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Clinical paper

Lung ultrasound during the initiation of breathing in healthy term and late preterm infants immediately after birth, a prospective, observational study☆

Douglas A. Blank[a,b,*], Sheryle R. Rogerson[a], C. Omar F. Kamlin[a], Lisa M. Fox[a], Laila Lorenz[a,c], Stefan C. Kane[d,e], Graeme R. Polglase[b], Stuart B. Hooper[b], Peter G. Davis[a]

[a] Newborn Research Centre, The Royal Women's Hospital, Melbourne, Australia
[b] The Ritchie Centre, Hudson Institute of Medical Research, Monash University, Melbourne, Australia
[c] Department of Neonatology, University Children's Hospital of Tübingen, Germany
[d] The University of Melbourne, Department of Obstetrics and Gynecology, Melbourne, Australia
[e] Pregnancy Research Centre, The Royal Women's Hospital, Melbourne, Australia

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A B S T R A C T

Introduction: Lung ultrasound (LUS) has shown promise for evaluation of newborns with respiratory distress. However, no study has described the appearance of LUS during the initiation of breathing. We used LUS to describe the appearance of the lungs in healthy infants immediately after birth, starting with the infant's first breath, through the first 20 min after birth.

Methods: This was a single-center observational study enrolling neonates born at ≥35 weeks. We obtained LUS video recordings with the initiation of breathing. Recordings that captured one of the 1st four breaths after birth were included. We also obtained recordings at 1–10 and 11–20 min after birth. Recordings were graded using a modified version of a previously published system, with additional grades to describe the appearance of the lungs prior to establishment of the pleural line.

Results: We studied 63 infants, mean gestational age = $39^{1/7} \pm 2$ days, mean weight = 3473 g ± 422, 33 infants were delivered vaginally and 30 via cesarean section. We captured the first breath after birth in 28 infants and within the first four breaths from the remaining 35 infants. The pleural line was established by a median of 4 breaths (3–6). At the 1–10 min examination, all infants had an established pleural line and 89% demonstrated substantial liquid clearance. At the 11–20 min examination, all infants had substantial liquid clearance.

Conclusion: Establishment of the pleural line, indicating lung aeration and substantial liquid clearance is achieved with the first few breaths after birth in term and near term infants.

Introduction

Lung ultrasound (LUS) has shown promise as a diagnostic tool for evaluation of newborns with respiratory distress.[1–15] Following birth, the organ responsible for gas exchange transitions from the placenta to the lungs.[16] To establish pulmonary gas exchange, the airways must be cleared of liquid to allow the entry of air. LUS may be able to characterize this process. LUS can be performed at the bedside in real time, may be easily repeated during clinical changes and treatments, and does not expose the infant to ionizing radiation.[17,18]

Ultrasound beams penetrating an unaerated, liquid-filled lung create true ultrasound images as the density of liquid changes between the tissue layers. In contrast, ultrasound beams passing through an aerated lung produce artifacts.[1,8,19,20] Traditionally, the interference of sound waves caused by air in the lungs has discouraged the use of LUS as a diagnostic tool. However, an understanding of these characteristic artifacts has led to the recognition that these artifacts are consistent and have diagnostic importance.[1,6,8,9,12,13,21] Our hypothesis is that we can use lung ultrasound to describe initial lung aeration and liquid clearance as healthy term and near term infants initiate breathing after birth.

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* Corresponding author at: Newborn Research, The Royal Women's Hospital, Locked Bag 300, 20 Flemington Road, Parkville, 3052 Victoria, Australia. Fax: +61 3 8345 3789.
E-mail addresses: douglas.blank@thewomens.org.au, blankdouglas@gmail.com (D.A. Blank).

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Methods

This was a prospective, observational study of newborn term and late preterm infants. We used ultrasound to characterize the appearance of the lungs as infants initiate breathing after birth. The study was conducted at the Royal Women's Hospital, in Melbourne, Australia, a regional referral hospital averaging more than 7000 deliveries per year.

Inclusion criteria and consent

Infants born at >35 weeks without an antenatal diagnosis of significant pulmonary pathology (i.e. diaphragmatic hernia) were eligible for participation. Written, informed, antenatal consent was obtained prospectively from expecting mothers. We also obtained oral permission from the delivering obstetrician or midwife to be present at deliveries and conduct the study. The patients included in this study represent a convenience sample, with a target enrollment of 50 infants, half delivered vaginally and half delivered via elective cesarean section (CS) without labor. In addition, we studied a third group of infants, not included in our goal sample size of 50, who were born via unplanned CS after labor (cervical dilation ≥5 cm and ≥2 h of uterine contractions). The infants in this study represent a subset of a larger cohort to describe the changes using LUS through the first 24 h after birth (ANZ Clinical Trials Registry Number 12615000380594). Our goal was to obtain 10–20 s lung ultrasound video recordings as the infant initiated breathing after birth. Patients were also included if we were able to obtain lung ultrasound video recordings beginning prior to the 4th breath after birth. The study was approved by the Royal Women's Hospital human research ethics committee.

Data collection

We obtained serial LUS video recordings, using a GE Venue 50 ultrasound machine (GE Healthcare, Chicago, USA) and a "hockey-stick," L8-18i linear transducer with a depth of 2.5 cm and a gain of 60.

As soon as the delivering infant's chest was exposed, the researcher placed the transducer on the chest and obtained a 10–20 s video recording using B-mode and M-mode capturing the initiation of breathing, referred to as the "birth" examination. For the birth exam, we obtained video recordings of either the right or left chest, depending on which side was available. In the event of a cesarean delivery, the researcher scrubbed in using sterile technique to enter the surgical field. The ultrasound transducer was placed in a sterile plastic sheath and sterile ultrasound gel was used. Infants were either being held by the delivering midwife or obstetrician or were placed on their mother's chest during the birth examination. In addition to the birth examination, we also obtained 3 s video recordings from both the right and left side of the chest using B-mode and M-mode at 1–10 min after birth and 11–20 min after birth. In subsequent examinations, infants were either held by their mother or placed on a warming bed.

During each examination, the LUS transducer was placed in the infant's axillae with the notch pointed superiorly towards the infant's head. The transducer was 3.5 cm long, typically capturing images from 2 to 3 intercostal spaces. We placed the LUS transducer in the infant's axillae because we could obtain consistent images regardless if the infant was prone or supine, while minimizing handling. The transducer was then adjusted until a "bat sign" was achieved and the lungs appeared as aerated and dry as possible.[8,19,22] We also collected clinical and demographic information until discharge from the hospital.

Lung ultrasound grading

Ultrasound examination of the lung depends on attenuation of sound waves and interpretation of characteristic artifacts. In healthy, aerated lungs, the ultrasound beam passes through the pleural line and encounters air. The air scatters the ultrasound beam and gives rise to horizontal, hyperechoic reverberation artifacts called "A-lines," in which the pleural line is regularly repeated through the depth of the ultrasound window [Figs. 1 & 2].[1,6,8,19,20] A healthy lung has characteristic movement of the pleural line with respiration, seen as "lung sliding" on B-mode video recordings and the "seashore sign" on M-mode.[22–26] Retention of lung liquid after birth is associated with the presence of hyperechoic vertical projections, called "B-lines," that arise from the pleural line and extend through the ultrasound image [Figs. 1 & 2].[3,5,8,15,19,20,27]

We modified a previously validated lung ultrasound grading system described by Raimondi et al. (Fig. 2).[1–3] Type 3 is seen in healthy lungs with full aeration and liquid clearance. Type 3 is characterized by a lack of B-lines and the presence of horizontal, hyperechoic A-lines that repeat regularly through the ultrasound window.[8] We evaluated each video recording for the presence of "lung sliding" on B-mode video recordings and the "seashore sign" on M-mode to rule out pneumothorax.[23–26,28] Type 2 is characterized by the presence of discrete vertical B-lines, arising from a clearly defined pleural line. Type 1 images are created by the coalescence of vertical B-lines that blunt the pleural line and produce a uniform, hyperechoic image called the "white-out" lung. Type 1 is associated with respiratory distress syndrome.[1,2,6,8,13]

We added two additional grades to describe the appearance of the lung prior to the establishment of the pleural line. Type 0 is seen prior to the initiation of breathing and establishment of the pleural line. This is a true US image (no air artifacts) as the US beam passes exclusively through liquid. The ribs and acoustic shadow of the ribs are still visible; the pleural line is either too hypoechoic to be seen or appears as an extremely thin line. This image is also described as "hepatization" of the lungs as they appear to have the same US feature as the liver. [Video examples 1 & 2 in the online version at DOI: 10.1016/j.resuscitation.2017.02.017] Type 0.5 depicts the pleural line with a patchy appearance with poor definition, consisting of speckled hyperechoic areas mixed with hypoechoic lung tissue. This image was visible, transiently, after the initiation of breathing, before the establishment of the pleural line. We also considered the LUS grade to be 0.5 if one area of the ultrasound window showed an established pleural line and another area of the window showed lung without an established pleural line [Fig. 1.3 and 1.4 and Video example 2 in the online version at DOI: 10.1016/j.resuscitation.2017.02.017].

Analysis and statistics

The birth examinations were graded on the above scale at the beginning and end of the video recording. We recorded the number of breaths the infant had taken prior to placing the transducer on the infant's chest to determine if we captured the initiation of breathing. Recordings that started within the infant's first 4 breaths were included for analysis. At the 1–10 min and 11–20 min examination, the LUS grade from each side was combined for analysis, i.e. infants could have a grade of type 3/3, type 2/3, type 2/2, type 2/1, type 1/1, etc.

Means are reported for normally distributed continuous variables and medians with 25–75% interquartile ranges are reported when the distribution was skewed. The Friedman test was used to analyze changes in LUS grades at different time points for the whole cohort. We compared LUS grades at the start and end of the birth exam and each side of the chest at the 1–10 min and 11–20 min exams. The Kruskal–Wallis H Test using Dunn's proce-

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