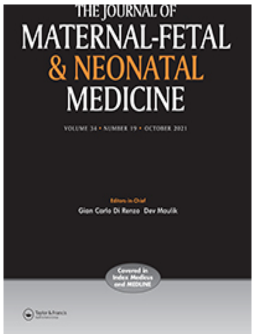

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The Journal of Maternal-Fetal & Neonatal Medicine

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ijmf20

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To cite this article: Jing Liu, Guo Guo, Dalibor Kurepa, Giovanni Volpicelli, Erich Sorantin, Jovan Lovrenski, Almudena Alonso-Ojembarrena, Kai-Sheng Hsieh, Abhay Lodha, Tsu F. Yeh, Mateusz Jagła, Heli Shah, Wei Yan, Cai-Bao Hu, Xiao-Guang Zhou, Rui-Jun Guo, Hai-Ying Cao, Yan Wang, Hai-Feng Zong, Li-Li Shang, Hai-Ran Ma, Ying Liu, Wei Fu, Rui-Yan Shan, Ru-Xin Qiu, Xiao-Ling Ren, Roberto Copetti, Javier Rodriguez-Fanjul, Francesco Feletti & On behalf of the Society of Pediatrics, Asia-Pacific Health Association; the Division of Critical Ultrasound, Pediatric Society of Asia-Pacific Health Association; the Critical Ultrasound Group of Neonatal Specialty Committee, the Cross-Straits Medicine Exchange Association as well as the World Interactive Network Focused On Critical Ultrasound China Branch (2021): Specification and guideline for technical aspects and scanning parameter settings of neonatal lung ultrasound examination, The Journal of Maternal-Fetal & Neonatal Medicine, DOI: 10.1080/14767058.2021.1940943

To link to this article: https://doi.org/10.1080/14767058.2021.1940943

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THE JOURNAL OF MATERNAL-FETAL & NEONATAL MEDICINE
https://doi.org/10.1080/14767058.2021.1940943

GUIDELINE

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Specification and guideline for technical aspects and scanning parameter settings of neonatal lung ultrasound examination

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ABSTRACT

Lung ultrasound (LUS) is now widely used in the diagnosis and monitor of neonatal lung diseases. Nevertheless, in the published literatures, the LUS images may display a significant variation in technical execution, while scanning parameters may influence diagnostic accuracy. The inter- and intra-observer reliabilities of ultrasound exam have been extensively studied in general and in LUS. As expected, the reliability declines in the hands of novices when they perform the point-of-care ultrasound (POC US). Consequently, having appropriate guidelines regarding to technical aspects of neonatal LUS exam is very important especially because diagnosis is mainly based on interpretation of artifacts produced by the pleural line and the lungs. The present work aimed to create an instrument operation specification and parameter setting guidelines for neonatal LUS. Technical aspects and scanning parameter settings that allow for standardization in obtaining LUS images include (1) select a high-end equipment with high-frequency linear array transducer (12–14 MHz). (2) Choose preset suitable for lung examination or small organs. (3) Keep the probe perpendicular to the ribs or parallel to the intercostal space. (4) Set the scanning depth at 4–5 cm. (5) Set 1–2 focal zones and adjust them close to the pleural line. (6) Use

ARTICLE HISTORY
Received 2 June 2021
Accepted 6 June 2021

KEYWORDS
Diagnostic image; intensive care unit; lung diseases; lung ultrasound; newborn

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Supplemental data for this article is available online at https://doi.org/10.1080/14767058.2021.1940943.
This article has been republished with minor changes. These changes do not impact the academic content of the article.

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fundamental frequency with speckle reduction 2–3 or similar techniques. (7) Turn off spatial compounding imaging. (8) Adjust the time-gain compensation to get uniform image from the near-to far-field.

Abbreviations: CXR: chest X-ray; LDNs: lung diseases of the newborn; LUS: lung ultrasound; MAS: meconium aspiration syndrome; NICU: neonatal intensive care units; SRI: speckle reduction imaging; SCF: spatial compounding function; TGC: time-gain compensation; RDS: respiratory distress syndrome

Introduction

Over the past 20 years, lung ultrasound (LUS) has been successfully used to diagnose and monitor lung diseases of the newborn (LDNs) [1–7]. In addition, it played a crucial role in the disease follow up and facilitated NLDs management procedures [8–12]. Due to the sharp learning curve, ease of use, minimization of overall radiation exposure, the application of LUS has significantly increased or even completely replaced chest X-rays (CXR) in some neonatal intensive care units (NICU) across the world [13–15]. Widespread adoption of LUS requires structured education and accurate, and reliable image technical characteristics [16–19].

To improve the popularization and promotion of the technology, some academic organizations have issued guidelines for neonatal LUS as a reference [20–22]. Despite these attempts, there is still a significant variation in clinical practice, specifically related to equipment settings, which are often influenced by different manufacture techniques and different settings. Ultimately, all of these aspects affect the accuracy and reliability of diagnosis [23,24]. Therefore, the purpose of this specification and guideline is to define technical parameters for the standardization of neonatal LUS imaging. Understanding and mastering these principles will assure operators to rapidly learn neonatal LUS technology and optimize the accuracy and reliability of study results.

Methods

In January 2021, the Neonatal Lung Ultrasound Training Center in conjunction with the society of Pediatrics, Asia-Pacific Health Association; the Division of Critical Ultrasound, pediatric society of Asia-Pacific Health Association; the Critical Ultrasound Group of Neonatal Specialty Committee, the Cross-Straits Medicine Exchange Association as well as the World Interactive Network Focused On Critical Ultrasound China branch assembled an international LUS expert panel with the goal of shaping guidelines that will help standardize neonatal LUS imaging methodology.

The definition of the present document was obtained through a process involving four distinct stages.

First, the organizers thoroughly and carefully compared the effects of different grades of machines, different types, and different frequencies of probes on inspection results and image quality combined with their long-term clinical practice and study.

The second stage involved the experts being asked to search, review, and study the relevant key documents thoroughly in critical databases (such as PubMED, Web of Science, the Cochrane Library, CNKI, and Wanfang database) and propose at least three statements relative to the technical execution and equipment setting in neonatal LUS.

The suggested statements were enlisted in the document and organized into different sections by the project organizer (L. J.). Two of the experts (F. F. and G. G.) independently reviewed the statements.

The third, all the experts were subsequently asked to (1) propose new sections, (2) suggest deletion or modification of any existing sections or statements, and (3) provide new statements for each section.

The fourth step of the process, the first draft was shared among participants, and each one was asked to comment or propose modifications or specifications. The final agreement was obtained from each participant. The whole process took place *via* e-mail exchange, phone communication, or virtual meeting discussion. All the contents were approved unanimously.

Results

A total of 29 experts from nine countries or regions contributed to the preparation of the present document. We address nine sections (20 points) that pertain to the technical aspects and equipment settings while performing neonatal LUS: equipment and transducer selection, transducer disinfection, patient preparation, partitioning the lungs, scanning presets, major parameter setting, scanning methods, scanning mode, and comprehensive inspection.

Operating specification and parameter setting guidelines

Equipment and transducer selection

The effects of different probes on LUS image quality and reliability have been described [25]. Image quality and results of a LUS exam may depend on the differences among probe types and frequencies in different equipment or even in the same instrument. Both low-end ultrasound equipment and low-frequency transducer may conceal certain lung characteristics and may not reflect the true severity of lung disease [26], consequently, using a high-end US equipment with high-frequency linear array transducer is highly recommended when performing neonatal LUS examination. The transducer frequency is generally above 10 MHz to ensure sufficient resolution and detection of minor lesions [27]. In general, for the lower birth weights and gestational age infants, the higher frequency linear transducer is required. However, the transducer frequency should not be too high to penetrate far enough. Because the higher the frequency, the more attenuation it happens, the attenuation coefficient is approximately 0.5 dB/cm/MHz in the soft tissue [28,29]. The transducer frequency is usually 12–14 MHz in neonatal LUS examinations. Convex array transducers are rarely used in neonatal LUS as opposed to LUS exams performed in adults [30,31] (Figures 1–3).

Key points

- It is highly recommended to use a high-end ultrasound equipment with a high-frequency linear transducer when performing neonatal LUS examination.

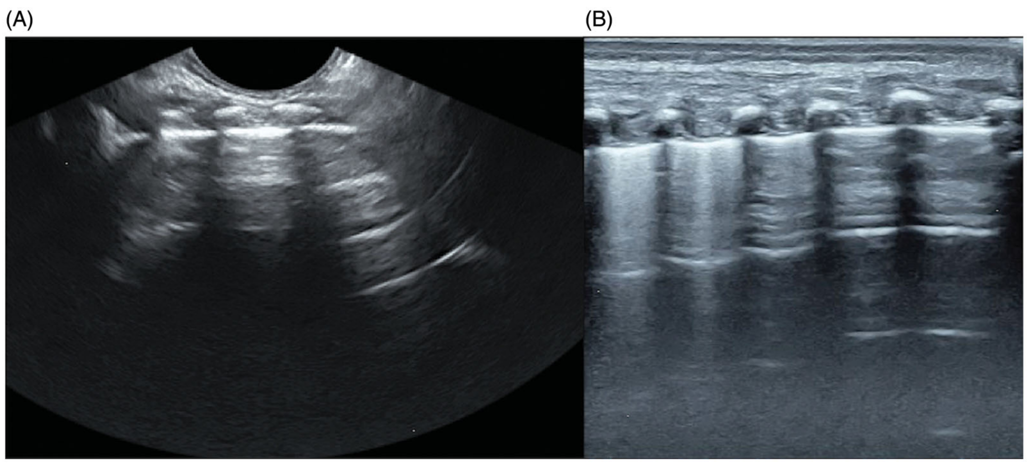

Figure 1. Impact of US probe type on the LUS image quality. (A) Image by convex transducer. (B) Image by linear transducer. It can be seen from the picture that the LUS image quality is much better by using linear array transducers comparing to convex array transducers.

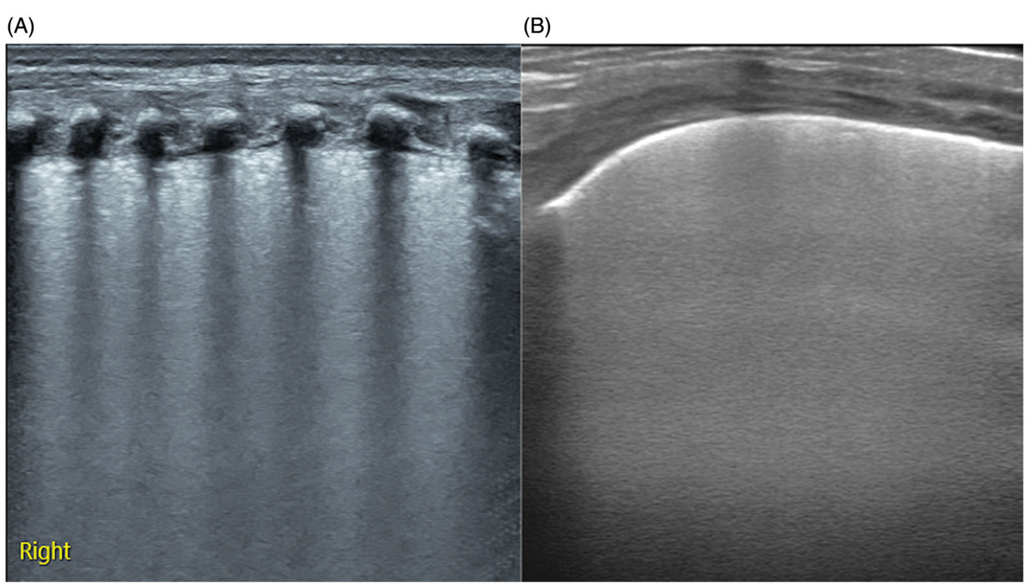

Figure 2. Impact of the low-end equipment on the LUS image quality. Different images from the same area in an infant with respiratory distress using different equipment with identical high-frequency transducers. Clinically, the patient was diagnosed with RDS. (A) The image from the high-end machine showed typical snowflake-like lung consolidations suggested RDS [35,42]. (B) The image from the low-end machine showed only coalescent B-lines suggested transient tachypnea of the newborn [18,43].

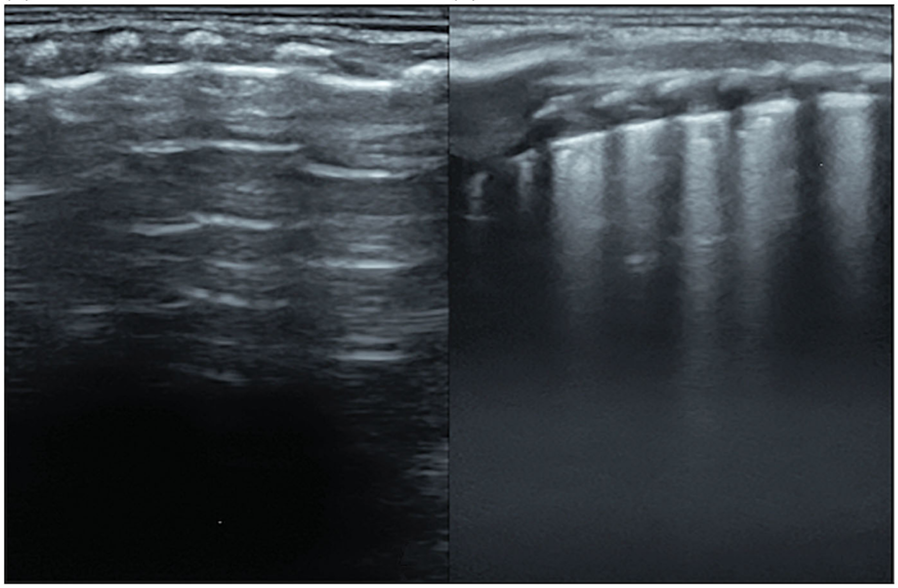

Figure 3. Impact of US transducer frequency on the LUS image quality. Different images from the same area in an infant with respiratory distress using different frequency transducers. (A) The image by linear transducer with a frequency below 9 MHz showed normal ultrasound findings. (B) The image by linear transducer with a frequency higher than 10 MHz showed subpleural lung consolidation and coalescent B-lines.

Transducer disinfection

Before and after the examination, the transducer and the connecting lines should be disinfected to prevent nosocomial infection and cross-infection among infants. The most accessible, convenient and effective disinfecting method is to use special disinfection wipes. Alternatively, powderless gloves or transducer covers can also be considered [20].

Patient preparation

Keep the infant in a quiet state and warm setting

Avoiding crying and keeping the infant quiet during examination is essential. However, sedation is not recommended while glucose solution pacifier dips are usually sufficient. Besides, it is necessary to keep the infant in a warm setting, always use heated ultrasound gel during the whole exam process to avoid infant discomfort.

Body position

During the LUS, the infant should be placed in a position that suitable for a particular target examination and make sure that the exam does not interfere with infant's clinical management, especially mechanical ventilation.

Generally, the infant can be placed in supine, prone, or lateral position. If permits, it may be preferable to use a posterior approach for the LUS. This is preferable since the back of the infants is relatively flat and, therefore, aligns well with the linear transducer. In addition, interference from the thymus, heart and large blood vessels is avoided. However, the examination should be started from the most convenient part of the chest according to the infant's position at that time.

Key points

- Keep the infant in a quiet state and suitable position.
- Start LUS scanning from the most convenient part of the chest.

Partitioning the lungs

Each lung is divided into three areas:anterior, posterior, and lateral areas with the anterior and posterior axillary line as the boundaries. Therefore, the bilaterally lung is divided into six areas (that is six area division method) [20,21]. Another approach is to additionally divide each side of the lung into upper and lower fields along the nipple connection and its extension line thus, the both lungs are divided into 12 regions (that is 12-area division method) [20,21]. In this condition, the right/left (R/L) 1–6 zone marks are used to facilitate the lateral orientation. But in very low birth weight infants, it may be difficult to divide the lateral field into an upper and lower field,

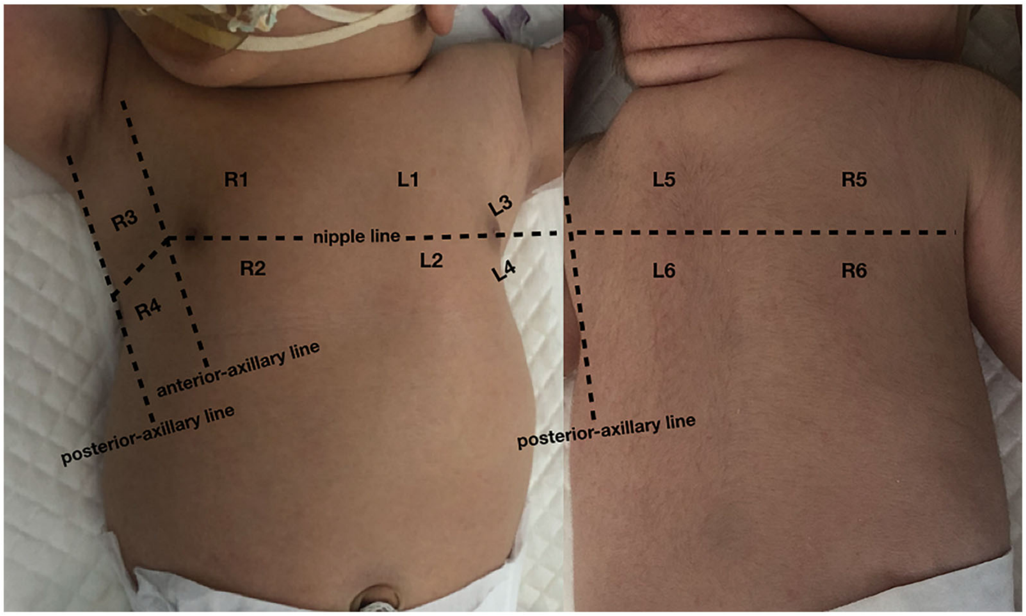

Figure 4. Lung division and mark methods. The bilateral lung was divided into 12 regions by the anterior axillary line, posterior-axillary line, and nipples connection line. R represents the right lung. R1: right anterior upper area, R2: right anterior lower area, R3: right axillary upper area, R4: right axillary lower area, R5: right posterior upper area, R6: right posterior lower area. L represents the left lung. L1: left front upper area, L2: left front lower area, L3: left axillary upper area, L4: left axillary lower area, L5: left anterior upper area, L6: left posterior lower area.

therefore, the subaxillary area is considered as one region, this is the 10 area division method [31,32] (Figure 4).

Scanning presets

If available, it is recommended to use "lung preset" when performing the LUS exam. However, most US devices do not have such a preset at the moment, requiring the operator to set scanning parameters by him/herself. In such a case, it is suggested to use the preset suitable for examining small organs (such as the thyroid) and then finely tune the parameters according to the following recommendations.

Major parameter setting

Scanning depth

Scanning depth is usually adjusted to 4–5 cm depending on the infant's gestational age and birth weight [26]. Smaller infants require shallower scanning depths, on the contrary, the depth may be somewhat deeper in infants with large gestational ages and large bodies. As the sound attenuation increases with the depth increasing based on the equation of attenuation coefficients equal to 0.5 dB/cm/MHz [27,28], therefore, the depth should be not too shallow or too deep, otherwise it will limit display of the information in the far-field or the deeper target (Figure 5).

Focal zones

Focusing narrows the sound beam and improves US image lateral resolution. The image has the best lateral resolution at the point of focus, therefore, multi-point focal zones can be used to improve the lateral resolution. However, the frame rate decreases as the number of focal points increases. On the other hand, newborns with lung disease require a higher frame rate to capture information because of their faster respiratory rate. Consequently, in neonatal LUS, it is recommended to set 1–2 focal zones and adjust them close to the pleural line. Because the A-line is an artifact formed by the reflection of the pleural line, when the focal zone is close to the pleural line, the pleural lines are displayed clearly, and, thus, the A-lines also displayed clearly (Figure 6).

Fundamental frequency imaging

Harmonics can decrease the reverberation which is the key reason results in the A-lines and B-lines. When using harmonics, the A-line and B-line are weakened compared with using fundamental frequency, meanwhile, because of higher frequency, the attenuation in the far field increased even though the image looks very fine [33,34]. Therefore, it is recommended to use fundamental frequency when performing neonatal LUS in most cases (Figures 7 and 8).

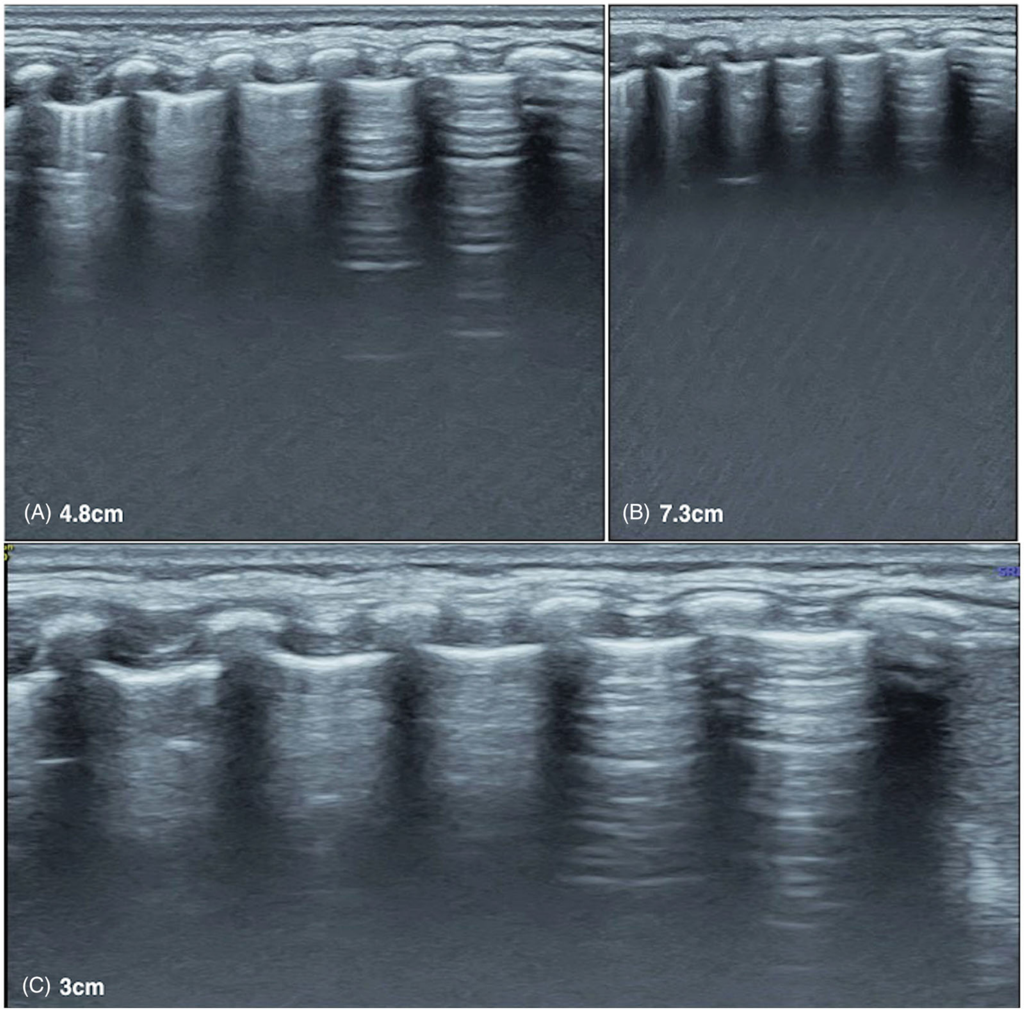

Figure 5. Impact of scanning depth on image quality. Images from the same scanning area of an infant by the same probe with different scanning depth. (A) Scanning with a depth of 4.8 cm, the whole image is satisfactory, clear and diagnostically valid. (B) Scanning with a depth of 7.3 cm. The deeper depth setting makes the structures seem smaller and no information display in the far field. (C) Scanning with a depth of 3 cm, and the whole picture appears too shallow with an incomplete display of the information.

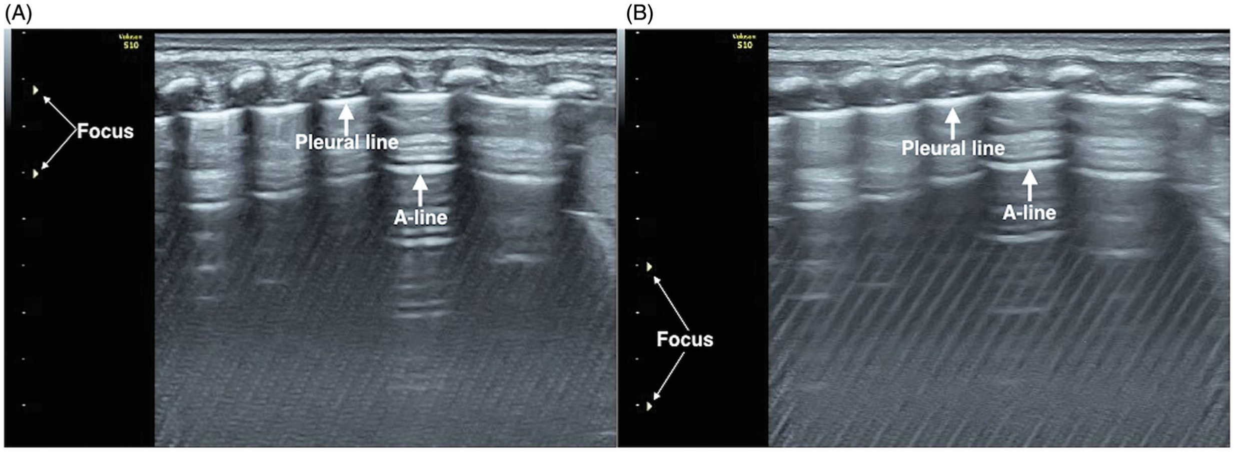

Figure 6. Impact of the focal zones position on the image quality. (A) The focal zones close to the pleural line. Both the pleural line and the A-line are displayed clearly. (B) The focal zones located at the far-field, which is far away from the pleural line. Both the pleural line and the A-line are weakened.

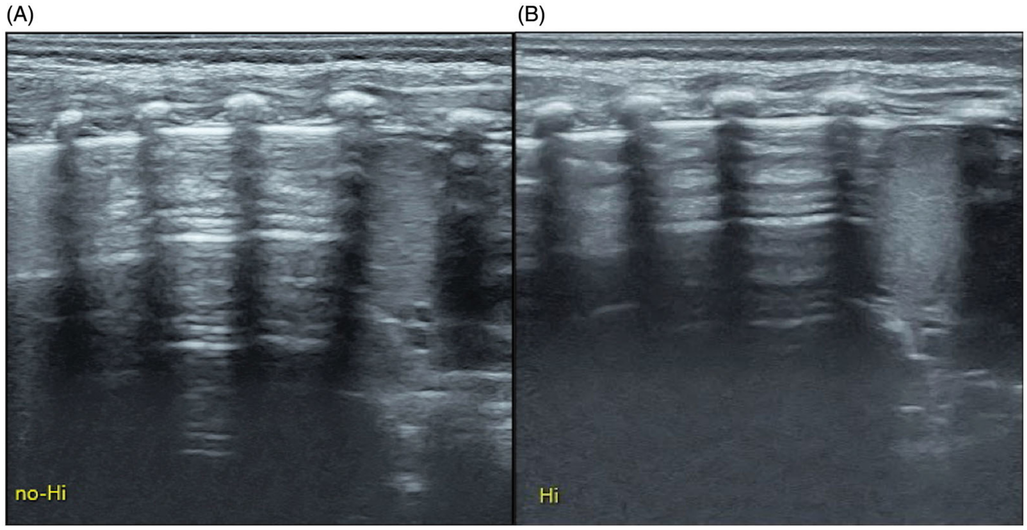

Figure 7. Impact of fundamental frequency and harmonics on A-lines. (A) Image by fundamental frequency, both pleural line and A-line look much clear, more A-lines can be showed. (B) Image by harmonics, although the image is delicate, the pleural line and A-line look fine, smooth and less clear, also less A-lines be showed and there is no echo information displayed in the far-field due to the reflection of pleural line was significantly weakened.

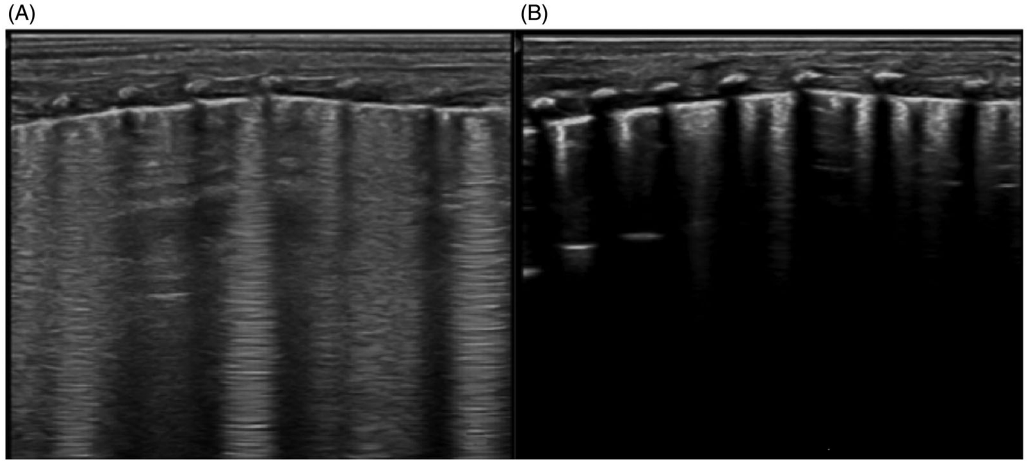

Figure 8. Impact of fundamental frequency and harmonics on B-lines. (A) Fundamental frequency image, the B-line displayed sufficiently. (B) Harmonics, the image is delicate, but the B-lines are weakened and shortened.

Speckle reduction imaging (SRI) function

SRI function or similar techniques should be turned on to reduce US speckle noise when performing LUS examination. Speckle noise makes the image granular appearance, degrades contrast resolution, and obscures underlying anatomy. SRI is an adaptive, real-time software algorithms to reduce specks while retaining all anatomical structures and it can smooth boundary and enhance the contrast while preserving details. SRI is often set to 2–3 when performing neonatal LUS exam (Figure 9).

Spatial compounding function (SCF)

When SCF is turned on, pulses are transmitted both perpendicular to the acoustic window and in oblique directions, multiple pulses are correlated to form one image which resulting in B-lines appear chaotic, cross and overlap each other or even make the rib shadow disappear. This may not only affect the image quality, but also affect the judgment of the inspection results. Therefore, it is recommended to turn off this function during LUS examination (Figure 10).

Time-gain compensation (TGC)

TGC is also known as distance gain compensation. When US waves propagate through tissues, the reflecting US signal attenuation gradually increases as the depth increases. The gain can be gradually enhanced from near-field to far-field by adjusting the TGC keys

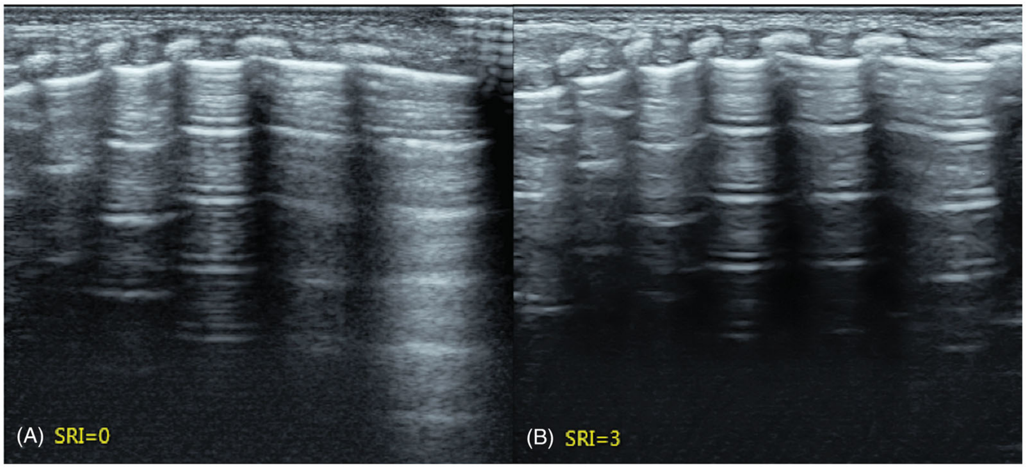

Figure 9. Impact of SRI on image quality. (A) Turn off SRI, the image is grainy, and the pleural line and A-lines are blurred. (B) Turn on SRI (level 3), the image is more delicate, the pleural line and the A-lines are well defined.

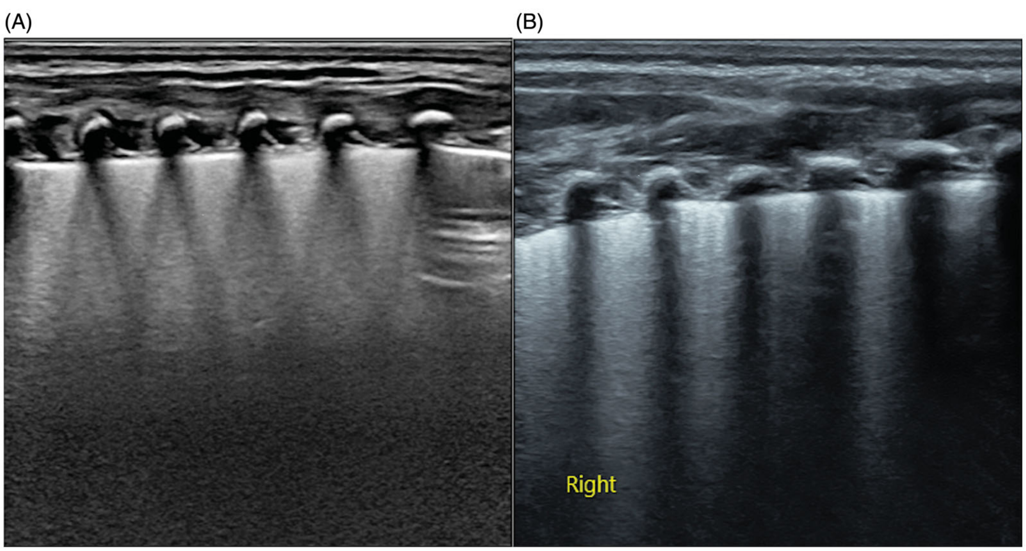

Figure 10. Impact of spatial compounding on image quality. (A) With spatial compounding function, the B-lines diverge from different angles to different directions, the image appears messy. (B) Without spatial compounding function, the B-lines arise from the pleural line vertically to the deeper lung field and reaches the edge of the screen.

to obtain a uniform image during LUS examination [18,28] (Figure 11).

Edge enhancement

By increasing the grayscale difference, the boundary and subtle tissue differences between adjacent tissues are made more prominent. The higher the value, the better the sharper of the boundary. Edge enhancement can be appropriately increased during LUS examination so that the linear structures such as the pleural line or A-line can be displayed more clearly while not compromising the overall image quality.

Dynamic range

The dynamic range refers to the ratio of maximum amplitude and the minimum amplitude that can be displayed. A smaller dynamic range or a more considerable dynamic contrast increases US signal differences significantly, makes comet artifacts and multiple reflections more obvious. However, the image may appear rougher and obviously grainy. The more extensive the dynamic range or the smaller the dynamic range contrast refines the image. In neonatal LUS imaging, the contrast resolution needs to be improved when observing lung sliding or B-lines. Contrary, when we scan the thymus, consolidation or effusion, the contrast resolution needs to be moderate.

Key points

- Depth 4–5 cm.
- Focal zones 1–2, close to the pleural line.
- Fundamental frequency imaging is recommended.
- SRI 2–3 or similar speckle reduction techniques.
- SCF is not recommended.
- TGC decreasing gradually from near- to far-field of the lungs.

Scanning methods

Scanning each lung area requires the US transducer to be positioned longitudinally (the transducer is perpendicular to the ribs) or transversely (the transducer runs along or parallel with intercostal spaces). We should follow the principle of moving the probe from top to bottom and from inside to outside of the chest when performing the longitudinal or transverse scanning.

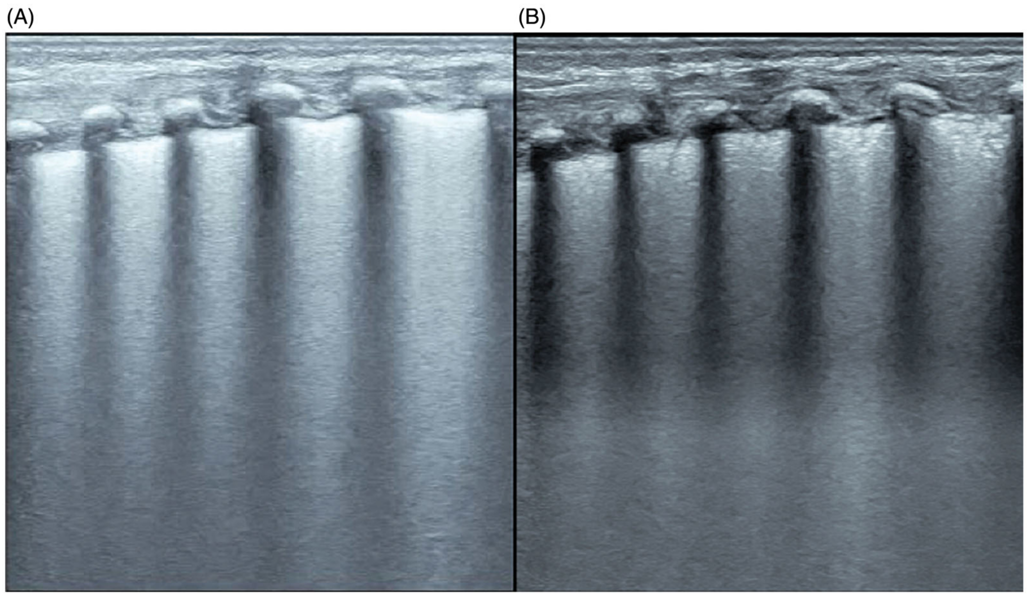

Figure 11. Impact of TGC on image quality. (A) It looks like the ground-glass opacity signs because the high gain in the near-field accentuated the echo but also artificially gave the near-field coarse and too bright echotexture, which suggesting grade I RDS [35]. (B) It presents as snowflake sings because gain adjustment is optimal, which is the typical signs of grade II RDS [35,42].

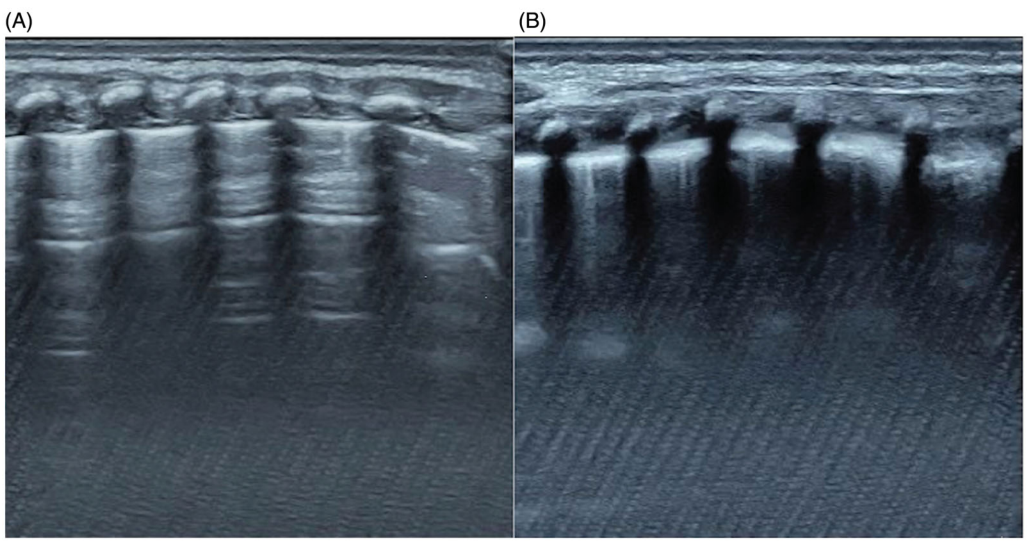

Figure 12. Longitudinal scanning. Use the same equipment and the same transducer with the same parameters to scan the same part of an infant without lung disease. (A) The transducer is perpendicular to the ribs. The pleural line and the A-line are smooth, clear and regular, showing normal LUS features. (B) The transducer was slightly tilted. The pleural line is rough and fuzzy, A-line disappears, there seems lung consolidation in some intercostal spaces.

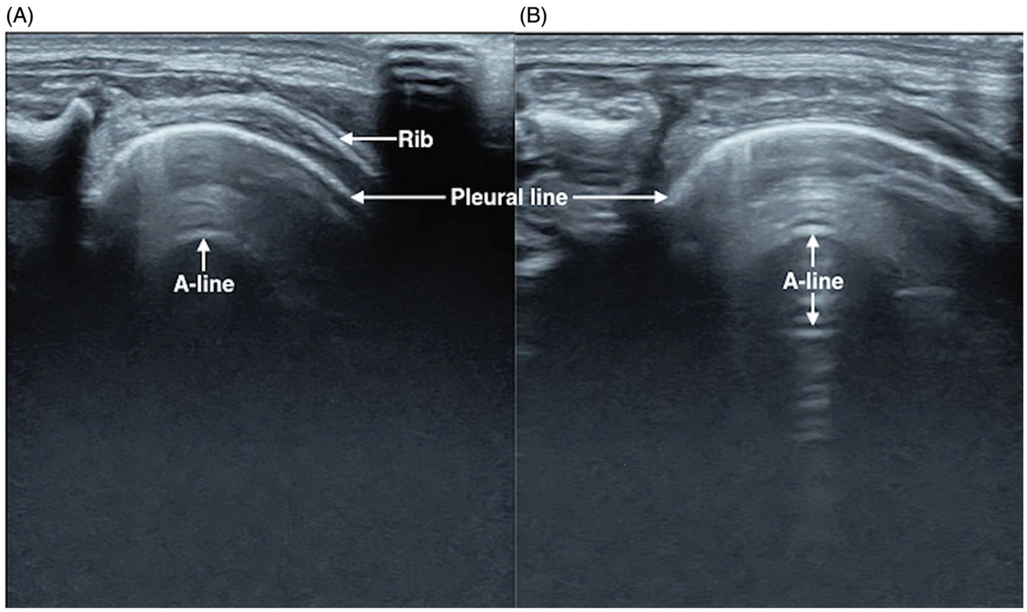

Figure 13. Transverse scanning. The pleural line and A-lines can be seen in the image. (A) Clearly shows the rib image, the pleural line is blurred due to the shade of the ribs. Only one A-line can been seen. (B) The ribs do not shade the pleura, therefore the pleural line displays more precisely, also multiple A-lines are generated. Because the transverse scanning during LUS examination requires the transducer to scan along with the intercostal space. (B) Shows the image by accurate transverse scanning; however, (A) is an image by not truly parallel scanning.

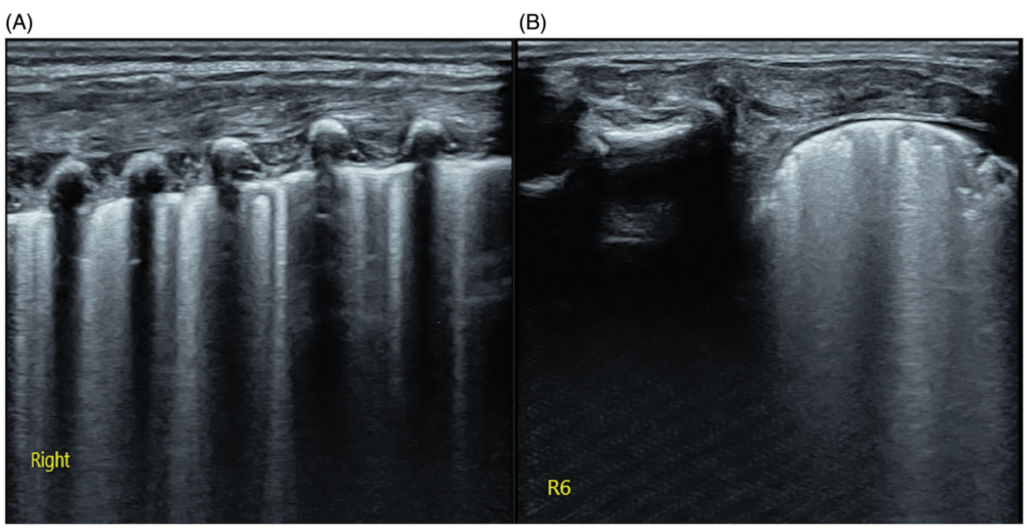

Figure 14. Transverse scanning help to find the limited subpleural consolidation. (A) Longitudinal scanning shows only obvious B-lines, thickening, and blurring of pleural line and breaking with no consolidation. (B) Transverse scanning shows evident subpleural consolidation in addition to B-lines and abnormal pleural line.

Longitudinal scanning

Longitudinal scanning is the most important and most commonly used scanning method for neonatal LUS exam. Preciseness in longitudinal scanning is key to ensure the accurate and reliable LUS results. If the US probe is not perpendicular to the pleural line, the image will appear as grainy and fuzzy with artifacts similar to B-lines or looks-like lung consolidations. This may affect the interpretation of the results. Adequate perpendicular scanning displays the ribs and the pleural line clearly as linear, hyperechoic structures that run approximately parallel to the pleural line, while inadequate perpendicular scanning displays the ribs as pea-shaped or curved structures. Based on these

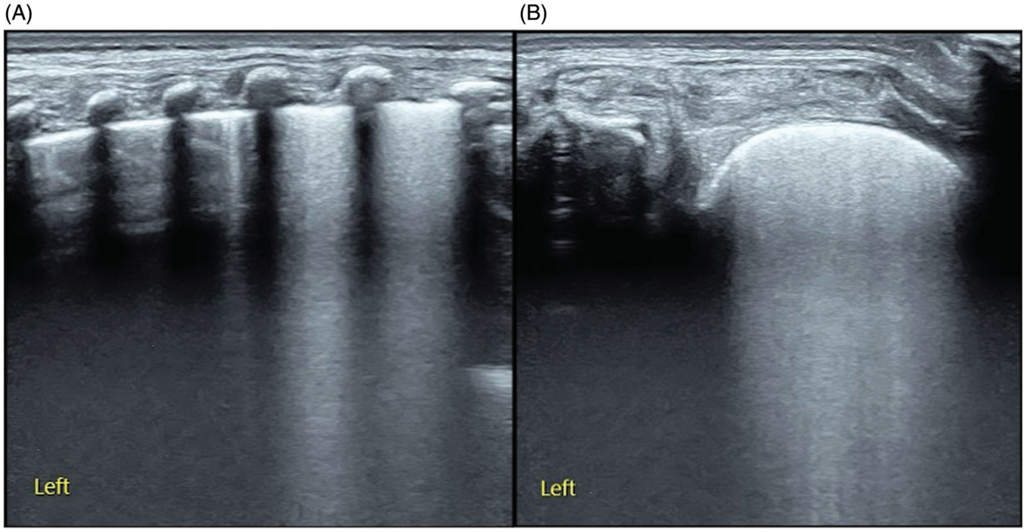

Figure 15. Transverse scanning help to diagnose Grade I RDS. A premature infant with progressive dyspnea and moaning was admitted to the hospital. (A) Longitudinal scanning indicates only mild lung edema, suggesting the wet lung's possibility. (B) Transverse scanning shows typical ground-glass opacity signs,which are typical ultrasound characteristic of Grade I RDS [35].

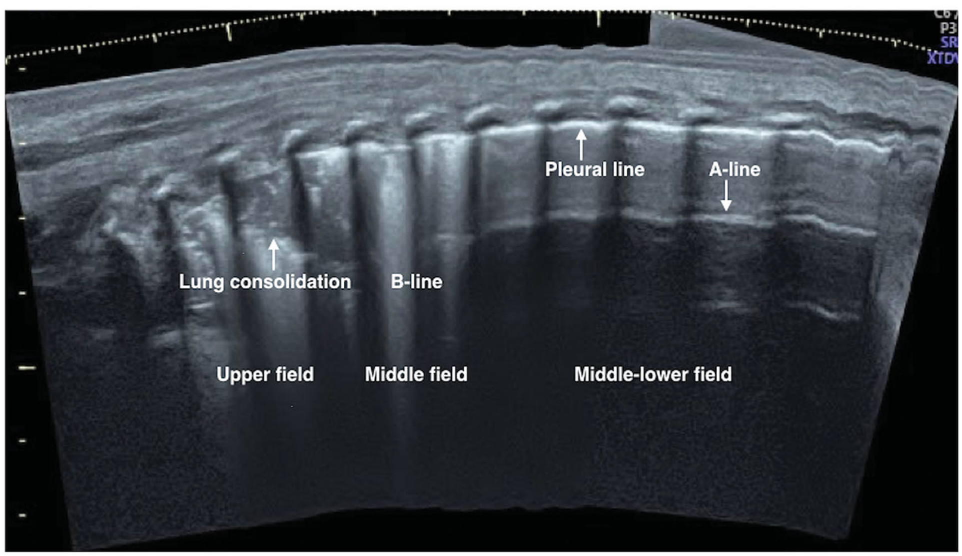

Figure 16. Extended-view imaging. The extended view helps to show the different conditions in the whole lung fields. This picture showed significant lung consolidations in the upper lung field, edema (that is B-lines) in the middle lung field and completely normal (clear pleural line and A-lines) area in the middle-lower lung field.

characteristics, the operator can preliminarily determine whether the probe is vertical or not when performing LUS examination (Figure 12).

Transverse scanning

Transverse scanning is an essential supplement to longitudinal scanning. It is useful in the evaluation of small consolidations, particularly within the subpleural zone, as well as the grade I respiratory distress syndrome (Grade I RDS) which typically presented the ground-glass opacity signs on LUS [35]. It is also easy to find the lung point, a specific sign of mild pneumothorax [20,21] (Figures 13–15, Supplementary avi 1) of moving the probe.

Transdiaphragmatic scanning

Transdiaphragmatic scanning involves placing the probe below the xiphoid process and angling it from side to side to scan the diaphragm and the bottom of the lungs *via* liver acoustic window. Increasing the depth and using virtual convex scanning allows expansion of the far field area if needed [20]. Generally, transdiaphragmatic scanning is rarely used in actual practice.It may be utilized when the lesion mainly involves the lung bottom, to examine

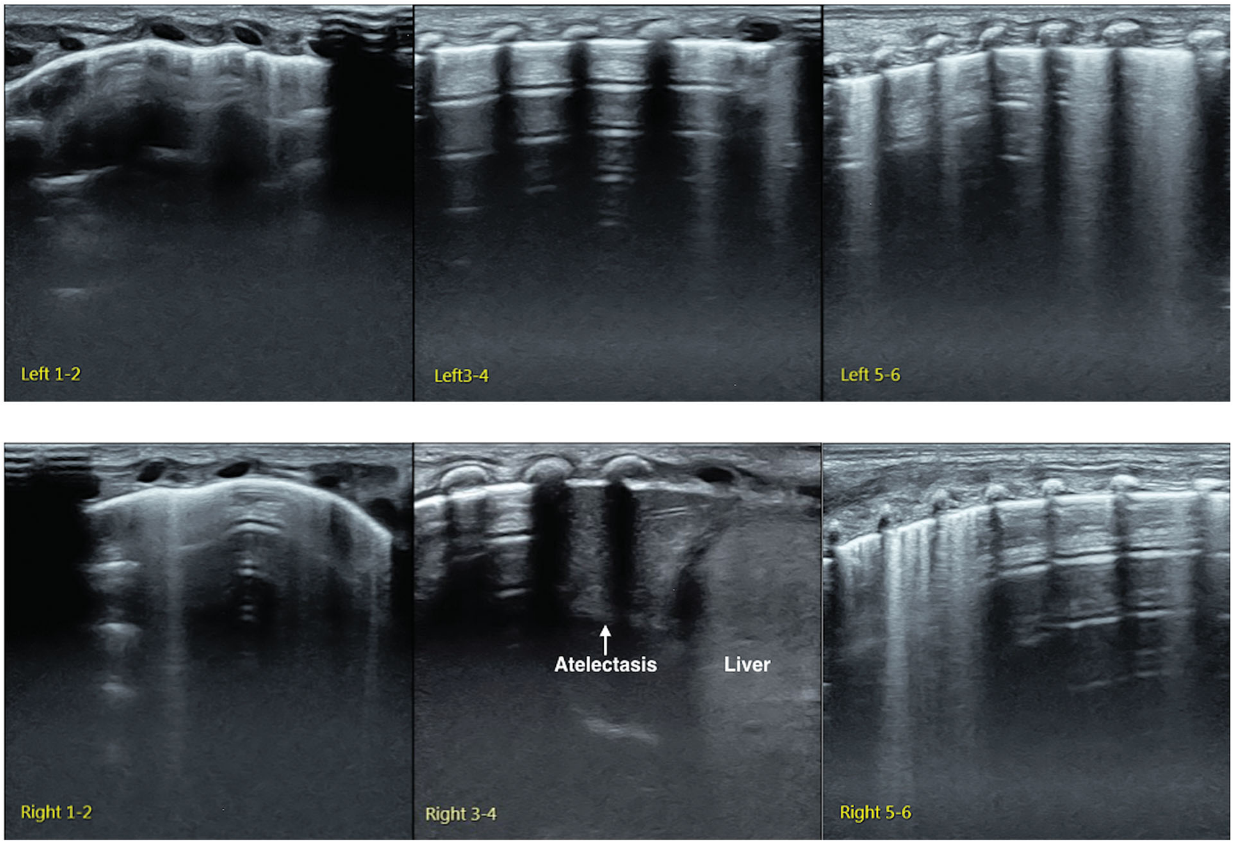

Figure 17. The value of a comprehensive scanning. A baby with a gestational age of 30^{+5} weeks and a birth weight of 1690 g was admitted to the hospital due to RDS and was given ventilatory treatment and was weaned the next day. Breathing difficulty occurred again on the 4th day after birth. *Left lung*: LUS showed that the left anterior chest (Left 1–2), subaxillary region (Left 3–4), and posterior area (Left 5–6) no obvious abnormality. *Right lung:* Scanning at the right anterior chest (Right 1–2) and the posterior area (Right 5–6) showed only several B-lines, but when the probe was moved to the right axillary area for detection, it was found that there was typical atelectasis (Right 3–4) in this area. It was confirmed that the presence of atelectasis was the cause of the infant's dyspnea again.

the integrity of the diaphragm, or to evaluate the presence of a minor pleural effusion [20].

Key points

- Keep the transducer precisely perpendicular to the ribs (as close as possible to 90°) is the key technique of neonatal LUS.
- Transverse scanning is an essential supplementation to longitudinal scanning.
- Follow the principle of moving the transducer from top to bottom and from inside to outside of the chest when scanning.

Scanning mode

The most commonly used neonatal LUS scanning mode is B-mode or 2D US. In fact, we can precisely diagnose the majority of the LDNs by B mode [1,2,19,20]. M-mode is mainly used to assist in the diagnosis of pneumothorax [36–38]. Occasionally, color Doppler US is used to distinguish blood vessels and bronchi or to identify whether blood supply exists within a consolidation [39].

Extended-view imaging involves sliding the US probe laterally along the probe mark point. Each static frame of the image that is acquired is constructed into an extended image. Extended-view image is much wider than the probe footprint which allows a full display of the area of interest and its neighboring structures. This technology allows more comprehensive evaluation of the lungs. While performing an extended-view imaging scan, the probe should be moved at a constant speed and only in probe mark point direction along the narrow axis (Figure 16).

Key points

- Using B-mode to detect most of LDNs.
- M-mode is used to confirm the presence of pneumothorax.
- Extended-view imaging may help to detect a wider lung field.

Comprehensive inspection

In most cases, a definite diagnosis can be made by examining one or two regions of the lung. A more extensive study is not expected when the diagnosis can be confirmed by scanning 1–2 target areas.

If an infant is highly suspected with LDN but there is no abnormality found by exploring the more easily accessible parts of the lungs, the examination should be extended to evaluate all lung areas thoroughly, especially in the case of mild pneumonia, gravity-dependent pneumonia or atelectasis, meconium aspiration syndrome (MAS), or pseudo-atelectasis, etc. [16]. It should be noted that the LUS exam should be focused whenever possible in critical neonates (Figure 17).

Conclusions

Point-of-care or bedside LUS is an important method for patient's lung examination, diagnosis, and management. This specification and guideline for technical aspects and scanning parameter. Settings resume the most crucial adjustment techniques for neonatal LUS. Understanding and following this protocol will help the standardization of neonatal LUS examination, which will lead to improved interobserver consistency in diagnostic accuracy, reliability, and patient outcomes.

Both experience and literatures have shown the result consistency of LUS examination come from experienced operators [24,40]. Therefore, to properly leverage the outstanding advantages of LUS in the management of LDNs, we suggest that the protocol and guideline should be carried out by clinicians themselves after they have been adequately trained [40,41].

Author contributions

J. L. conceived the study, organized, and coordinated the work and wrote the first draft of the article. G.G. wrote the protocol and organized the data. F.F. contributed to the design and the organization of the work and revised the manuscript critically for important intellectual content. All authors contributed to the contents as specified in the method's section, corrected the article draft and approved the final version.

Disclosure statement

The authors report no conflict of interest. The authors alone are responsible for the content and writing of the paper.

Funding

This work was supported by the Social Development Projects, Beijing Chaoyang District Bureau of Science, Technology and Information [CYSF1922 and CYSF1820] and the Clinical Research Special Fund of Wu Jieping Medical Foundation [320.6750.15072].

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