Application of new imaging methods in the evaluation of the fetal chest

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Abstract
The advancement of examinations done with the use of prenatal ultrasound (US) and fetal magnetic resonance imaging (MRI) has changed the practice of perinatology. Improved visualization of the chest and neck of the fetus increased the accuracy of prenatal diagnosis and at the same time offered more opportunities for optimal pregnancy management, planning the delivery at the in utero stage and postnatal care. The present article is a review of the current state of fetal chest imaging.

Key words: prenatal ultrasound imaging, prenatal magnetic resonance imaging, fetal chest imaging

Ultrasound (US) is the method of initial imaging which is commonly used to evaluate the fetal chest and which is widely available and easy to carry out. However, the accuracy of the diagnosis may be limited by a number of factors such as the mother’s obesity, oligohydramnios, position of the fetus and osseous structures. Gestational age as well as the skills of the person performing the examination may affect the sensitivity of the test. The ultrasound examination yields variable results when it comes to detection rate for the lesions located within the fetal chest ranging from 22% up to 90%. In case of pathological changes within the abdominal cavity detection rate is ranging from 50% up to 90% [1, 2]. With the progressing development of the devices and high resolution sounds as well as advanced pulsed, color and power Doppler imaging and suitable post-processing 3D/4D software, the ultrasound examination of fetal lungs abnormalities and the ultrasound procedures continuously evolve.

The fetal chest that is developing in a normal way has a round or oval shape with ribs surrounding over a half of the circumference. The chest, lungs and heart grow proportionally with a stable cardiothoracic ratio during the entire pregnancy. The heart is located in the anterior part of the chest and when this position is different it may be an indication of pathological changes in the lungs.

The ultrasound is relatively sensitive to lesions within the fetal lungs due to their abnormal echogenicity and the effect on the adjacent structures. Nevertheless, a number of these lesions have similar echogenicity in the ultrasound examination, therefore the specificity level is low. When abnormality is recognized in the lungs a detailed examination of the fetus should be performed. When evaluating the fetal lungs also the airway should be examined, however it is usually difficult to visualize the larynx, pharynx and trachea directly by means of the ultrasound. Sometimes, in the later weeks of the pregnancy a larynx filled with fluid is visible. Anatomical evaluation of the lungs plays a significant role together with the assessment of the fetal lungs volume. Normative data regarding the fetal lung volume are available, but they are limited for different gestational ages and characterized by significant variability depending on the methodology applied [2, 3]. The measurements of the lung volume with the use of the ultrasound are used in the evaluation of pulmonary hypoplasia. The ratio of thoracic circumference/abdominal circumference, lung length/thoracic circumference and lung length/head circumference are the examples of data that are being described, but they are characterized by variable reliability.

The increasing number of MRI systems and the growing availability of this examination allow to use the method in imaging diagnostics and detection of fetal abnormalities.

Magnetic resonance imaging (MRI)
Magnetic resonance imaging (MRI) has been used in the clinical practice for over 20 years and it is considered as a supplementary method to the ultrasound

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examination of the fetus, in particular when it comes to the evaluation of abnormalities within the chest and the brain. Fast scanners with ultra-fast sequences are applied more frequently and effectively in the fetal imaging due to a significant decrease in the effect of motion artifacts and reduced need for sedation.

MRI presents numerous advantages as far as the evaluation of pathological changes in the fetal lungs is concerned. First of all, it allows to perform multiplanar imaging, gives large fields of view and optimal tissue resolution.

Contrary to the ultrasound (US), MRI it is not dependent on the operator and is not subject to limitations resulting from the position of the fetus, surrounding maternal bowel gases and bones. However, MRI remains an expensive method which not always is available. Moreover, the examination may be affected by such factors as the mother’s obesity, claustrophobia or discomfort felt by the mother or by the fetus movement. New MRI systems are equipped with high-gradient magnets and the application of fast sequences reduced some of these limitations.

At the first stage of the examination a multiplanar image is obtained in fast spoiled gradient echo sequence or large field of view coronal localiser ssFSE in order to assess the position of the fetus. Each subsequent plane constitutes an orthogonal view in relation to the previous sequence which reflects the movements of the fetus. The examination of the fetus may take from 20 to 40 minutes, especially when polyhydramnios is present and when the movements of the fetus are more dynamic. Other sequences that are useful in the evaluation of the heart and the brain of the fetus are SSFSE (single slice fast spin echo) (GE, Milwaukee, WI) and HASTE sequence (half-fourier acquisition single shot turbo spin echo (Siemens, Erlangen, Niemcy) [5, 6]. The acquisition of layers proceeds one by one where each layer is acquired by a single pulse lasting no longer than 400 milliseconds. A series is obtained after less than 30-40 seconds with 2-3 mm thick layers. Also heavy T2-weighted hydrographic images are used for evaluation of the fetal chest as well as fast T1-weighted sequences including FMPSPGR (fast multiplanar spoiled gradient echo), diffusion weighted images (DWI) and 2D FLASH (fast low angle shot). However, such sequences usually take more time and they may require breath holding and thicker slices to obtain sufficient S/N ratio.

With regard to long-term effect of MRI use, i.e. the effect of high magnetic field on the fetus, so far no adverse effects have been found at least in case of 1.5 T magnets as it has been recently reported [7-9]. Further tests are carried out to assess the impact of stronger magnets (3T) and the effect of MRI examinations repeated throughout a longer period of time, which so far have not shown any definite growth abnormalities or genetic anomalies in tests performed on animals and embryos [11-13].

Gadolinium chelates may pass through placenta and transmit to the fetal blood circulation. Retardation in the growth of the tested animals was noted after administration of high doses of a contrast material. In the first trimester of pregnancy MRI should be avoided and in principle the administration of gadolinium chelates is contraindicated in fetal MRI [14].

In the MRI image the fetal lungs are homogenous and characterized by hyperintense signal in comparison to muscle and after 24th week of pregnancy they show higher signal which stems from increased amount of fluid as alveoli develop. Both T1-weighted and T2-weighted imaging allow to differentiate a normal lung parenchyma from the adjoining structures. In T2-weighted tests lungs give hyperintense signal in comparison to liver and spleen, but in T1-weighted images liver, spleen and meconium are hyperintense compared to lungs. The signal of the thymus is hyperintense compared to the heart and becomes very clear in the third trimester of pregnancy. Flow void is observed in the heart in T2-weighted SSFSE image sequence and intensive signal in bright blood sequences.

MRI is a better method than the ultrasound for imaging fluid filled fetal airway. The typical image of larynx, pharynx and trachea usually contains fluid filled, high intensity signal structures. The locations where the airway is narrowed are evaluated in all three planes with high spatial resolution. Currently, such advanced techniques as virtual bronchoscopy may be applied in fetal MRI as well [15] (ryc. 1).

The measurements of lung volume done with the use of magnetic resonance include the evaluation of total lung volume by planimetry [16]. Other methods include counting pixels in the area of interest – the entire lung, lobe multiplying by the area corresponding to the pixel and by the slice thickness and volume calculation on the basis of reconstructed 3D images, where the images are automatically processed with the use of post-processing technique [17-19]. The values of lung volume are highly variable ranging from 20 to 35 ml in 25th week of gestation and 58 to 95 ml in 35th week [18]. The right lung has slightly bigger volume than the left one (56% of the total lung volume).
Fetal lung anomalies

Congenital bronchopulmonary malformations (BPM) constitute a group of anomalies including congenital pulmonary airway malformation (CPAM), bronchopulmonary sequestration (BPS), congenital lobar overinflation (CLO). A wide spectrum of anomalies resulting from airway obstruction and subsequent malformations are considered as BPMs depending on the timing, level in the tracheobronchial tree and extent of airway obstruction [11, 13, 14]. When it comes to imaging BPMs, thanks to new technologies and possibility to apply different diagnostic methods complementarily our knowledge and understanding of how these pathologies evolve has critical importance for management and counseling.

Congenital pulmonary airway malformation (CPAM)

CPAM is the most common abnormality representing 30-47% of all thoracic anomalies [22, 23]. CPAMs are connected with growth disorders within the lung tissue characterized by abnormal branching of bronchioles that communicate with normal tracheobronchial tree. In case of these malformations the blood supply comes from the normal pulmonary circulation with venous drainage into normal pulmonary veins. CPAM is most commonly placed only in one lung (95% of cases), but it may occur bilaterally as well. For management purposes CPAM may be divided into two types depending on the lung image and general anatomy. These types are as follows: 1) macrocystic CPAM with multiple cysts > 5 mm, which is characterized by slower growth rate and more positive prognosis; 2) microcystic CPAM with cysts < 5 mm characterized by solid appearance and worse prognosis [18, 22] (ryc. 2).

Depending on the type of malformation differences in MRI and US images are observed. Cystic structures are anechoic in US and in T2-weighted MRI images they are hyperintense. Solid structures of the malformation are homogenous and uniform in US and hyperintense in T2-weighted images. Large lesions may lead to mediastinal shift to the normal, healthy side and hinder proper lung growth, which may result in pulmonary hypoplasia [23]. The solid mass (tumor) in the lungs may press on the vena cava and the heart impairing venous return (features of right heart chamber failure) which leads to pleural effusion, pericardial effusion and/or ascites.

The ratio of CPAM volume to the head circumference is used in prenatal examination to assess the risk of hydrops [21]. The CPAM volume ratio (CVR) is obtained from the calculation of the lung volume and by dividing it by the head circumference in order to compare with the standard for a given gestational age. When the ratio is lower than 1.6, there is 14% risk of hydrops appearing...
in macrocystic CPAM and 3% risk of hydrops for microcystic CPAM. When the fetus has the CVR ratio of more than 1.6, the risk of hydrops is 75%.

Apart from CVR the prognostic indicators cover also the lesion’s type, its location, extent of mediastinal shift and hemodynamic alterations observed in the fetus including polyhydramnios and hydrops.

Hydrops are the most important prognostic factor. When no hydrops are found, the outcome is excellent with survival rate at the level of 95%. If hydrops develop, there is a risk of perinatal death which in case of lack of treatment is as high as 100%. In such cases surgical intervention should be considered. The maximum growth of the lesion related to CPAM takes place between 20th and 26th week of gestation. Between 26th and 28th week the growth of the lesion stabilizes and the lesion may even start to decrease or disappear, which happens in 50% cases. However, even if no lesion is recognized in further control prenatal tests, postnatal imaging should be performed anyway as in 40% of cases residual mass is observed in the lungs. Differential diagnosis of CPAM lesions based on prenatal imaging includes bronchopulmonary sequestration, congenital lobar overinflation, bronchogenic cysts, congenital diaphragmatic hernia, laryngeal or tracheal atresia, ureteric/enteric cysts and mediastinal cystic teratomas and pleuropulmonary blastomas.

**Bronchopulmonary sequestration (BPS)**

Bronchopulmonary sequestration is the second most common pulmonary malformation characterized by lesions within lungs with non-functioning lung tissue not communicating with bronchial tree and supplied by systemic arteries coming from the lower thoracic or upper abdominal aorta.

Bronchopulmonary sequestration is most often observed in the form of hybrid lesions containing the components of both sequestration and CPAM. Sequestration may occur in one of three types: supradiaphragmatic, diaphragmatic or infradiaphragmatic [17, 18, 20].

In US images BPS is usually visualized as homogenous, echogenic mass most often located by the diaphragm. Doppler examination helps to identify the systemic blood supply vessels. The hybrid lesion is described as hybrid cyst supplied by systemic vessels, although the vascular structures are not always identified. MRI helps to assess BPS by differentiating the mass and allowing to evaluate the contralateral lung. Sequestration appears in T2-weighted images as hyperintense mass in the lower lobe. In hybrid lesions large cysts occur (macrocysts). If feeding systemic vessels are seen in the MRI image, they usually appear in the form of linear low signal structures running from the aorta to BPS lesion [20].

Ryc. 3. BPS (bronchopulmonary sequestration). Sagital scan GRE T2W shows a left lower intralobar sequestrian (arrow)

Prognosis for fetus with diagnosed bronchopulmonary sequestration is favorable with hydrops rarely developing.

**Congenital lobar overinflation**

Congenital lobar overinflation also known as congenital lobar emphysema is an anomaly characterized by hyperinflation with normal pulmonary vascular supply without macrocysts or microcysts. In the postnatal period it is usually located in the apical and posterior sections of the left upper lobe, but it may appear also in other lobes (ryc. 4).

Ryc. 4. CLO (Congenital Lobar Overinflation). Coronal scan T2W fetal MRI at 30 weeks’ gestation

In the second trimester of gestation echogenic, homogenous and hyperechogenic mass without visible cysts may be seen in the ultrasound image. Normal pulmonary vascularity may be observed in this area. Increased echogenicity of congenital lobar overinflation (CLO) is con-
sidered to be secondary to abnormal accumulation of fluid in the lung. By the third trimester the mass often becomes isoechogenic to adjacent normal pulmonary tissue and may be difficult to visualize. In T2-weighted MRI the lesion is hyperintense. If lobar overinflation is significant, contralateral mediastinal shift, polyhydramnios and hydrops may be observed [17, 20].

In prenatal period it may be difficult to differentiate lobar overinflation from macrocystic CPAM or pulmonary sequestration. The diagnosis may be confirmed in the postnatal period with radiographic examination or CT imaging [21, 22].

**Congenital high airway obstruction (CHAOS)**

If bilateral, large, echogenic masses are identified in the course of prenatal imaging, the differential diagnosis should take into account congenital high airway obstruction (CHAOS). CHAOS is a rare entity that may result from laryngotracheal atresia, tracheal stenosis, laryngeal cyst, subglottic stenosis, and laryngeal or tracheal agenesis. It leads to extensive lung expansion and impaired venous return to the heart causing hydrops and ascites. In US imaging both lungs are symmetrically expanded and echogenic because fluid is being held up [11, 12]. The heart is located centrally and compressed, whereas the diaphragm is inverted. MRI shows abnormally enlarged lungs with high T2-weighted signal and inverted diaphragmatic domes. Diagnosing CHAOS is extremely important to allow proper planning of perinatal interventions. Differential diagnosis covers bilateral CPAM type III and extrinsic tracheobronchial obstruction resulting from cervical teratoma, lymphatic malformation or vascular ring. In the past CHAOS was lethal [16, 19]. However, thanks to the advances in the development of perinatal intervention methods EXIT procedure with airway control is performed before the occurrence of hypoxia, brain injury or death. The outcomes of the treatment have been improved, but still the prognosis remains to be negative. Pulmonary abnormalities are permanent in surviving children and a long-term tracheostomy is required [21, 22].

**Conclusion**

Thanks to technological advance in ultrasound and magnetic resonance imaging prenatal diagnosis may be reached earlier and it is more accurate. As the application of US imaging increases, pulmonary anomalies are identified more frequently. Fetal examination with the use of magnetic resonance contributes to further advancement in perinatal care by helping to confirm the diagnosis and indicating border structures of anatomical structures, which are poorly visualized in US imaging as well as demonstrating the coexistent anomalies. MRI allows experts specializing in disciplines other than pediatric surgery who do not feel comfortable interpreting prenatal US images to see the anomalies in the areas of fetal neck and chest in three dimensions. This provides support for multidimensional approach needed for effective counseling and management of fetus with complicated thoracic abnormalities.

**References**


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