Pulmonary ultrasonography in the follow-up of respiratory distress syndrome on preterm newborns. Reduction of X-ray exposure

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KEYWORDS

Respiratory distress syndrome;
Neonates;
Pulmonary ultrasonography;
Ionizing radiation exposure.

Abstract *Purpose:* Respiratory distress syndrome (RDS) is the most common cause of respiratory failure in preterm neonates, whose lungs are often immature. The diagnosis and follow-up are based on clinical and radiographic findings. Due to the problem of air artifacts, ultrasonography (US) is not used routinely in the diagnosis of lung diseases. However, when the alveolar air content decreases, as it does in RDS, characteristic patterns appear that can be observed during US lung examinations. The aim of this study was to determine whether the use of chest radiographs in neonates with RDS could be reduced by the routine use of chest US for follow-up examinations.

Materials and methods: From April through September 2008, were enrolled all preterm newborns, with very low birth weight (VLBW), consecutive admitted in NICU with clinically and radiologically diagnosed RDS. We performed lung ultrasound examination in this patients. Video-taped US examinations were done every 8–12 h until clinical resolution of the disease was observed. Chest X-rays were performed only in unclear cases. We compared the number of chest radiographs obtained in the NICU during this period and during the preceding six months.

Results: 105 serial US lung examinations were performed in 21 preterm infant with clinically and radiologically diagnosed RDS. US lung examinations revealed “comet-tail” artifacts that were compact, diffuse, and symmetrically distributed throughout both lung fields. In 8 cases, the pleural line was also extensively thickened and irregular, and in 7 cases multiple subpleural hypoechoic areas indicative of lung consolidation were observed (mainly on posterior and lateral scans). The mean number of chest radiographs per infant performed in the NICU during

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the study period was significantly lower than that of the preceding six months (2.6 ± 1 versus 3.8 ± 1.5 ; $p < 0.05$).

Conclusions: Chest ultrasound is a valid alternative for the follow-up of VLBW infants with RDS, which can decrease the need for chest X-rays and reduce patient exposure to ionizing radiation.

Sommario *Introduzione:* La sindrome da distress respiratorio (RDS) è tra le cause più frequenti di insufficienza respiratoria dei neonati pretermine dovuta ad un'immaturità morfo-funzionale dei polmoni. La diagnosi e il follow-up sono basati sulla clinica e sui rilievi radiografici. L'ecografia non è ancora usata routinariamente nelle diagnosi delle malattie polmonari a causa degli artefatti dovuti all'aria. Tuttavia quando l'aria si riduce negli alveoli, come nella RDS, si osservano dei caratteristici segni ecografici. Lo scopo di questo studio è di determinare se l'uso dell'ecografia polmonare nel follow-up dei neonati con RDS possa ridurre l'uso degli esami radiografici.

Materiali e metodi: Da Aprile 2008 a Settembre 2008 è stato eseguito un follow-up ecografico polmonare a tutti i neonati pretermine, con peso alla nascita inferiore a 1500 g (VLBW) consecutivamente ricoverati con diagnosi clinica e radiografica di RDS. Ogni 8–12 ore venivano registrati i quadri ecografici su video-tape fino alla risoluzione clinica della malattia, mentre la radiografia del torace veniva eseguita solo nei casi poco chiari. Sono stati confrontati il numero degli esami radiografici eseguiti durante questo periodo con quelli eseguiti nei sei mesi precedenti in una simile popolazione.

Risultati: Sono state eseguite 105 ecografie polmonari in 21 neonati pretermine con diagnosi clinica e radiologica di RDS. I pazienti studiati presentavano all'ecografia del torace un'immagine polmonare caratterizzata da artefatti di tipo "comet-tail" diffusi e ravvicinati tanto da conferire al campo polmonare un aspetto iperiflettente. In 8 casi era anche presente ispessimento e irregolarità della linea pleurica, in 7 casi sono stati osservate aree ipoecogene sub pleuriche, principalmente nelle porzioni laterali del polmone, compatibili con aree di consolidamento polmonare. La media delle radiografie eseguite per paziente durante il periodo di studio è stato $2,6 \pm 1$ mentre quello dei precedenti sei mesi era di $3,8 \pm 1.5$ ($p < 0.05$).

Conclusioni: L'ecografia polmonare è utile per il follow-up nei neonati pretermine con RDS, si è infatti ridotto il numero di radiografie del torace e quindi dell'esposizione alle radiazioni ionizzanti in questa categoria di pazienti.

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Introduction

Respiratory distress syndrome (RDS) is a common disease among very low birth weight (VLBW). It is frequently encountered in neonatal intensive care units (NICUs), where it is managed with specific, well-defined diagnostic and therapeutic algorithms [1–4]. RDS is caused by delayed maturation of the surfactant system and structural immaturity of the lungs, which are characterized by poorly developed alveoli and an excess of connective-tissue matrix. The disorder begins right after birth and shows various degrees of severity [4]. The natural history of RDS has changed considerably thanks to the use of prenatal administration of corticosteroids, administration at birth of surfactant, and the presence in NICUs of increasingly sophisticated systems for providing ventilatory assistance.

The diagnosis of RDS is based mainly on clinical findings along with blood gas analysis and chest radiography. Chest X-rays reveal diminished expansion of the lungs, varying degrees of generalized symmetrical opacification, and air bronchograms – a picture referred to as the "reticulogranular" or "ground-glass" pattern (Fig. 1). The opacity, which resembles a fine, diffuse, reticulogranular network, reflects the combined presence of collapsed alveoli, interstitial imbibition, and air-induced distention of

numerous bronchioles, which in the absence of surfactant remain more compliant than the rest of the lung [3]. In addition to their role in the diagnosis of RDS, chest radiographs are also necessary for monitoring the response to

Fig. 1 Chest radiograph of a newborn with RDS: Poorly aerated lungs with the ground-glass reticulonodular pattern.

therapy and detecting any complications that may occur. However, the use of ionizing radiation is by no means risk-free in this patient population: its damaging effects can be similar to those produced by fetal exposure at the corresponding gestational age [5,6].

Enormous strides have been made in the use of ultrasonography in NICUs, where it is used to diagnose diseases of the nervous system and to investigate abdominal and cardiac disease. It offers a number of advantages, including low cost. In addition, scans can be performed rapidly and repeatedly, without removing the newborns from their incubators and without exposing them to ionizing radiation. Thus far, however, this imaging modality has found limited applications in the study of the lungs. The high air content of these organs reduces the progression of the ultrasound beam, and the images obtained in a normal lung consist almost exclusively of meaningless artifacts [7].

Nonetheless, in some settings, such as the emergency department or adult intensive care units, US has been used for several years to evaluate lung conditions like pneumothorax, the alveolar–interstitial syndrome (AIS) [8], and pleural effusions [9], and it has also been employed to diagnose pneumonia [10,11] and to differentiate cardiogenic pulmonary edema from exacerbations of chronic obstructive pulmonary disease [12]. More recently some authors have suggested that transabdominal [13] or trans-thoracic [14,15] sonography can also be a valid tool for the study of certain forms of neonatal lung disease, including transient tachypnea of the newborn (TTN) and RDS.

The aim of the present study was to determine whether systematic use of chest US in newborns with RDS could reduce the number of chest radiographs obtained in this population. Our hypothesis was that the evolution of RDS could be monitored effectively with US, thereby reducing exposure to ionizing radiation in NICU patients.

Sonographic features of the normal lung

The sonographic appearance of the chest in a newborn infant is not very different from that of an adult. The first layers depicted in the sonographic image represent the skin, subcutaneous tissue, and the muscles of the chest wall. In longitudinal scans, the ribs appear as curved hyperechoic bands with typical posterior shadowing. The pleura is represented by a regular hyperechoic line (Fig. 2), which moves in synchrony with the breathing movements. The pleural movement is referred to as the “lung sliding sign” and its absence is an important sign of pneumothorax [16,17].

Beneath the pleura lie the air-filled alveoli, which prevent visualization of the normal lung parenchyma. The interface between the superficial soft tissues and the air-filled lung tissue is characterized by high acoustic impedance. As a result, the ultrasound beam is almost completely reflected, producing a pattern of horizontal artifacts described by Lichtenstein as A lines. They consist of a series of regularly spaced, hyperechogenic lines lying parallel to the scanning plane (Fig. 2). In the normal lung, there are also less common artifacts, such as the “ring-down” or “comet-tail” artifacts: vertical reverberations (B lines in the Lichtenstein classification) that radiate from the pleural line to the deeper layers of the ultrasound image.

Fig. 2 Longitudinal scan of the chest with a normal lung. The ribs produce posterior shadowing. The pleural line (vertical arrow) is seen beneath the chest wall between two ribs. A line artifacts appear as regularly spaced horizontal lines (curved arrow).

In many forms of lung disease, the air content of the lungs is reduced, and this changes the sonographic picture appreciably. In RDS, for example, there is a substantial increase in the number of closely packed ring-down and comet-tail artifacts. In addition, the horizontal artifacts are absent, and there are also changes in the pleural line, which often appears thickened and irregular.

Materials and methods

From April through September 2008, all newborns admitted in the NICU with clinical signs of RDS were subjected to a chest X-ray and lung ultrasonography. If the diagnosis of RDS was confirmed on the basis of the baseline radiological and sonographic findings, infants were enrolled in the study (Group I) and a thoracic US follow-up was performed. During the follow-up each patient was re-examined by chest US every 8–12 h until the lung disease had resolved. Chest X-ray was performed only when discrepancies emerged between clinical and US findings. We calculated the number of chest roentgenograms done per patient during this period. These data were then compared with data for patients with RDS consecutively admitted to the unit during the 6 months immediately preceding the this study period (i.e., October 2007 through March 2008) (Group II).

Chest radiography was done with a portable machine (Intermedical Basic 100-30, USA) (50 kV, 2.5 mA) at a distance of 90 cm. With these settings, the calculated radiation dose was 69 μ Gy, which is consistent with diagnostic reference values for the entrance surface dose (80 μ Gy) established in European Union guidelines [18]. We kept the dose below this limit by elaborating the image obtained with the CR Regius system (Konica Europe GmbH) according to a specific protocol for pediatric patients. After the first diagnostic X-ray, the evolution of the disease and response to treatment were monitored with sonographic examinations of the chest.

The US scans were performed with a scanner produced by the Hitachi Medical Corporation (Japan) and a linear 7.5 MHz transducer (for transthoracic studies) or a convex 3.5 MHz transducer for the transabdominal examinations, which were used to identify the presence of pleural effusions. The 7.5 MHz transducer was used to evaluate the lungs themselves. To this end, longitudinal and transverse scans were made over the entire chest wall, with video-clip recording. Images acquired over the midaxillary and mid-clavicular lines (bilaterally) were photographed and used as references for later studies.

Results

From April through September 2008, a total of 105 sonographic examinations of the chest were performed on 21 patients in the NICU. The gestational ages of the babies ranged from 25 weeks + 5 days to 32 weeks + 6 days (mean $\pm$ SD: 30 ± 2 weeks), and birth weights ranged from 668 g to 1440 g (mean $\pm$ SD: 1159 ± 283 g). During this same period, a total of 56 chest roentgenograms were done in the NICU (mean $\pm$ SD: 2.6 ± 1 per patient).

During the 6 months immediately preceding the study period (i.e., October 2007 through March 2008), 18 infants with RDS were admitted to the NICU. They had gestational ages ranging from 26 weeks + 1 day to 32 weeks + 4 days (mean $\pm$ SD: 29.1 ± 1.85 weeks) and birth weights ranging from 810 g to 1635 g (mean $\pm$ SD: 1204 ± 223 g) (Group II) (Table 1). In this group, 69 chest radiographs were performed (mean $\pm$ SD: 3.8 ± 1.5 per patient).

Thanks to the use of lung US in the NICU, there was a significant decrease in number of chest X-rays performed on the newborns with RDS and also in the amount of radiation they were exposed to. In fact, the mean number of radiographs per patient dropped to 2.6 ± 1 during the study period from 3.8 ± 1.5 during the 6 months that preceded it ($p < 0.05$).

In the neonates with clinical and radiological diagnoses of RDS, the sonographic appearance of the chest was characterized by the disappearance of the horizontal artifacts (A lines in the Lichtenstein classification) that are seen in normal chests and by the presence of closely packed vertical artifacts (Lichtenstein's B lines) (Fig. 3), which were associated with irregularity of the pleural line. In the patients with the most severe disease, the pulmonary artifacts were replaced by small inhomogeneously hypoechoic areas beneath the pleural line (Fig. 4), which probably represented areas of atelectasis [19].

In all 21 patients, the images exhibited vertical artifacts (B lines) lying close together and distributed in a uniform

Fig. 3 Longitudinal scan of the chest of a newborn with RDS. Compact B lines (arrows) can be seen between the ribs (curved arrows).

manner throughout both lung fields so that the entire image was almost completely hyperechogenic (compact B lines). In 8 cases, there was also thickening and irregularity of the pleural line (Fig. 5), and in 7 cases there were subpleural hypoechoic (usually located in the lateral portions of the lung), which were compatible with areas of lung consolidation (Table 2). In US images obtained later, the initiation of the healing phase was heralded by the return of the A lines, i.e., the physiological artifacts typically seen in normal lungs.

Discussion

Ultrasonography is an extremely accurate and low-cost imaging technique that has essentially no contraindications

Fig. 4 Transverse intercostal scan of the chest in a newborn with RDS. The pleural lines appear irregular (arrow), and a hypoechoic area is visible at the subpleural level (arrow head).

Table 1 Clinical features of the two study groups.

	Group I	Group II
Patients (no.)	21	18
Mean gestational age (weeks)	30 ± 2	29.1 ± 1.85
Mean birth weight (g)	1159 ± 283	1204 ± 223
Mean no. radiographs per patient (mean $\pm$ SD)	2.6 ± 1	3.8 ± 1.5

Fig. 5 Longitudinal scan of the chest of a newborn with RDS shows thickening of the pleural line.

and none of the adverse effects caused by exposure to ionizing radiation. For these reasons, its use as a diagnostic tool has increased considerably in recent years. At the present, its use in the investigation of chest disease in neonates is fairly limited.

Diseases of the respiratory system are studied almost exclusively with radiography, which provides a panoramic view of the lungs and cardiomeastinal structures, and even the subdiaphragmatic region. In clinical practice, newborns are often subjected to repeated chest X-rays, which are used for the initial diagnosis (RDS, pneumonia, pneumothorax, meconium aspiration, congenital heart disease, pulmonary malformations and masses), for monitoring the evolution of the disease, for evaluating the efficacy of therapy, and to check the position of endotracheal tubes and central venous catheters. With each study, the cumulative exposure to ionizing radiation increases. Although the dose received during each single exposure is low, attempts must be made when possible to reduce such exposures in newborns and premature babies, who are particularly vulnerable to the adverse effects of such radiation. In this patient population, the risk of inducing cancer associated with a given dose of radiation is believed to be 2 or 3 times higher than that documented in the general population and 6–9 times higher than that observed in 60-year olds [20]. For this reason, respiratory disease in newborns must be diagnosed and monitored with alternative approaches that are not associated with these potentially noxious effects.

Compared with the lungs of an adult, those of a newborn (especially those that are premature) are more

suitable for US assessment because their chest cavities are smaller. The entire neonatal lung can be examined with a few scans. In contrast, multiple scans are necessary to visualize the adult lung, and as a result, the panoramic view one has of the neonatal chest cavity cannot be achieved during the examination of an adult (Fig. 6).

Sonographic examination of the lungs was first described in 1961 by Dunn [21]. Since then, the topic has been explored more thoroughly in numerous studies. Lichtenstein et al. [13] described the artifacts that occur when the ultrasound beam penetrates the skin, subcutaneous tissues, and muscles of the chest wall and encounters the visceral pleura and the subpleural alveoli with their high air content. Transmission of the ultrasound waves through the tissues is accompanied by various phenomena, including reflection, refraction, dispersion, and absorption. The degree to which each of these occurs depends on the tissue being examined, the frequency of the ultrasound waves, the relation between ultrasound wave length and the dimensions of the structure being examined, the spatial orientation of the surface being examined, and the acoustic impedance of the structure examined, which is closely related to the speed at which the ultrasound waves propagate within the tissue [22]. In the lung, artifacts (i.e., sonographic images that have no anatomic or structural correspondent) are produced because the ultrasound beam emitted by the transducer is almost entirely reflected when it encounters the interface between surface tissues and a structure with high air content. As long as the alveoli contain air, as they normally do under physiological conditions, the sonogram will contain only artifacts that are of little diagnostic value. But true sonographic images are produced when the air content of the alveoli diminishes, as it does in the presence of RDS, pneumonia, pleural effusions, and pulmonary masses that are in contact with the pleura [23].

Fig. 6 Longitudinal scan of the chest done along the mid-clavicular line in a newborn with RDS.

Table 2 Ultrasound patterns observed in newborns with RDS.

Patterns	No. of patients
Compact B lines	21
Thickened pleural line	8
Irregular pleural line	7
Subpleural hypochoic areas	7

Conclusions

RDS is a common finding in NICUs, and its diagnosis generally requires the use of chest radiography. In a considerable proportion of cases, multiple chest X-rays are performed during the NICU stay to evaluate the effectiveness of treatment. In this study, we evaluated the routine use of chest US in the follow-up of patients with RDS and found that this disease is associated with characteristic sonographic patterns. The routine use of US also allowed us to decrease the frequency of chest X-rays in this population, with consequent reductions in the infants' exposure to ionizing radiation.

Conflict of interest statement

The authors have no conflict of interest.

Appendix Supplementary material

Supplementary data related to this article can be found online at [doi:10.1016/j.jus.2011.04.004](https://doi.org/10.1016/j.jus.2011.04.004).

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