Assessment of Carina Position Antenatally and Postnatally in Infants with Congenital Diaphragmatic Hernia

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Objective To determine whether endotracheal tube (ETT) insertion depth should be modified in infants with congenital diaphragmatic hernia (CDH) to reduce the risk of main-stem intubation.

Study design The distance from the thoracic inlet to the carina was measured antenatally by fetal magnetic resonance imaging (MRI) between 20-28 weeks' (early) and 30-34 weeks' (late) gestation in 30 infants with CDH and compared with 12 early and 36 late MRIs in control infants without CDH. Postnatal tube position was assessed by chest radiograph in the same 30 infants with CDH and compared with 20 control infants with postnatal birth depression.

Results The carina position was displaced upward in fetuses and newborns with CDH. Distance from the thoracic inlet to the carina compared with controls was 1.04 ± 0.1 cm vs 1.42 ± 0.07 cm on early MRI ($P < .05$), 1.43 ± 0.14 cm vs 1.9 ± 0.04 cm on late MRI ($P < .01$), and 2.36 ± 0.07 cm vs 3.28 ± 0.05 cm on postnatal radiographs ($P < .01$). Adjusting the ETT depth by 1 cm resulted in a median distance of 1.27 cm from the tip of the ETT to the carina.

Conclusion Cephalad displacement of the carina in infants with CDH may predispose them to right main-stem intubation and subsequent development of pneumothorax. We speculate that modifying the ETT insertion depth to 5.5 cm + weight in newborns born at term may prevent pneumothoraces and improve outcomes for infants with CDH. *(J Pediatr 2018;192:93-8).*

Congenital diaphragmatic hernia (CDH) is a severe birth defect, with a prevalence of 1:2000 to 1:3000 live births.[1,2] In infants with CDH, a defect in the diaphragm results in herniation of the abdominal contents into the chest and compression of the intrathoracic structures.[3] Displacement of the heart and compression of the intrathoracic structures contribute to pulmonary and left ventricular hypoplasia and abnormal development of the pulmonary vasculature in utero.[4-9] These abnormalities cause persistent pulmonary hypertension of the newborn and respiratory insufficiency after birth.[3,10,11] Initial stabilization of infants with CDH involves endotracheal intubation for the management of respiratory failure and prevention of gaseous distention of the intestines and stomach.

Despite advances in neonatal care, mortality in infants with CDH remains high and ranges from 15% to 80% depending on the severity of the defect.[12,13] In addition to the severity of the defect, several postnatal factors contribute to mortality in CDH. Pneumothorax is a complication that occurs frequently in this group of patients and increases the risk of mortality by 4-fold when it develops pre-repair.[14,15] Historically, the development of a pneumothorax pre-repair was thought to be a marker of lung hypoplasia and representative of overzealous resuscitation and barotrauma.[14] However, other factors may contribute to postnatal development of pneumothorax in infants with CDH. With the abdominal organ herniation associated with CDH, it is possible that the carina is displaced cephalad, predisposing the infant to right main-stem intubation during initial endotracheal tube (ETT) placement. Resuscitation of the newborn infant with CDH with the ETT in the right main-stem bronchus overexposes the right lung to the initial inflating pressure used during newborn resuscitation and impedes emptying of the lung, predisposing the infant to the development of a pneumothorax.

Prenatal magnetic resonance imaging (MRI) at 20-24 weeks and 34 weeks can be used to define the anatomy of infants with CDH and predict the outcome and severity of the defect.[16-18] By using these images, the position of the carina can be determined and compared in utero with age-matched control subjects. We hypothesized that the abdominal organ herniation in infants with CDH displaces the carina upward and that this displacement progresses from mid- to late gestation and after birth. We examined the position of the carina in fetuses with CDH at 20-28 weeks' gestation, 32-35 weeks' gestation,

AP	Anteroposterior	MRI	Magnetic resonance imaging
CDH	Congenital diaphragmatic hernia	NTL	Nasal tragus length
CHCO	Children's Hospital Colorado	PPLV	Percent predicted lung volume
ETT	Endotracheal tube	TI	Thoracic inlet
LHR	Lung/head ratio	TLV	Total lung volume
MGI	McGoon index		

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and postnatally and confirm progressive cephalad displacement of the carina.

Methods

After approval from the institutional review board, prenatal MRIs at Children's Hospital Colorado (CHCO) were reviewed in 30 patients with left-sided CDH managed between April 2011 and March 2015. Infants with right-sided defects and Morgagni hernias were excluded from analysis. A total of 30 patients were managed at our institution who met inclusion criteria over that time period. At CHCO, fetal MRI is performed on all infants with CDH between 20 and 24 weeks' gestation (early) and at 34 weeks' gestation (late) to assess lung volumes (percent predicted lung volume [PPLV] and total lung volume [TLV], degree of liver herniation, the presence of a hernia sac, McGoon index [MGI; diameter of the right pulmonary artery + left pulmonary artery/diameter of aorta at the level of the diaphragm]) and to determine whether other anomalies are present. Early MRI studies were available for 30 infants and late MRI studies available for 24 infants, as 6 infants were delivered before 34 weeks' gestation.

All MRIs were performed in 2 60-inch bore, 1.5-Tesla scanners (Siemens Healthcare USA, Malvern, PA) via the use of 2 6-channel surface coils and a Philips Ingenia scanner (Philips Healthcare, Highland Heights, OH) with a 32-channel surface coil. The sequences obtained were similar for both scanners and followed pre-existing fetal MRI protocols. All studies were performed in the morning with the pregnant patients under the same nil per os status, which consisted of no solid or liquids 4 hours before the scheduled MRI time.

The best, motion-free coronal plane single-shot sequences were used to measure the distance of the carina to the thoracic inlet (TI). Initially, the area of the TI was determined by correlating sagittal, axial, and coronal views of the chest. The line was placed on the coronal plane right above the lung apex, which on fetal MRI correlates with the postnatally described TI. Because our protocols were the same for early and late MRIs, all the coronal planes were acquired based on a parallel plane to the thoracic spine, which corrects for the normal fetal thoracic curvature position seen in most fetuses. This provides consistent plane acquisition among all the cases, although a slight variation on the axis on each plane could exist.

Once the TI was determined, the distance between the carina to the TI was measured in centimeters only in the coronal plane via the measuring tools built in picture archiving and communication system). To prevent bias, the early gestational age group was evaluated first, masking the radiologist to images of the late gestation (and vice versa) as well as to postnatal radiographic measurements. Age-matched control fetal MRI studies performed for nonpulmonary-related pathology were used as controls. A total of 12 early and 36 late control MRI studies were available for comparison. Indications for control fetal MRIs are presented in **Table I** (available at www.jpeds.com). The distance in centimeters between the TI (calculated in the same way as in the CDH cases) and the carina was measured as described previously.

Postnatally, for infants with CDH, the distance between the TI and carina was measured on the first anteroposterior (AP) chest radiograph obtained at our institution. Because infants with CDH in this study were born at CHCO, the first AP chest radiograph was obtained in the delivery room. In our practice, the first chest radiograph is only obtained in the AP plane; therefore, a lateral view was not available in any of the cases. Evaluating the position of the carina on lateral radiographs (either true lateral or cross-table lateral) is challenging in the CDH population because of the superimposition of opacities mixed with lucencies (arising from mediastinum, herniated bowel, and sometimes liver), and a comparison with a healthy patient's chest would have not been consistent. Chest radiographs at admission performed in infants admitted for birth depression and selective head cooling were used as a comparison group (normal controls). These initial 30 CDH and 20 control AP chest radiographs were used for comparison.

To prevent potential bias and to enhance consistency, we established a consensus on how to identify the TI before beginning image analysis. This was defined as a horizontal line placed at the level of the first thoracic vertebral body and the first ribs. A variation in obliquity of the AP plane could not be addressed because these images already were obtained. All postnatal chest radiographs were reviewed by a radiologist and an attending neonatologist. In addition, for each individual chest radiograph, the distance from the TI and carina was measured by a radiologist and an attending neonatologist and the distance compared and correlated to determine whether similar measurements were obtained. For all chest radiographs, similar measurements were obtained by a radiologist and an attending neonatologist.

Demographic information collected for all infants with CDH included gestational age at birth, birth weight, sex, the presence of anomalies (anatomic/chromosomal), prenatal markers of CDH severity, early PPLV, late TLV, MGI, the presence of liver herniation, lung/head ratio (LHR), and observed-to-expected LHR. For control subjects, gestational age at birth, birth weight, and sex were collected.

Statistical Analyses

The unpaired *t* test was used to determine differences in the distance from the TI to the carina, antenatally on early and late MRI studies and postnatally on chest radiographs, with $P < .05$ considered significant. To determine whether the severity of CDH correlated with the distance between the TI and carina (for each marker of CDH severity, early PPLV, late TLV, MGI, presence of liver herniation, LHR, and observed-to-expected LHR) the median was calculated and distance from the TI to carina on early and late MRI and postnatal chest radiograph stratified into 2 groups either greater than or less than the median. Distance from the TI to carina was compared with an unpaired *t* test, with $P < .05$ considered significant.

Results

Table II shows the median gestational age, 25th percentile, 75th percentile, and IQRs for early and late control and CDH MRI