Seminars in Pediatric Surgery 22 (2013) 30–36

Contents lists available at SciVerse ScienceDirect

Seminars in Pediatric Surgery

journal homepage: www.elsevier.com/locate/sempedsurg

Use of ultrasound and MRI for evaluation of lung volumes in fetuses with isolated left congenital diaphragmatic hernia

Teresa Victoria [a,b,*], Enrico Danzer [b], N. Scott Adzick [b]

[a] Department of Radiology, Children's Hospital of Philadelphia, Pennsylvania
[b] The Center for Fetal Diagnosis and Treatment, Children's Hospital of Philadelphia, Pennsylvania

ARTICLE INFO

Keywords:
Congenital diaphragmatic hernia
Fetal MRI
LHR
O/E fetal lung volume

ABSTRACT

Congenital diaphragmatic hernia (CDH) is an anomaly that results in lung hypoplasia and pulmonary hypertension. The lungs of the CDH fetus have an abnormal architecture, with fewer bronchial branches and decreased number of arteries and veins, factors which result in pulmonary compromise postnatally. The goal of this review is to evaluate prenatal prognostic factors in the fetus with isolated left CDH, with particular emphasis on fetal MRI. These imaging indicators may be used to provide health professionals and the parents with the most accurate information about fetal prognosis.

Introduction

Congenital diaphragmatic hernia (CDH) is a developmental defect of the diaphragm that allows the abdominal viscera to herniate into the chest. The herniation of abdominal contents through the diaphragmatic opening leads to pulmonary compression and resultant pulmonary hypoplasia. Herniation also occurs at a crucial time in the development when bronchial and pulmonary artery branching occurs, leading to fewer branch points and vascular units compared to the normal lung.[1,2] The end result is decreased alveolar exchange surface and increased vascular resistance, leading to various degrees of pulmonary hypoplasia and hypertension.

In the last two decades, a large body of work has focused on improving prenatal ultrasound (US) and magnetic resonance imaging (MRI) techniques to accurately evaluate parameters that may predict postnatal outcome in the CDH fetus, particularly using lung volumetric measurements. The ability to accurately determine prognosis for CDH impacts prenatal counseling, possible selection for fetal intervention, and decisions for postnatal management. This review will summarize the progress in lung volume measurements in the CDH fetus.

Ultrasound, the lung-to-head ratio (LHR), and the fetal lung

Prenatal evaluations begin with US, an imaging modality that is widely available, relatively inexpensive, and routinely used in the evaluation of congenital defects. It is observer dependent, allows bedside evaluation, and carries essentially no maternal discomfort. Improvements in equipment and technique in the last few years has led to increased sensitivity in the prenatal identification and evaluation of the fetus carrying a CDH.

The sonographic estimation of lung volumes was first proposed by Metkus et al. in an initial cohort of 55 fetuses with left CDH.[3] Their rationale was to measure the contralateral right lung as a way of estimating the degree of pulmonary hypoplasia and mediastinal shift, because the ipsilateral left lung was often difficult to distinguish from herniated bowel or liver. The LHR was determined by calculating the ratio of right lung area (the product of the longest two perpendicular lines seen in an axial image at the level of the atria) to head circumference (to minimize lung size differences due to gestational age). The Metkus study, and others thereafter, showed that postnatal survival improves with increased LHR measured antenatally.[4,5]

Subsequently, two alternative methods of measuring LHR were developed: (1) the AP method, which involves multiplying the anteroposterior (AP) diameter of the lung at the midclavicular line times the perpendicular diameter at the midpoint point of the AP diameter; (2) the tracing method, which manually traces the limits of the right lung (Figure 1). These three methods of measuring LHR were evaluated in a study by Peralta et al. including 650 normal singleton pregnancies between 12 and 32 weeks of gestation.[6] They found that in normal fetuses, the most reproducible method of measuring LHR was by manual tracing of

* Corresponding author at: Department of Radiology, Children's Hospital of Philadelphia, 34th St and Civic Center Boulevard, Philadelphia, Pennsylvania 19103.
E-mail address: victoria@email.chop.edu (T. Victoria).

1055-8586/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1053/j.sempedsurg.2012.10.006

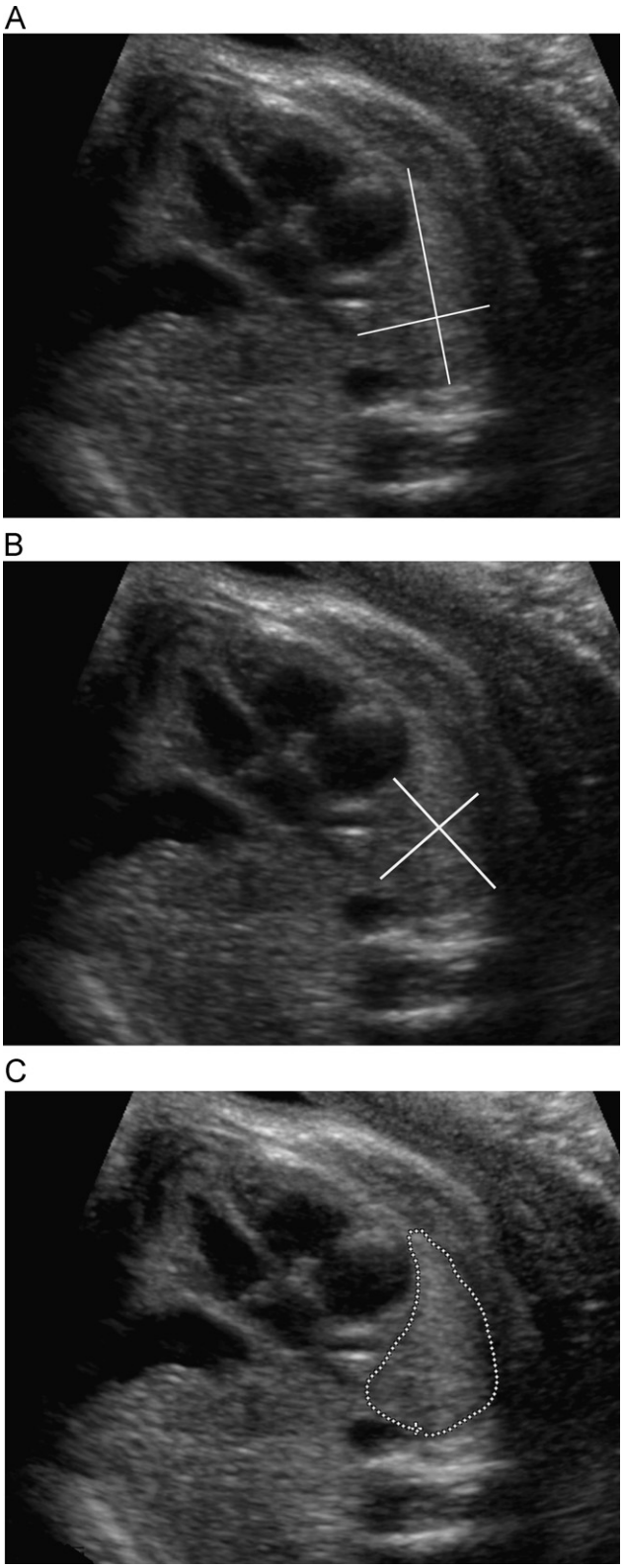

Fig. 1. Calculation of the sonographic LHR. (A) describes the original method of calculating LHR by estimating the right lung area (the product of the longest perpendicular lines at the level of the 4-chamber heart) to head circumference. (B) demonstrates the AP method, where the AP diameter of the right lung at the mid-clavicular line is multiplied by its perpendicular diameter at the midpoint. (C) illustrates the tracing method, where the operator manually traces the limits of the right lung, creating a measurement of the lung area at the level of the 4-chamber view of the heart. This number is then divided by the head circumference to yield the LHR.

the lung borders, whereas the least reproducible method was that of the original method which utilizes the longest perpendicular diameters. When compared to the tracing method, the longest diameter method overestimated the area of the left and right lung by about 45%, and the AP method overestimated the right lung area by about 35%. The discrepancies may be explained, in part, by the assumption that the lung area is provided by the multiplication of two perpendicular measurements, which erroneously assumes that the shape of the lung is a rectangle. When the three LHR measurements were tested in fetuses with isolated unilateral CDH (either left or right) at 21–33 weeks gestation, the tracing method was found to be the most reproducible way to measure fetal lung volume; this method also had smaller inter- and intra-observer differences.[7]

All types of LHR measurement have several limitations. First, LHR underestimates the actual lung volume in the CDH fetus, thought to be due in part to compression of the right lung by the mediastinum and herniated viscera in the chest. This compression is more pronounced in the *lateral* rather than in the *vertical* plane, as supported by the findings that in fetuses with CDH, the mean lung length is about 15% longer than in gestation-matched normal controls, whereas the mean lung area is about half.[8] Second, variability in LHR measurements among different observers and among same observers at different time points has also been demonstrated.[6]

Finally, the main limitation of the LHR is its dependence on gestational age. In the above-mentioned 2005 study including 650 normal fetuses, Peralta et al. determined that while there is a 16-fold increase in lung area between the gestational ages of 12–32 weeks, only a 4-fold increase in head circumference was seen during the same time period,[6] rendering the LHR measurement inadequate for proper evaluation of lung growth at different gestation ages. In order to overcome this deficiency, the concept of Observed compared to Expected (O/E) LHR emerged, in which the LHR is corrected for gestational age[9] using the expected normal range lung values provided by the cohort of normal fetuses in Peralta's study. The O/E LHR is calculated by the simple ratio, observed or expected LHR $\times$ 100, a ratio which does not change significantly with gestational age. The O/E LHR not only provides a gestation independent assessment of lung size, but also a gestation independent prediction of postnatal outcome.[10] When utilizing the corrected LHR, the following numbers are quoted from the antenatal CDH registry in 184 fetuses with isolated left CDH evaluated between 22 and 28 weeks gestation[11]:

- Fetuses with O/E LHR $<15\%$ have *extreme pulmonary hypoplasia*, with virtually no survivors.
- Fetuses with O/E LHR between 15% and 25% have *severe pulmonary hypoplasia*, with a predicted survival of 20% (those with liver completely down in the abdomen fare better than those with liver herniated up into the chest).
- Fetuses with O/E LHR between 26% and 35% and those with O/E LHR between 36% and 45% but liver up have *moderate hypoplasia*, with expected survival between 30% and 60%.
- Fetuses with O/E LHR between 36% and 45% with liver down and O/E LHR $>45\%$ have *mild hypoplasia* and are likely to survive ($>75\%$).

A number of limitations in the use of US are apparent. Among these is the sometimes difficult soft tissue distinction between lung and liver and the limited acoustic window in the obese patient. Work with a promising 3D US lung volume measurement has shown an underestimation of the contralateral fetal lung volume by as much as 25% (compared to MRI) and inadequate visualization of the ipsilateral lung in as many as 45% of the cases