results

The search getting as a result a total number of 1157 studies. Of these 1157 studies we selected articles with *"Child (birth -18 years)"* obtaining 203 studies. Only articles in "*English*" were selected, thus obtaining a total of 174 items. Not time-limited articles and considered studies from 1967 to date, because we wanted to include all the studies that reported the experience with the use of diaphragmatic ultrasound and its potential applications. According to PRISMA statement, among these studies, 24 were eligible (flowchart 1) and in details they were 11 prospective study, 6 case reports, 1 narrative review, 1 clinical trial, 3 retrospective study, 1 comparative study, 1 mixed retrospective and prospective (Table 1). 4 out of 24 studies dealt with the usefulness of

Table 1
Summary of Findings: Systematic pediatric literature Reviewed.

Author (pubblication year)	Category	Study type	Aim	Patiens (n)	Age (median)	Main findings
Urvoas et al. (1994) (19)	Pediatric ICU	Prospective observational	To report and describe US signs of DD in children	27	3.9 (4.3) years	TM-mode allows one to diagnose diaphragmatic paralysis in children
Balaji et al. (1990) (20)	Pediatric cardiac ICU	Prospective observational	To assess the accuracy of US *vs* fluoroscopy to diagnose diaphragmatic palsy after surgery	16	8 months	US allows one to identify diaphragmatic palsy without fluoroscopy
Sanchez de Toledo et al. (2010) (21)	Pediatric cardiac ICU	Prospective observational	To assess accuracy of US for diagnosis of DD	25	3 months)	DU performed by cardiac intensivists allows for an early diagnosis of DD
Montoro et al. (2021) (22)	Pediatric ICU	Prospective, observational	To describe the evolution of diaphragmatic morphology and functional measurements by US in ventilated children.	47	3 months	Point-of-care diaphragmatic US can detect diaphragmatic atrophy in mechanically ventilated children.
Hamadah et al. (2016) (23)	Paediatric cardiac ICU	Retrospective	To evaluate the role of bedside US performed by an intensivist to diagnose DD and the need for plication after pediatric cardiac surgery.	17	10.8 months	US assessment of diaphragmatic movement is a useful and practical bedside tool that can be performed by a trained paediatric cardiac ICU intensivist. It may help in the early detection and management of DD after paediatric cardiac surgery through a decision-making algorithm that may have potential positive effects on morbidity and outcome.
Weber et al. (2021) (24)	Pediatric ICU	Narrative review	To summarize the current literature regarding techniques, reference values, applications, and future innovations of diaphragm POCUS in pediatric critical care	Not applicable	Not applicable	Optimizing respiratory mechanics using US-derived measures of the diaphragm has the potential to provide sufficient support while limiting ventilator-induced DD resulting in successful weaning and extubation.
Noh et al. (2016) (25)	Pediatric dpartment	Case series	To determine intertester and intratester reliability of US measurements of bilateral diaphragm excursions in the thoracic and thoracolumbar spinal curves	31	14.1 years	n evaluating diaphragm movement in idiopathic thoracic scoliosis and idiopathic thoracolumbar scoliosis
Xue et al. (2020) (26)	Pediatric ICU	Prospective observational	To identify risk factors associated with DD, and to investigate the effects of DD on clinical outcomes among critically ill children.	70 (46 and 24 children)	Two group: Non DD 33.50 (12.00–72.00) DD 45.50 (20.75–135.00)	DD diagnosed by US is associated with poorer clinical outcomes in critically ill childern, which include a longer PICU length of stay, higher rate of weaning or extubation failure and a higher mortality.
Kharasch et al. (2021) (27)	Pediatric ICU	Case series	To evaluate for ventilator-induced DD by POCUS	24	4.89 years	To accurately detect DD, by POCUS, in children with medical complexity and dependence on long-term MV
Buonsenso et al. (2020) (28)	Pediatric department	Prospective	To investigate the US features of diaphragm motion and function in a cohort of SMA-1 patients. To correlate SMA 1 diaphragm US findings with type of respiratory support, genetic abnormalities, SMA-1 subtypes, and different treatment protocols.	23	23 month	US can be used to provide additional information to the clinical examination and functional respiratory tests, describing a characteristic contractility pattern.
Lee et al. (2017) (31)	Pediatric ICU	Prospective	To study diaphragm atrophy and DD by US in mechanically ventilated children that may develop them.	31	3 years	Diaphragm US is a promising tool for assessing diaphragmatic function in mechanically ventilated children
Maffey et al. (2019) (32)	Pediatric department	Observational Study	To evaluate clinical, pulmonary, and diaphragmatic function and radiological outcome in patients hospitalized with pleural empyema.	30	9.7 years	Follow-up by diaphragm US in previous pleural empyema.
De Bruin et al. (1997) (33)	Pediatric department	Case reports	To evaluate morphometric characteristics of diaphragm thickness during tidal breathing and the diaphragm in patients with Duchenne muscular dystrophy.	10	10.3 years	Resting diaphragm thickness is increased in young patients with Duchenne muscular dystrophy with impaired respiratory muscle force
Gil-Juanmiquel et al. (2017) (34)	Tertiary university hospital	Clinical trial	To assess the utility of bedside US combining B- and M-mode in the diagnosis of abnormal diaphragmatic motion in children after heart surgery.	26	5 months	US is a valid tool for the diagnosis of diaphragmatic paralysis, presenting greater sensitivity and specificity than fluoroscopy
Laviola et al. (2018) (35)	Pediatric department	Prospective	To noninvasively assess diaphragmatic function in dystrophy Duchenne by measuring diaphragmatic thickness by US	44	<18 years	US could be used as a noninvasive method to assess progressive diaphragmatic weakness.

(*continued on next page*)

Table 1 (*continued*)

Author (pubblication year)	Category	Study type	Aim	Patiens (n)	Age (median)	Main findings
Bahgat et al. (2020) (36)	Neonatal ICU	Prospective, observational, cohort	US assessment of the diaphragmatic dimensions and excursion for mechanically ventilated preterm infants as a predictor for success of extubation.	43	<32 weeks	Diaphragmatic excursion is a useful indicator for successful extubation of preterm infants from mechanical ventilation.
Laing et al. (1988) (37)	Neonatal ICU	Prospective	To provide normative data on the range of diaphragmatic motion in full-term, healthy newborn infants. In addition observations of diaphragmatic movement in infants during mechanical ventilation and pharmacologic paralysis.	46	1–4 days	The use of real-time US may allow correlation of observed movement of the diaphragm with measurements of flow at the airway opening and may therefore contribute to understanding of respiratory mechanics in infancy.
Nozaki et al. (2018) (38)	Neonatal ICU	Case report	To use the diaphragm thickness fraction to diagnose diaphragm paralysis in a neonate during positive pressure ventilation support	1	10 days	The diaphragm thickness fraction method can help diagnose diaphragm dysfunction using only US.
Ambler et al. (1985) (39)	Neonatal ICU	Case report	To monitor in term infant diaphragm activity after bilateral diaphragmatic paralysis by US	1	12 days	US assessment of diaphragm contraction may be used to study progress in diaphragmatic paralysis.
Lemmer et al. (2007) (40)	Pediatric cardiac	Retrospective and prospective	To look at the mid-term outcome with postsurgical diaphragmatic paralysis	15	1.4 years	Ultrasound showed that in the majority of cases with history of DP the paralysed diaphragm was static, independently of whether it was plicated or not.
Zifko et al. (1995) (41)	Neonatal ICU	Case reports	To study diagnostic and therapeutic experiences in newborns with birth-traumatic phrenic nerve injury	4	23 months	US examination of the diaphragm and phrenic nerve conduction studies turned out to be the diagnostic methods of choice.
Diament et al. (1985) (42)	Neonatal ICU	Retrospective study	To use ultrasonography as the primary imaging modality for evaluation of suspected abnormalities of diaphragmatic motion or position	14	27 months	Real-time sector US should be used as the primary imaging modality for evaluation of suspected abnormalities of diaphragmatic motion and position.
Şık et al. (2021) (43)	Pediatric Emergency Department	Prospective	To evaluate diaphragmatic parameters in bronchiolitis and identify correlations between clinical and US severity scores and outcomes to develop a more objective and useful tool in the emergency department	104	6.5 months	Agreement between the clinical and sonographic severity scores
Şık et al. (2021) (44)	Pediatric Emergency Department	Prospective	To evaluate diaphragm US parameters as a new useful tool to objectively score the severity of the disease and predict outcomes in children with pneumonia.	96	30.0 months	Diaphragm parameters may provide objective and reliable information to predict the severity of the illness, the need for respiratory support, and outcomes.

ICU: Intensive Care Unit; US: ultrasound; DD: diaphragm dysfunction; POCUS: Point-of-care ultrasound; DP: diaphragm paralysis.

ultrasound in diaphragmatic assessment (paralysis or the need for diaphragmatic plication) after pediatric cardiac surgery [20,21,23,40]. 6 out of 24, performed in neonatal intensive care, for ultrasound evaluation of diaphragm size and excursion for ventilated preterm infants as a predictor of extubating success, for the study of diaphragmatic movements for diaphragmatic paralysis induced by drugs or mechanical ventilation [36–39,41,42]. Diaphragmatic dysfunction in diaphragmatic paralysis due to surgery or ventilation has been described in 6 out of 24 pediatric intensive care studies, evaluating, in some, the accuracy of ultrasound versus fluoroscopy [19,22,24,26,27,31]. In 2 out of 24 studies, conducted in pediatric emergency department, ultrasound of the diaphragm with related parameters has been used in case of bronchiolitis or pneumonia as a tool to assess clinical severity and predict outcomes in children in the emergency room [43,44]. Finally, diaphragmatic ultrasound was used to evaluate diaphragmatic parameters in neuromuscular patients affected by spinal muscular atrophy (SMA) or Duchenne muscular dystrophy (DMD), or children with previous pleural empyema [25,28,30,32–35].

4. Discussion

The morphological and functional evaluation of the diaphragm by ultrasound technique is becoming an increasingly widespread practice not only in intensive care units (ICU), but also medical and surgery category. Diaphragmatic ultrasound is a non-invasive diagnostic tool, not use ionizing radiation, easy, quickly and at bedside patient. It is possible to perform serial examinations over time without risks and costs. The ultrasound study of the diaphragm today represents a key element for the diagnosis, monitoring and follow-up from preterm to adulthood. However, to date, in the paediatric age there are no standardized methods of assessment and it enter in clinical practice with greater difficulty. Ultrasound is indicated in all cases of diaphragmatic dysfunction. This term refers to a condition that extends from a partial loss of pressure capacity (diaphragmatic weakness) to a complete loss of muscle function (diaphragmatic paralysis). In the literature there are no reference for normal values of diaphragm dimensions, function, or quantitative parameters in children. Diaphragmatic motion has previously been categorized as normal, decreased, absent, or paradoxical [19]. In children suspected to have diaphragmatic paralysis, the diaphragm excursion was considered normal if inspiratory motion is toward the transducer, with an amplitude> 4 mm and a difference of DE between hemidiaphragms <50 %. An amplitude of ≤4 mm and a difference of DE between hemidiaphragms >50 % was considered decreased. Absent and paradoxical motion was characterized by no movement and inspiratory movement away from the transducer, respectively. However, this should take into account of the age [19,24].

From our systematic review it is clear that there are several indications to assess the diaphragm by ultrasound (Table 2). First of all, ultrasound, can be used to screen the lower thoracic and upper abdominal regions to exclude diaphragm contiguous pathologies (e.g., effusion, lung consolidation, or mass lesions). Clinical conditions characterized by air trapping or pleural empyema, may determine an abnormal profile of the diaphragm [30]. In the paediatric emergency room, diaphragm ultrasound was used by Şık et al., in 2021 in two studies, as a tool to predict clinical severity and outcome of children with acute bronchiolitis and pneumonia, respectively [43,44]. In both studies, ultrasound parameters such as diaphragmatic thickness at the end of inspiration and exhalation, thickening fraction, diaphragm excursion, inspiratory slope, expiratory slope and time of total duration of the respiratory cycle were measured. The authors demonstrated how fraction of thickening, slope in - and expiratory can provide objective and reliable information to predict disease severity, need for respiratory support and outcomes [41, 42].

Diaphragmatic ultrasound plays a role in the diagnostic process and monitoring of neuromuscular diseases such as SMA and DMD [28,30]. In particular, Buonsenso et al. [28] evaluated whether the diaphragmatic function and contractility pattern in patients with SMA type I is different compared to different types of SMA and neuromuscular pathologies with different types of respiratory support, genetic anomaly, genes and different treatment protocols. However, this study has limitations such as the small sample and not taking into account the effects on diaphragmatic functionality of the various therapeutic protocols [28]. De Bruin et al., in 1997 [33] and after Laviola et al., in 2018 [35] evaluated the diaphragmatic thickness in subjects with DMD, in the hypothesis that the progressive reduction of lung function is related to the alteration of the thickness [33,35]. Laviola et al. [35] studied two groups (DMD and control), measuring diaphragm weakness with thickness during silent, inspiratory breathing capacity, maximum inspiratory pressure and expiratory pressure manoeuvre. However, the only possibility to study the diaphragm in the supine and not seated position, for the underlying pathology of the patients, is only the right hemidiaphragm and costal region as well as the small number of the sample represent the limits [35]. Ultrasonography was also used to evaluate clinical, pulmonary and diaphragmatic function as well radiological outcome in hospitalized patients with pleural empyema [32]. Maffey et al. [32] monitored 30 children between the ages of 6 and 16 with previous pleural empyema, considering ultrasound as a useful tool for monitoring these children in predicting any complications. Diaphragmatic palsy is a rare but severe complication after paediatric cardiac surgery. An effective treatment of respiratory impairment is the transthoracic diaphragmatic plication [29]. Balaji et al., in 1992 found that ultrasound examination at the bedside was as effective as fluoroscopy in the diagnosis of a paralysed hemidiaphragm due to cardiac surgery in new born [20]. Ultrasound examination facilitates early diagnosis and is of particular benefit in infants, when plication is often necessary to achieve extubating [20]. Subsequently, in 2010, de Toledo et al. conducted a prospective study in paediatric patients with suspected abnormal diaphragmatic motion after cardiothoracic surgery [21]. In these patients, ultrasound is highly accurate in predicting fluoroscopy results, therefore serving as an equally useful [21]. Lemmer et al. [40] used the ultrasound to study the mid-term outcome with postsurgical diaphragmatic paralysis. Ultrasound showed that in the majority of cases with history of diaphragmatic paralysis, the paralysed diaphragm was static, independently of whether it was plicated or not [40]. Hamadah et al. [23], also promote the use of ultrasound for assessing diaphragmatic dysfunction after paediatric cardiac surgery. In a retrospective cohort study on prospectively collected data of postoperative children admitted to the paediatric cardiac ICU, the ultrasound turned out a bedside tool to early detection and management of diaphragmatic dysfunction through a decision-making algorithm that may have potential positive effects on morbidity and outcome [23]. Finally, as well as in paediatric intensive care, ultrasound is also used in neonatal intensive care for both term and preterm births. In preterm infant to assessment of the diaphragmatic dimensions and excursion for mechanically ventilated as a predictor for success of extubating [36]. In full-term, healthy new-born infants, to provide normative data on the range of diaphragmatic motion in addition movement observations in infants during mechanical ventilation and pharmacologic paralysis [37]. The use of real-time US may allow correlation of observed movement of the diaphragm with measurements of flow at the airway opening and may therefore contribute to understanding of respiratory mechanics in infancy [37]. Nozaki et [38], instead, focused on uses the diaphragm thickness fraction to diagnose diaphragm paralysis in a neonate during positive pressure ventilation support. The diaphragm thickness fraction method can help diagnose diaphragm dysfunction using only ultrasound [38]. To study diagnostic and therapeutic experiences in new-borns with birth-traumatic phrenic nerve injury. Ultrasound examination of the diaphragm and phrenic nerve conduction studies turned out to be the diagnostic methods of choice [41]. To use ultrasonography as the primary imaging modality for evaluation of suspected abnormalities of diaphragmatic motion or position, about Diament et al. [42], real-time sector US should be used as the primary imaging modality for evaluation of suspected abnormalities of diaphragmatic motion and position.

Table 2
Clinical indications for ultrasonography of the diaphragm in children.

Category	Indications
Medical	Neuromuscular disorders Follow-up in previous pleural empyema. Vertebral skeletrical disorders
Cardiac surgery	Diagnosis and the need for diaphragm plication Ultrasound accuracy *vs* fluoroscopy Traumatic phrenic nerve injury
Intensive Care	Diagnosis and monitoring of diaphragmatic paralysis Diaphragmatic atrophy or dysfunction in mechanically ventilated Diaphragmatic dysfunction with positive pressure ventilation support To predict the severity of the illness, the need for respiratory support, and outcomes in bronchiolitis and pneumonia Weaning and extubating

5. Conclusion

Diaphragm ultrasound has shown to be useful tool, non-invasive, reproducible, low cost and bedside to assessment all abnormalities of this muscle. Thanks to ultrasound parameters measurement, albeit limited by the lack of normal standardized values, appears a great technique for value diaphragmatic dysfunction. Current literature suggests and promotes the use of diaphragm ultrasound to detect diaphragmatic dysfunction in critically ill patients, or preterm or full term or children, to predict extubating success or failure, to monitor respiratory workload, and to assess atrophy in patients who are ventilated. After pediatric cardiac surgery, it seems that ultrasound is even more accurate than traditional fluoroscopy to monitor and evaluate surgical complications such as diaphragm paralysis and possible plication of the same muscle. Ultrasound, further, is a valuable tool in evaluating in chronic neuromuscular disease, SMA and Duchenne dystrophy or predict clinical severity and outcome in acute bronchiolitis and pneumonia in emergency department. Ultrasound currently has great clinical potential in the study of diaphragmatic dysfunction and, therefore, in respiratory evaluation. We believe ultrasound of the diaphragm should be a routine part of clinical practice.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wfumbo.2024.100033.

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