IMAGING

Fetal magnetic resonance imaging in isolated diaphragmatic hernia: volume of herniated liver and neonatal outcome

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OBJECTIVE: We sought to use magnetic resonance (MR) imaging (MRI) to estimate percentage of fetal thorax occupied by lung, liver, and other abdominal organs in pregnancies with congenital diaphragmatic hernia (CDH).

STUDY DESIGN: This was a retrospective study of pregnancies with isolated CDH referred for MRI between August 2000 and June 2006. Four regions of interest were measured in the axial plane by an investigator blinded to neonatal outcome, and volumes were then calculated. The percentages of thorax occupied by lung, liver, and all herniated organs were then compared with neonatal outcomes.

RESULTS: Fifteen CDH fetuses underwent MRI at a median gestational age of 29 weeks. Liver herniation was found in 93%. When the liver occupied > 20% of the fetal thorax, neonatal deaths were significantly increased. Percentages of lung and other herniated organs were not associated with outcome.

CONCLUSION: In our MR series of isolated CDH, neonatal deaths were significantly increased when > 20% of the fetal thorax was occupied by liver.

Key words: Congenital diaphragmatic hernia, magnetic resonance imaging, prenatal diagnosis

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BACKGROUND AND OBJECTIVE

Predicting neonatal outcome in the setting of antenatally diagnosed congenital diaphragmatic hernia (CDH) remains problematic. The overall mortality in affected offspring is approximately 50-60% despite advances in the respiratory treatment of critically ill neonates.[1-3] In fetuses without associated major anomalies or aneuploidy, perinatal mortality ultimately depends on the degree of pulmonary hypoplasia and the severity of the pulmonary vascular alterations with resultant pulmonary hypertension.[4] Consequently, the antenatal assessment of these isolated cases of diaphragmatic hernia has focused on the estimation of residual lung tissue and the identification of other markers of disease severity, including fetal liver herniation into the thorax.

The evaluation of the residual contralateral lung in CDH fetuses has been studied extensively using both ultrasound and magnetic resonance imaging (MRI). Although calculations of residual fetal lung volumes have been made with both ultrasound and MRI, these measurements have not consistently predicted neonatal survival.[1,4-8] Perhaps the most widely used estimation of residual fetal lung tissue is the sonographically measured lung-to-head ratio (LHR). Since its introduction by Metkus et al[9] in 1996, the usefulness of the LHR as a predictor of postnatal outcome has been confirmed in a number of studies.[10-13] The LHR is most predictive of outcome when used in the subset of fetuses who have intrathoracic liver herniation,[12] a variable that some believe is the single most important determinant of survival.[14]

Unfortunately, however, contemporary prenatal predictors of neonatal outcome are somewhat limited. Although the LHR is reassuring when it falls in the good prognosis range, a substantial number of fetuses will have ratios in the indeterminate range, and importantly, some fetuses with LHRs in the lowest range are now surviving.[15] Furthermore, although liver herniation is generally regarded as a poor prognostic factor, there are certainly varying degrees of hepatic involvement, and few studies have attempted to quantify the amount of herniated liver to refine the distinction of liver "up" vs "down."[7,16]

Fetal MRI is being increasingly used as an adjunct to ultrasound to better characterize suggested anomalies and improve antenatal diagnosis. With the advent of the single-shot fast spin echo sequence (SSFSE), which minimizes the artifact generated by fetal motion, high-quality MRI of the fetus can now be readily obtained. Although MRI has been used extensively to further evaluate fetal central nervous system anomalies, the applications of fetal MRI have ex-

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panded to include a variety of sonographically identified anomalies, including diaphragmatic hernias.[17] MRI, for example, has been demonstrated to be the most accurate method of determining liver position in fetuses with diaphragmatic hernia and can be used to differentiate this lesion from other chest masses if the diagnosis is in question.[18]

The purpose of this study was to use MRI to quantify the contents of the fetal thorax in an effort to refine the prognosis in severe cases of isolated CDH. Specifically, we sought to use volumetric measurements to estimate the percentage of the fetal thorax occupied by liver, stomach, bowel, and lung and to correlate these variables with postnatal outcome. We hypothesized that correlating these measurements with not only neonatal death but also with markers of serious neonatal morbidity may improve prediction of outcome in severe isolated cases of CDH.

MATERIALS AND METHODS

Patient selection

This study was retrospective and observational in design. We examined singleton pregnancies with isolated CDH, initially identified by ultrasound, referred for MRI between August 2000 and June 2006. In each case, T2-weighted SSFSE MRI was performed to better evaluate the lesion and characterize any associated anomalies. Fetuses with an antenatal diagnosis of aneuploidy or additional anomalies that precluded surgical correction were excluded from this analysis. Our fetal MRI department has become a referral center for further anatomic evaluation of selected severe fetal anomalies, including diaphragmatic hernia. Fetal MRI is not the primary method of evaluating these anomalies, but rather, is requested by maternal-fetal medicine specialists after the initial diagnosis is made to evaluate for the presence of additional abnormalities and assist in refining the diagnosis, so as to better counsel families and anticipate needs at delivery. The MRI examination was performed at the time of initial referral, and as such, we evaluated images from studies performed across a range of gestational ages. As a referral center with capability for extracorporeal membrane oxygenation (ECMO), we ascertained severe cases of CDH and included all pregnancies for which delivery and neonatal care occurred at our institution. This study was granted exempt status by our institutional review board.

MRI technique

MRI was performed using a 1.5-T Signa magnet (General Electric Medical Systems, Milwaukee, WI). A 15-second localizer 3-plane gradient echo T2-weighted sequence was performed to assess the orthogonal planes relative to the fetal position. A SSFSE sequence, with the repetition time (TR) set as long as necessary to virtually eliminate T1 weighting and complete the required acquisition, was used to obtain images. The parameters used were: TR range/effective time of echo range, 30,000-98,000/50-100; field of view, 12-36 cm; matrix, 256×128 or 512×256; bandwidth, 31.2 or 62.5 kHz; average number of excitations, 0.5; and slice thickness, 3-7 mm. Variation in slice thickness depended on the specific magnet in which the examination was performed, and in all but 2 examinations, the slice thickness was 5 mm. A surface coil was wrapped around the mother's pelvis and centered over the fetal region of greatest interest. No maternal sedation was given because, with acquisition times of 1.0-1.5 s/slice, fetal sedation was not necessary.[19] Time needed for a complete acquisition sequence varied from 40-90 seconds, depending on image quantity required. On average, 7 MR sequences (range, 5-9) were acquired with a total average scanning time of 9-12 minutes. The orthogonal MR planes were oriented in relation to the fetal position. The entire MR study, including the setup, was completed within 30 minutes.

Volumetric measurements and outcomes

The images were evaluated by a single investigator (D.M.T.) who was blinded to clinical information and neonatal outcomes. Liver position was considered "up" if any portion was in the chest above the normal level of the diaphragm and "down" if the liver was completely within the abdomen. From a representative sequence of images, 4 regions of interest (ROI) were measured in the axial plane: areas of total thorax (excluding spine), both lungs, liver, and remaining herniated organs (small and large bowel, stomach). Axial-plane images were used because they were easily identified and allowed for circumferential measurements of the fetal thorax to be made. In each sequence, all slices in which lung tissue could be identified were included. Mediastinal structures such as the fetal heart, great vessels, and thymus were identified and included in the measurements of the total thorax but were excluded from the other measurements. Volumes were calculated as the summation of areas multiplied by slice thickness. To correct for differences in gestational age, thoracic volume was used as the denominator, and the percentage of thorax occupied by lung, liver, and other herniated organs was calculated. These values were then compared with neonatal outcomes.

Neonatal outcome variables of interest were abstracted from hospital charts. These included the use of high-frequency oscillatory ventilation (HFOV); ECMO; the type, if any, of surgical correction undertaken (ie, primary closure vs Gore-Tex mesh [W.L. Gore and Associates, Inc, Flagstaff, AZ] patch closure); and neonatal survival to hospital discharge. Fetal growth restriction was defined as birth weight below the third percentile for gestational age, based on nomograms derived from our hospital population and adjusted for maternal ethnicity and infant sex.[20]

Neonatal treatment

Infants were initially transferred to our neonatal intensive care department for stabilization and were subsequently transferred to our adjoining children's hospital if they were potential candidates for ECMO. In general, the approach to ventilation was to support them using the least aggressive method feasible to avoid damaging the residual lung tissue. The decision to place an infant on ECMO was at the discretion of the pediatric intensive care attending and was