Editorial Commentary

Could lung ultrasound be a valid alternative to ionizing radiation or a complementary diagnostic choice in pediatric respiratory diseases?

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Respiratory diseases are among the most epidemiologically widespread pathologies in newborns and pediatric patients and are the major cause of mortality and morbidity worldwide, keeping in mind that acute lower respiratory infection (ALRI) is the most frequent cause of death in children under 5 years of age worldwide (1).

There are many respiratory conditions affecting children: acute chest syndrome, allergic diseases, bronchitis, bronchiolitis, bronchopulmonary dysplasia (BPD), chronic lung disease (CLD), congenital airway and lung malformations, cystic fibrosis, flu, laryngitis or croup, lung diseases secondary to immunodeficiencies and immune disorders, obstructive sleep apnea syndrome (OSAS), pediatric asthma, pediatric acute respiratory distress syndrome (PARDS), pleural effusion, pneumonia (probably the most devastating as it causes approximately 700,000 deaths per year), pneumothorax (PNX), pulmonary aspergillosis, primary ciliary dyskinesia, pulmonary contusion, pulmonary edema, pulmonary hypertension, pulmonary tuberculosis (TB), respiratory diseases in the newborns, sickle cell disease, sudden infant death syndrome, whooping cough or pertussis (2).

Although there is a wide range of pediatric respiratory illnesses (PRI): the main causes of pediatric emergency room (ER) visits and hospitalizations in the United States of America are asthma, bronchiolitis, pneumonia, croup, and influenza (3).

Traditionally the most used diagnostic tests in respiratory disorders in pediatric patients are: blood exams including emocrome and a comprehensive metabolic panel, C-reactive protein (CRP), blood cultures, pulse oximetry count, arterial blood gas analysis, spirometry, computed tomography (CT) and chest X-rays (CXR) (2). Despite chest CT, probably, can be considered the gold standard in respiratory disease diagnosis, CXR is still widely used and it is often the method of first choice because it exposes to significantly reduced doses of ionizing radiation, it is faster to carry out and easier available even in remote areas respect to chest CT.

For many years the possibility of using lung ultrasound (LUS), as an alternative or complementary diagnostic method to CXR and/or chest-CT, was excluded assuming that the air, the "enemy of ultrasound", did not allow to visualize the lung. The importance of LUS has been highlighted by the demonstration that ultrasound (US), upon encountering the lung, can detect "objectifiable artifacts" generated by the pleural line and the loss of part of the air content and/or the increase of the liquid content (for example in the wet lung of heart failure or in consolidations) or the air presence in an anomalous location

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(for example air in the pleural space: PNX) generate the artifacts.

Recently literature have highlighted the central role of LUS, because has proven to be, over the years, a sort of reasonable bedside "gold standard" method especially in emergency situations in the critically ill pediatric patients (4).

However, LUS in the pediatric population has pros and cons compared to CXR and chest CT (*Table 1*).

Importantly are well known the secondary effects related to repeated exposure to high doses of ionizing radiation in adult patients, even more so in pediatric patients in which, for example, were previously described the stochastic effects and the association between ionizing radiation with cancer, where the highest risks appear to be for newborn female and young girls: this would recommend evaluating the use of alternative diagnostic techniques, if available (5). The concept of non-invasiveness of LUS compared to ionizing radiation (CXR and CT) is even more invaluable in the pediatric population, but an US approach offers many distinct advantages and benefits, in addition to non-invasiveness. It is an inexpensive method compared to traditional imaging techniques, repeatable, safe, convenient and painless, which also saves time and resources as it can be taken directly bedside. Because its portability, allowing a rapid assessment of children with respiratory symptoms in different settings, to begin with remote areas or third world countries, where it may be the only imaging technique available, but also in an outpatient clinic or hospital. For all these reasons bedside LUS can reduce the number of CXR (6).

In four different common lung diseases (pneumonia, pleural effusion, pulmonary edema and PNX) LUS is a highly sensitive and specific imaging technique compared to CXR.

A systematic review with meta-analysis, considering 742 patients with pneumonia, showed high LUS sensitivity and specificity (95% and 90% respectively) compared to CXR sensitivity and specificity (77% and 91% respectively) (7). Hegazy *et al.* confirmed effectiveness of LUS in the diagnosis of children with respiratory distress (LUS sensitivity and specificity: 93.5% and 96.9% respectively, CXR sensitivity and specificity: 90.3% and 87.7% respectively) (8).

A systematic review with meta-analysis considering patients affected from PNX demonstrated a high LUS sensitivity and specificity *vs.* CXR (LUS: 87% and 99% *vs.* CXR: 46% and 100% respectively) (9).

Maw *et al.* showed a high LUS sensitivity and sensibility concerning pulmonary edema too (LUS *vs.* CXR sensitivity and sensibility: 88% and 90% *vs.* 73% and 90%) (10). Similar results were reported in a different study (LUS *vs.* CXR sensitivity and sensibility: 92.3% and 96% *vs.* 84.6% and 100%) (8).

In light of the scientific evidences, some of which is reported above, it appears reasonable to prefer the use of LUS instead of CXR in the neonatal and pediatric population.

Up-to-date, comparing the pros and cons of LUS *vs.* chest-CT, as also indicated in the *Table 1*, chest CT is the gold standard imaging technique for what concerns pediatric respiratory pathologies but I believe that the cons should be underlined in the routinary or unjustified use of CT scans in pediatric respiratory diagnostics, as unfortunately happened in the last years during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV2) pandemic (11). A reasonable compromise could be to use LUS as the first choice method integrating it into the clinic and using CT in well-selected cases to protect children from the potential risks of ionizing radiation.

Generally, the probes used in LUS diagnostics are high-frequency linear probes and low frequency convex probes but the transducers selection depends on the age and size of the child: generally, a high-frequency linear probe (7.5–10 MHz) is often used for LUS in children and is useful to detect pleural line and sub-pleural space; a lower-frequency micro-convex transducer (3–5 MHz) permits a panoramic view and can be useful to evaluate deeper structures. In neonatal patients and in pediatric intensive care unit (PICU), due to the chest anatomy, a high-frequency linear array transducer ≥10 MHz is suggested (12).

Usually the transducer, compared to the patient, is oriented longitudinally (vertical to the ribs), transverse (along the intercostal spaces) and obliquely for a better evaluation of the lung bases and it is mandatory to study lungs accurately without forgetting to scan: suprasternal notch, parasternal regions, intercostal spaces, trans-diaphragmatic scan, sub-costal scan, sub-xyphoid scans, in cranial/caudal orientation (12,13).

Many authors proposed a 12-zone method of reporting using LUS, in whom lung is divided in six areas for each hemithorax:

- ❖ The anterior region of each hemithorax with its right upper anterior and lower anterior quadrant (R1–R2) and its left upper anterior and lower anterior quadrant (L1–L2);
- ❖ The axillary region of each hemithorax with its right upper anterior and lower anterior quadrant (R3–R4) and its left upper anterior and lower

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Table 1 Comparison of the pros and cons between lung ultrasound, chest X-rays and chest-computed tomography in the pediatric population

Diagnostic tool	Pros	Cons
Lung ultrasound	• Not expensive	• Operator dependent (experience, skill)
	• Repeatable	• Patient dependent (physical characteristics of the patient: obesity, subcutaneous emphysema)
	• Bed-side	• Disease dependent (centrally located consolidations: far from the pleural line, significant overlap in lung ultrasound artifacts across common disease of acute respiratory failure)
	• Portable	
	• Easy transportable out-of-hospital and in remote areas	
	• Non-invasive	
	• Real-time lung imaging	
Chest X-rays	• Not expensive	• Invasive (ionizing radiation exposure)
	• Bed-side (only in some contexts)	
Chest computed tomography	• Gold standard in respiratory disease diagnosis	• Expensive
		• Invasive (ionizing radiation exposure)

anterior quadrant (L3–L4);

- ❖ The posterior region of each hemithorax with its right upper anterior and lower anterior quadrant (R5–R6) and its left upper anterior and lower anterior quadrant (L5–L6) (12,14).

According to Lichtenstein *et al.* (13), normal LUS US artifacts, showed between each intercostal space of the chest are:

- ❖ The hyperechoic line that represents the pleural line between the superior and inferior rib (this image is called "bat sign" because it reminds to the author a bat, where the superior and inferior ribs with the respective shadows, delimiting the intercostal space, represent the wings of the bat and the artifacts representing the area of lung between 2 ribs, the "*bat body*".
- ❖ The "*lung sliding*" which is the sliding movement of the visceral pleura on the parietal pleura consensual to the acts of ventilation.
- ❖ The horizontal lines called "*A lines*" which are horizontal artifacts parallel to the pleural line, expression of "*dry lung*".

Main LUS pathological artifacts, signs of the most common diseases detectable in pediatrics and neonatology, according to Lichtenstein *et al.* (13) are:

- ❖ The vertical lines called "*B lines*" which are vertical hyperechoic hydroaeric artifacts arising from the pleural line, moving in a consensual way with lung sliding. The B lines, by definition, erase the A lines and vice versa and do not represent a pathological sign if are less than 3 per intercostal space, especially in newborns in the first 2 days of life because the increased neonatal presence of lung fluid. A number of almost 3 or more B-lines for intercostal space is a pathological sign and the increasing number of B lines is a sign of increased liquid presence and reduced air content (12,13). When the B lines increase significantly, they can become compact and confluent and no longer distinguishable from each other, resulting in the so-called "white lung", typical for a severe alveolar-interstitial syndrome (i.e., pulmonary edema) (12).
- ❖ The "*lung point*" is the pathognomonic sign of PNX together with the absence of lung sliding since it is the point at which the lung returns to the wall and the parietal pleura returns to slide on the visceral pleura and the presence of A-lines (presence of B lines exclude PNX presence).
- ❖ The "*pleural effusion*" is typically represented with an anechoic image but, if it is rich in fibrin or corpuscular material, loses its anechogenicity and can appear hypoechoid or hyperechoic as it can

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be organised or septated. This is useful because it helps to understand whether that pleural effusion is suitable for drainage or whether, being organized, it will not be suitable for drainage.

- ❖ The "*lung consolidation*" in pediatrics patients sonographically has different characteristics: hepatization, shred sign, air bronchograms and focal/marginal B-lines (15).

Previously it was demonstrated that the bedside lung ultrasound in emergency (BLUE) protocol (13) represent an important concept in the assessment of all patients admitted to the ER with acute respiratory failure (ARF) and becomes an integral part of the physical examination itself, strengthened by the fact that there are growing evidence to support the use and usefulness of bedside LUS in the diagnostic path and clinical management of pediatric patients (16).

LUS is used in many other pediatric contexts such as: neonatal intensive care unit (NICU), PICU, pediatric inpatient ward and delivery room. Although there are now pediatric guidelines published in the literature recommending the use of LUS in critically ill pediatric patients in the PICU, unfortunately they are based on low quality evidence (level B and below) manly based on neonatal and adult intensive care unit (ICU) data (17).

Moreover LUS could avoid improper access to the ER, also reducing overcrowding, a worrying phenomenon. Furthermore, LUS could avoid the children from the psychological trauma of unnecessary access to the hospital.

Urbankowska *et al.* evaluated the usefulness and accuracy of LUS in diagnosing and monitoring community-acquired pneumonia in children. This study considered 106 children underwent LUS and CXR. The results were encouraging for LUS with a high sensitivity (93.5%) and specificity (100%) (18).

Interestingly in an observational cohort and prospective longitudinal and analytic study, which enrolled infants between 0–12 months, LUS proved to be useful in the management of infants with a diagnosis of bronchiolitis (19). Previously was demonstrated that point-of-care LUS, because its high specificity and sensitivity, represents a best practice in the management of many pediatrics respiratory diseases including pneumonia, pleural effusion, bronchiolitis and PARDS (20,21).

During the SARS-CoV2 pandemic, bedside LUS proved to be a valid aid in the integrated diagnostics of coronavirus disease 2019 (COVID-19) positive patients but probably it could have been used more than it was (22) in fact a review underlined that during the pandemia only few studies with small cohort used LUS in children with suspected infection preferring CXR and CT scanning, with the worrying discovery that, in some occasions, even with newborns CT scanning was used and repeated for follow-up, just because a nasopharyngeal swab was positive (11).

Even a recent review concluded that in the context of the COVID-19 pandemic, LUS could be used in a more systematic way ensuring that the healthcare professionals, have an adequate degree of training to maintain the credibility of this precious method, especially in those low-income countries that cannot access more sophisticated and expensive instrumental methods (23).

The possibility of using LUS at the point-of-care opens up very important and interesting perspectives such as that of being able to use LUS in general practitioner (GP) surgery, which in this way can diagnose and treat pediatric patients early. This allows us to make an early diagnosis of respiratory disease, which sometimes require early therapeutic treatment.

Chavez *et al.* underlined the importance of teaching GPs the use of LUS. The aim of their study was to demonstrate the importance to identify, already out of the hospital, children who need to receive antibiotic therapy early and to identify serious complications of respiratory disease. The objective was to increase, by using LUS early from GP, pneumonia diagnosis and reduce complications, antibiotic resistance, costs and mortality (24). Despite the growing interest and use of LUS, because the advantages it offers in terms of usability, costs and above all non-invasiveness which is probably and rightly the fact with the greatest impact in the field of pediatrics, LUS unfortunately is still used "patchily" around the world. Probably, to date, the greatest limitation is the lack of guidelines or behavioral rules that define the indication for carrying out LUS, instead of or in a complementary manner to other methods, in different circumstances. Another important limitation is due to the lack of a training path that codifies in a precise, well-defined and recognized way, by the global scientific community, the theoretical-practical training path necessary to acquire the skill in the field of LUS. In fact, despite being increasingly implemented, there is no international consensus on education, assessment of competencies and certification. Today, training is usually based on the concept of mastery learning, but often is unstructured and limited by bustle in a clinical daily life (25).

Currently LUS cannot completely replace diagnostics using ionizing radiation but integrates them, optimizing the

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use and timing of other diagnostics methods.

Many steps forward have been made in the last 20 years in the field of knowledge and applicability of US in the diagnosis of pediatric lung pathologies. LUS in pediatric field permit a safe and non-invasive method for monitoring the patient and verify the treatment effectiveness.

The overwhelming lung ultrasonographic revolution has literally changed the face of diagnostic imaging by moving away the spectrum of ionizing radiation because the possibility of avoiding the potential iatrogenic stochastic damage.

In perspective, it would be desirable to establish more precise rules concerning the training criteria to get the skill in LUS. Moreover, it is important to define through trials, multicentric studies and guidelines, useful principles, to guide healthcare professionals when using this tool, which is even more important in the pediatric field.

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Footnote

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