Three-dimensional Ultrasonography versus MRI in assessment of fetal Lung volumetric measurements ; A Comparative study

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Aims and objectives

**AIM OF THE WORK** To assess the agreement of lung volumes measured with 3D Ultrasonography and MRI in uncomplicated pregnancies.

**INTRODUCTION**

Prenatal diagnosis of pulmonary hypoplasia and evaluation of its severity are extremely important. Infants with pulmonary hypoplasia that affects respiratory function require intensive monitoring and care immediately after birth.[1-3] However, prediction of pulmonary hypoplasia is extremely difficult despite attempts with many antenatal determinants.[4, 5]

The mainstay of antenatal imaging is the ultrasound, which is cheap, safe, readily available, relatively quick and, in experienced hands, accurate and reliable.[6] Previous studies stated that use of 2D conventional ultrasonography in the measurements of fetal thoracic circumference, lung length an ratio of thoracic circumference to abdominal circumference does not have high enough sensitivity and specificity to be used for clinical decision making.[1-3]

With the introduction and technical improvement of 3-dimensional ultrasonography (3DUS), this technology became a potentially useful approach to assess prenatal fetal lung volumes. In addition to being easy and fast to perform and having high patient acceptability, it also allows access to any possible view and accurate determination of organ volume. Some limitations are still associated with 3DUS technique, as it may be affected by amniotic fluid volume or maternal obesity and does not provide any additional physiologic information relating to potential function.[7-11]

Fetal MRI, with its superior contrast resolution and true multiplanar imaging, has proven itself a useful additional tool in antenatal imaging.[6] The development of fast pulse sequences, such as those used in echo-planar imaging and single-shot rapid acquisition with relaxation enhancement has brought major advances in fetal MR imaging.[12-15]

Clearer fetal MR images with fewer motion artifacts can be acquired without fetal immobilization. These MR imaging techniques allow detailed anatomic assessments, including estimation of lung volume.[16-20] Moreover, the MR signal intensity of the fetal lung is a good indicator of fetal lung maturation.[19]
Methods and materials

MATERIAL AND METHODS

Research Ethics Committee approval and informed consent were obtained. Between (Aug 2012 & November 2013, Forty eight patients with singleton pregnancy who were included in this study. Patients were referred for assessment of the placental anatomy or for further assessment of fetal anomalies. All women volunteered to undergo 3DUS after being fully informed with the study protocol, technique and time of examination.

Inclusion criteria were singleton pregnancy, absent chest or abdominal anomalies and a match between the ultrasound calculated fetal gestational age and the gestational age calculated based on the Last Menstrual Period (LMP) of the patient. Exclusion criteria were fetal growth retardation or over growth, oligohydraminos, presence of obvious fetal lung anomalies or abdominal anomalies that may affect normal lung anatomy e.g. fetal abdominal masses.

Fetal MRI examination

All studies were performed on the GE 1.5 T Signa (GE Medical Systems of Wisconsin, USA) machine using phased array body coil. The patients were instructed to avoid food or drinks except water for a period of at least 4 hours prior to the examination to avoid excessive fetal motion and bowel motion artifacts. Patients were given the choice to either lie in a supine or a right or left decubitus position according to whatever position they felt comfortable with for the length of the examination. The body coil was placed around the lower abdomen and pelvis to achieve proper coverage of the gravid uterus. After performing the routine sequences for assessment of the placenta, T2-weighted images of the fetus were obtained by using Single shot fast spine echo (SSFSE) sequence (TR >10000, TE 100-120, FOV 30 cm, matrix 256 x 256 , slice thickness 3mm, spacing 0-0.5 mm) in axial, coronal and sagittal planes planned on the fetal orthogonal planes. The images were then transferred in DICOM format to a dedicated workstation for volumetric measurements. 3D Slicer Version 4.3.1 software (www.slicer.org) was used for calculation of lung volumes on MRI images. Coronal images were preferred, due to the best delineation of hilar, mediastinal structures and costophrenic recesses. The MR images were loaded as volumes into the software, which in turn produced multiplanar reformats of the axial and sagittal planes. Using the software segmentation tool each lung outline was manually traced on the sequential cuts of the coronal images, adjustment of the trace was done on the axial and sagittal reformatted images if required. Then a 3D model of the lungs and their volumes were processed by the software using its quantification tool. Segmentation and quantification was done 3 times and the average of the 3 measurements was recorded.

Fetal 3DUS examination
All examinations were performed by using a commercially available Ultrasonography scanner (Voluson 730 Pro; GE, Milwaukee, WI) equipped with a 4-8 MHz abdominal probe for 3-dimensional volume scanning which was used to assess the fetal lung volume. A two dimensions transverse section of the fetal thorax at the level of the four chamber view with the fetal heart proximal to the transducer was taken. The volume box was adjusted to scan the entire fetal thorax. After scanning the volume, multiplanar imaging is reconstructed in the 3 orthogonal Ultrasonographic sections; the axial, the coronal and the sagittal plans and each lung was carefully identified on each of the three planes. To measure lung volume, we used the rotational technique that consists of the Virtual Organ Computer-Aided Analysis (VOCAL) imaging program, an extension of 4DView software (GE Healthcare, Kretztechnik). The axial section of the multiplanar imaging was chosen as the reference image for volume analyses.

Right and left lung volumes were measured separately by a series of area tracing of the studied lung after serial rotations of 30° (6 rotations). Monitoring of the parallel multiplanar slices through the whole lung in the 3 perpendicular planes allowed confirming the correct of the rotational area traced. After finishing the rotational tracing, the chosen lung volume was automatically measured.

Statistical analysis tests performed was Bland-Altman[21] test to calculate the mean volumetric difference between the 3D ultrasound and MRI measurements, the Standard deviation of the difference between the two methods and the absolute limits of agreement (1.96 SD of mean difference). Statistical software used was Medcalc.
Results

RESULTS

The study included 48 patients with their age range between 19 and 36 years with a mean age of 27 years. The most frequent cases measured were at 27 & 29 weeks GA, represented by 5 cases for each.

The mean volume of the right lung measured by 3DUS ranged from 5.12 cm$^3$ at 20 weeks to 40.44 cm$^3$ at 34 weeks. The mean volume of left lung measured by 3DUS ranged from 4.05 cm$^3$ at 20 weeks to 32.39 cm$^3$ at 34 weeks. The total mean lung volume ranged from 9.17 cm$^3$ at 20 weeks to 72.83 cm$^3$ at 37 weeks. Volumes for right, left, and both lungs as measured by 3D US are shown in (Table 1).

( Table 1 ) The right, left and total lung volumes and their percentiles as measured by 3D ultrasound.

<table>
<thead>
<tr>
<th>GA</th>
<th>N</th>
<th>Right lung Vol. cm$^3$</th>
<th>Left lung Vol. cm$^3$</th>
<th>Total Lung Vol. cm$^3$</th>
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<td>27.23 30.77 34.65</td>
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<td>33.63 37.89 42.95</td>
<td>27.12 27.42 29.96</td>
<td>61.68 68.49 70.71</td>
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The mean volume right lung measured by MRI ranged from 5.16 cm$^3$ at 20 weeks to 42.12 cm$^3$ at 34 weeks. The mean volume left lung measured by MRI ranged from 4.07 cm$^3$ at 20 weeks to 33.26 cm$^3$ at 34 weeks. The total mean lung volume ranged from 9.23 cm$^3$ at 20 weeks to 75.32 cm$^3$ at 37 weeks. Volumes for right, left, and both lungs as measured by MRI are shown in Table 2.

( Table 2 ) The right, left and total lung volumes and their percentiles as measured by MRI.

<table>
<thead>
<tr>
<th>GA</th>
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<th>Right lung Vol. cm$^3$</th>
<th>Left lung Vol. cm$^3$</th>
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<td>36.93</td>
<td>42.12</td>
<td>47.30</td>
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It was noted that 3DUS measurements of the lungs were less than those measured by MRI. Results of the Bland-Altman analysis of mean difference between the lung volumes measured by 3DUS and MRI were -0.71 ± 0.56 cm$^3$ (Absolute limits of agreement -1.83 to 0.40 cm$^3$) for the right lung (fig.1), -0.59 ± 0.42 cm$^3$ (Absolute limits of agreement -1.42
to 0.24 cm$^3$) for the left lung (Fig.2), and lastly for the total lung volumes -1.3 ± 0.92 cm$^3$
(Absolute limits of agreement. -3.11 to 0.51 cm$^3$) (Fig.3)

( Figure 1 )

Fig. 1: Bland-Altman analysis plot of the mean volumetric difference between the Right lung volumes as measured by 3DUS and MRI

References: RADIODIAGNOSIS, TANTA UNIVERSITY, TANTA - Qwuesna/EG

Bland-Altman analysis plot of the mean volumetric difference between the Right lung volumes as measured by 3DUS and MRI.

( Figure 2 )
Fig. 2: Bland-Altman analysis plot of the mean volumetric difference between the left lung volumes as measured by 3DUS and MRI.

References: RADIODIAGNOSIS, TANTA UNIVERSITY, TANTA - Qwuesna/EG

Bland-Altman analysis plot of the mean volumetric difference between the left lung volumes as measured by 3DUS and MRI.

(Figure 3)
**Fig. 3:** Bland-Altman analysis plot of the mean volumetric difference between the Total lung volumes as measured by 3DUS and MRI.

**References:** RADIODIAGNOSIS, TANTA UNIVERSITY, TANTA - Qwuesna/EG

Bland-Altman analysis plot of the mean volumetric difference between the Total lung volumes as measured by 3DUS and MRI.

( Figure 4 )
**Fig. 4:** The fetal thorax in axial plan (upper left) sagittal (Upper right) and Coronal (lower left). The contour of the lung on the three planes was outlined. After finishing the complete rotation, the program automatically gives the left lung volume (the lower right).

**References:** RADIODIAGNOSIS, TANTA UNIVERSITY, TANTA - Qwesna/EG

The fetal thorax in axial plan (upper left) sagittal (Upper right) and Coronal (lower left). The contour of the lung on the three planes was outlined. After finishing the complete rotation, the program automatically gives the left lung volume (the lower right)

( Figure 5 )
Fig. 5: The rotational technique (VOCAL). Tracing are performed on the axial section as a reference, then rotating the lung image 30°, and then contouring it again, and this is repeated successively 6 times until the rotation of 180° is completed.

References: RADIODIAGNOSIS, TANTA UNIVERSITY, TANTA - Qwuesna/EG

The rotational technique (VOCAL). Tracing are performed on the axial section as a reference, then rotating the lung image 30°, and then contouring it again, and this is repeated successively 6 times until the rotation of 180° is completed.

(Figure 6)
**Fig. 6:** The final three-dimensional model of the fetal lung shows the grooves of the mediastinal structures indenting the lung surface

*References:* RADIODESIGNOSIS, TANTA UNIVERSITY, TANTA - Qwuesna/EG

The final three-dimensional model of the fetal lung shows the grooves of the mediastinal structures indenting the lung surface

( Figure 7 )
Fig. 7: MR image shows coronal (middle lower), sagittal (right lower) and axial (left lower) plans of the fetal thorax, the process used to measure the fetal lung volume by covering the entire both lungs in coronal sections and correction by other plans. The upper image shows the both lungs and each lung volume overlying the fetal lungs.

References: RADIODIAGNOSIS, TANTA UNIVERSITY, TANTA - Qwuesna/EG

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Fig. 4: The fetal thorax in axial plan (upper left) sagittal (Upper right) and Coronal (lower left). The contour of the lung on the three planes was outlined. After finishing the complete rotation, the program automatically gives the left lung volume (the lower right)

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Fig. 8

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Conclusion

DISCUSSION

Multiple imaging modalities have been used to predict pulmonary hypoplasia by means of lung volume calculations.[22, 23] These calculations are made by expressing the observed value as a percentage of the expected value with use of biometric parameters.[23] The previously published papers on fetal lung volume stated that the two recent techniques which enable to measure prenatal lung volumes directly are MRI and 3D ultrasonography.[17, 24] 3D ultrasonography is a technology that enables visualization of an entire volume in a single image. With the volume rendering mode it is possible to measure volumes of different organ systems.[25] In the literatures, three main methods of estimating fetal lung volumes by 3DUS, by first method the pulmonary volume was obtained by subtracting the heart volume from the thoracic volume. Both thoracic & cardiac volumes are estimated by adding together the areas of serial slices of the thorax and heart respectively on a transverse section, starting from the apex of the diaphragm to the clavicle. This method tends to overestimate the pulmonary volume as themain mediastinal structures, such as the thymus gland, trachea, esophagus, and great vessels, are included in the volume.[7] In the second method, the technique of parallel slices was used and each pulmonary volume was estimated individually. The main advantage of this technique is to reduce the error of the first method by eliminating the extra-pulmonary structures.[11] Recently the new rotational technique is used for more accurate assessment of fetal lung volume. In this technique each lung volume is obtained by serial contouring of the pulmonary area after rotating the volumetric image.[26]

In this study we have chosen the Virtual Organ Computer-Aided Analysis (VOCAL) multiplanar rotation technique for fetal lung volume assessment because it seemed to be more adapted to measuring the volume of small and irregularly shaped lungs.[27]

In this study we used the transverse section as the reference image for volume analysis as we found that maximum image resolution of fetal lungs is obtained in a transverse plane section. Similar finding was observed by Pohls and Rempen[11] The right and left lung volumes were measured by a series of area tracing of the studied lung after serial rotations of 30° (6 times). In the study of Kalache et al.[28] they used the longitudinal plane as a reference & its rotation around the vertical axis.

The gestational ages included in this study ranged between 20-34 weeks as the image quality more influenced by the shadowing of the spine and ribs especially after 34 weeks with inaccurate measurement of the lung volume and this is in agreement with the study of Osada et al.[29]
In this study, Bland Altman[21]test was used to assess the agreement between MRI and 3D ultrasonography regarding the lung volume measurements of both lungs. It was noted that 3DUS measurements of the lungs were less than those measured by MRI, however the mean difference between the lung volumes measured by 3DUS and MRI were found to be within the absolute limits of agreement. This is in agreement with the results reported by Gerards et al.[30]

**CONCLUSION**

At the end of this study we conclude that both 3DUS & MRI can be used in measurement of fetal lung volumes with nearly the same degree of accuracy. We should weigh between the advantages & disadvantages of both modalities. 3DUS has the advantage of being easily available, less coast & easily performed in short time. On the other hand some obstacles are faced with 3DUS, especially in obese patients with thick parietal walls, another disadvantage is that technique is more operator dependent, in such cases fetal MRI is the method of choice as alternative for assessment of the fetal lung volume.
**Fig. 1:** Bland-Altman analysis plot of the mean volumetric difference between the Right lung volumes as measured by 3DUS and MRI

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Fig. 2: Bland-Altman analysis plot of the mean volumetric difference between the left lung volumes as measured by 3DUS and MRI.

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Fig. 3: Bland-Altman analysis plot of the mean volumetric difference between the Total lung volumes as measured by 3DUS and MRI.

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Personal information

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