

# Prenatal Observation of Fetal Trachea and Bilateral Bronchi using Ultrasonography

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## ABSTRACT

The fetal airway tract can be observed using the planes of view in cardiac screening. In three-vessel-tracheal view, the cross-section of the trachea is identified adjacent to the right-posterior side of the middle transverse aorta. In three-vessel view, the cross-section of the right bronchus is observed adjacent to the right side of the ascending aorta. In aortic and ductal arch views, the short axis of the left bronchus is confirmed inward of the arch. In oblique three-vessel view, the right bronchus is seen on top of the ascending aorta coursing toward the azygos vein. To exclude the vessels, absence of blood flow signals in the trachea and bronchi should be reconfirmed by using pulsed and color Doppler imagings. In the whole 'Y-shaped' image, the right main bronchus depicts the more linear extension from the trachea than the left bronchus and the first lobar bronchus that branches near the carina to the right upper lobe. Segmental bronchi also can be depicted in both bilateral bronchi. Several new modalities, including three-dimensional (3D) ultrasound, simultaneous visualization of the fetal trachea and esophagus, and fluid flow waveforms in the fetal airway tract, makes feasible detailed prenatal assessment, prediction of neonatal respiratory condition, and most especially identification of anatomical deformity and pathologic entities.

**Keywords:** Fetus, Trachea, Bronchus, Two-dimensional ultrasound, Color Doppler, Three-dimensional ultrasound, Inversion mode.

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## INTRODUCTION

For the neonate, the first few minutes after birth represent the most important period of transition to adapt to extra-uterine life; wherein, respiratory gas exchange occurs without placental circulation. The airway tract plays an important role in respiratory function besides the lungs. Congenital airway abnormality is one of the most critical

life-threatening pathologies of the neonate in order to survive.<sup>1</sup> However, neonatal diagnosis and treatment of airway abnormalities are often delayed due to the lack of prior information rooted to the difficulty in prenatal examination and diagnosis. Prenatal information could provide favor in anticipating the need for respiratory treatment in neonates.

Prenatal ultrasonographic examination of the fetal thorax has focused on the investigation of both cardiac and pulmonary abnormalities. The airway tract is positioned adjacent to these organs; therefore, it could be observed through the similar imaging plane of cardiac or pulmonary screening. However, the spatial relation of the airway tract to the heart and great vessels is anatomically complicated; hence, its image is clinically hard to depict. The aortic arch, three-vessel, and three-vessel-tracheal views are the possible planes for fetal airway observation because the cross-sectional image of the trachea and bronchus appears within these planes.<sup>2</sup> These views are also commonly used for screening of fetal cardiac anomalies. Therefore, the detection rate and quality of airway tract imaging through these essential planes remain to be investigated for clinical convenience.

Meanwhile, the airway tract consists of stereoscopic structures, such as the carina, main bronchus (MB), lobar bronchus (LB) and segmental bronchus (SB), which suffer three-dimensional (3D) deformities from compression or anomalies. To assess these abnormalities, 3D visualization is also needed for the interpretation of stereoscopic characteristics.

We, herein, describe the technique to observe the fetal trachea and bronchi and the morphological characteristics in normal and abnormal cases using a new approach with two-dimensional (2D) and 3D ultrasonography.

## How to Depict Image of Fetal Trachea and Bronchi?

### *In the Essential Planes, Including Three-Vessel View*

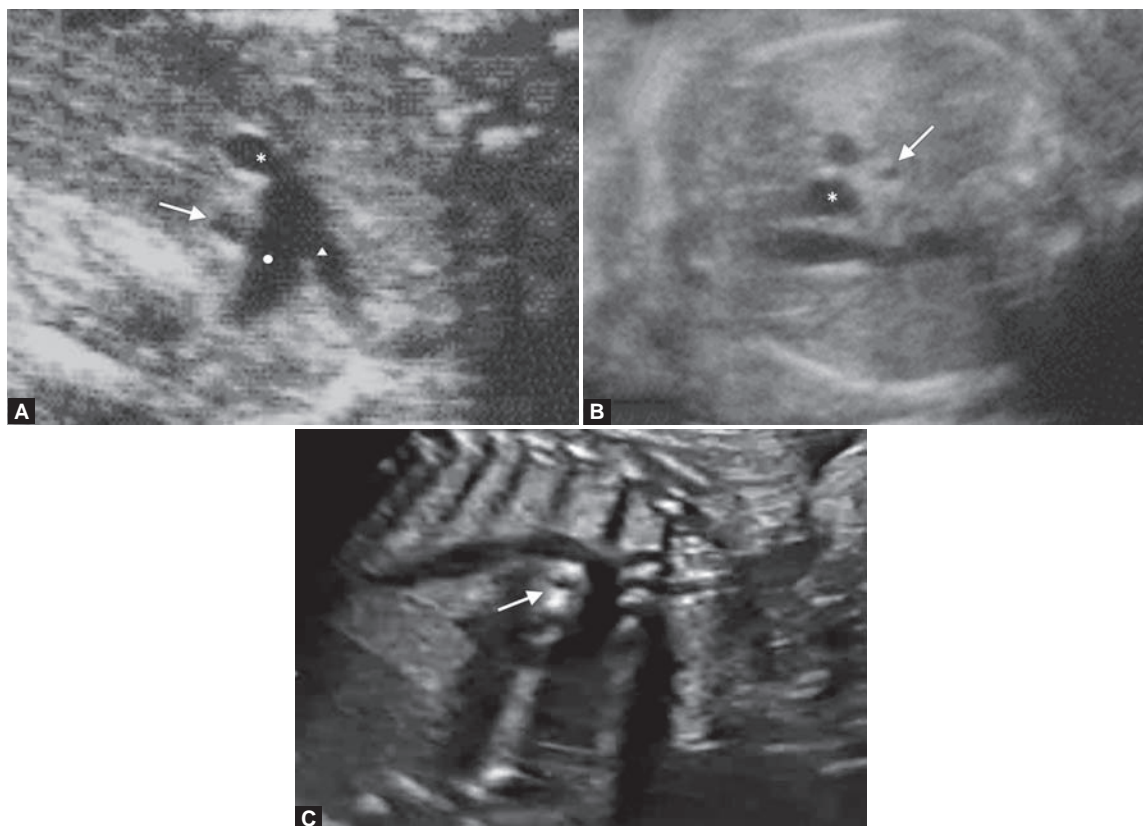
Three-vessel-tracheal view, aortic arch view, and ductal arch view, a cross-section of the trachea or bronchi can be depicted as follows:

1. In three-vessel-tracheal view, the cross-sectional image of the trachea can be identified adjacent to the right-posterior side of the middle transverse aorta (Fig. 1A).

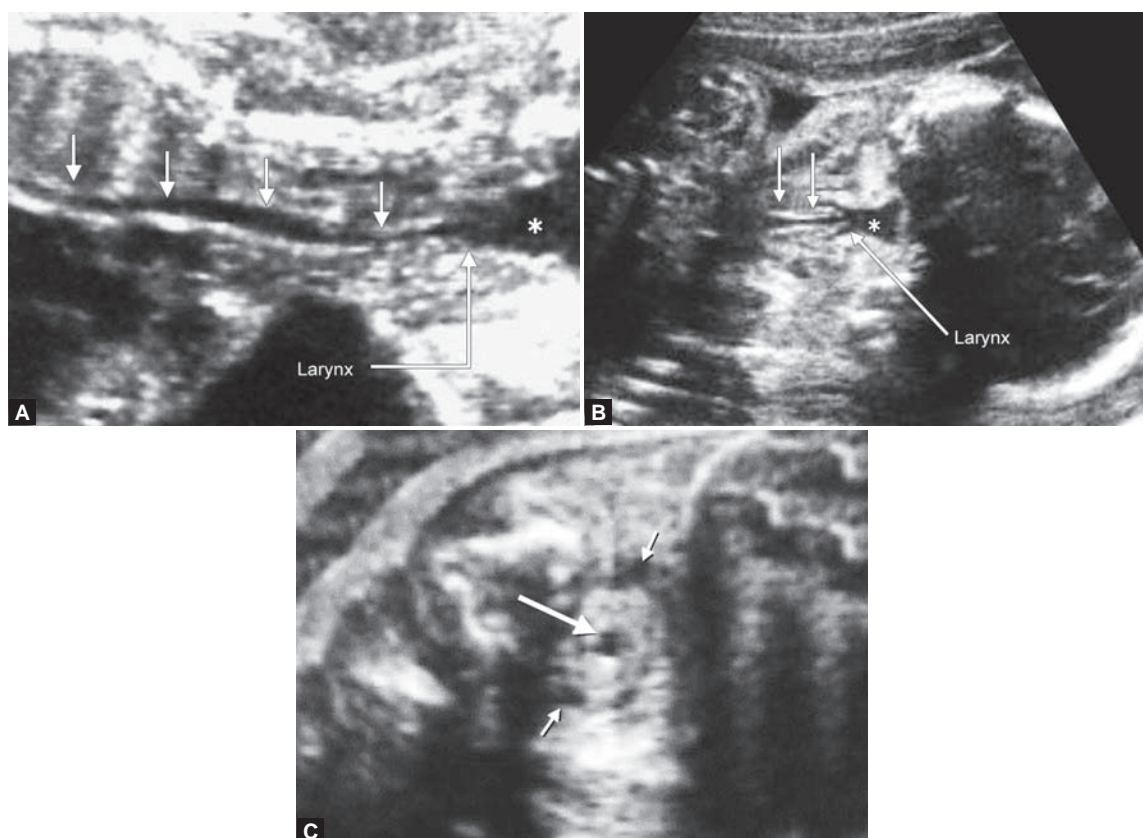
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**Figs 1A to C:** (A) In three-vessel-tracheal view, cross-section of the trachea (arrow) is identified in the right-posterior side of the middle transverse aorta (\*: Descending aorta; •: Transverse aorta; ▲: Ductus arteriosus), (B) in three-vessel view, cross-section of the right bronchus (arrow) is observed adjacent to the right side of the ascending aorta (\*) and (C) in aortic arch view, short-axis of the left bronchus (arrow) can be confirmed inward of the arch



**Figs 2A to C:** (A and B) Connection of the trachea to larynx and pharynx is ascertained in longitudinal section of the neck (arrows: trachea; \*: Pharynx) and (C) in cross-section of the fetal neck, short-axis view of the trachea (arrow) is located between the bilateral carotid arteries (small arrows)

2. In three-vessel view, the cross-section of the right bronchus is observed adjacent to the right side of the ascending aorta (Fig. 1B).
3. In aortic arch view, the short axis of the left bronchus can be confirmed inward of the arch (Fig. 1C).

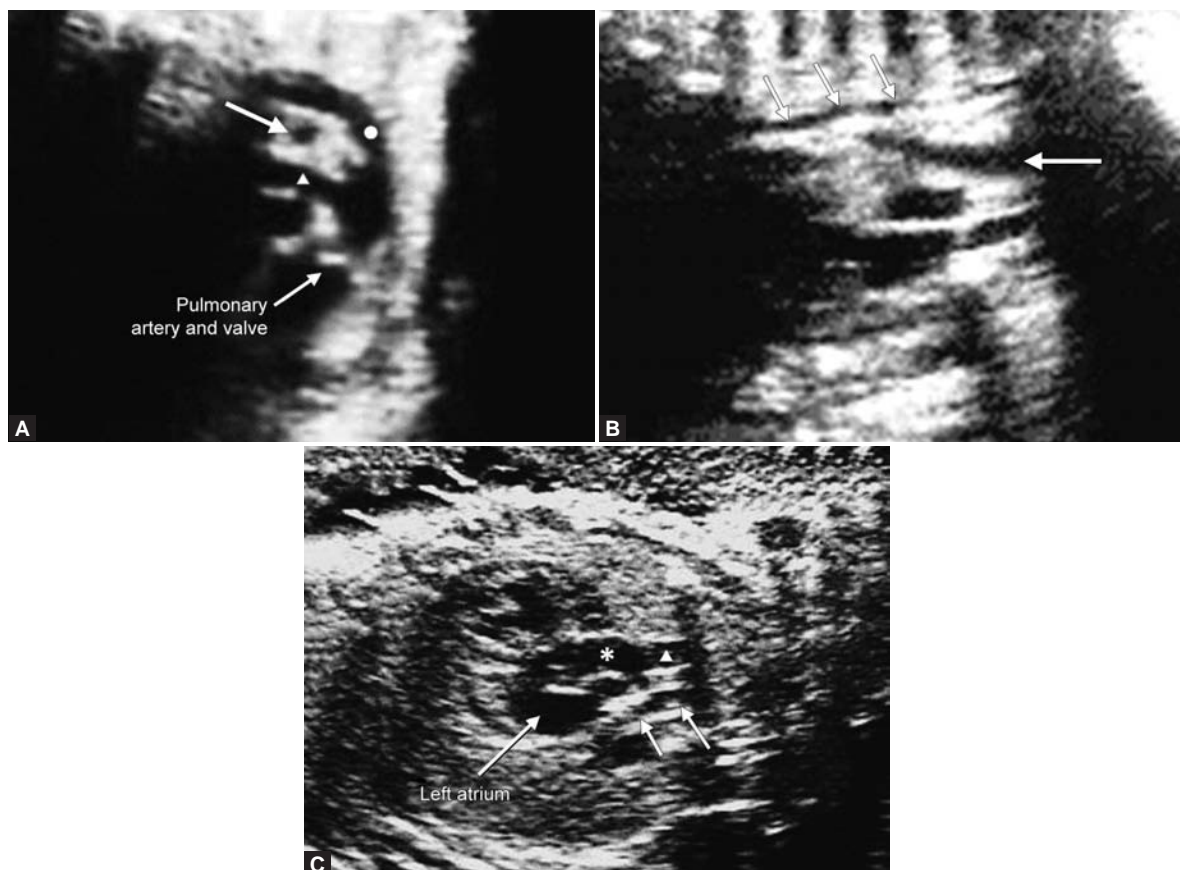
#### Alternative Planes for Fetal Trachea and Bronchi

1. At the fetal neck level, the larynx and trachea are observed as contiguous long tubular structures in both sagittal and coronal planes (Figs 2A and B). In short axis view, the trachea is identified to be located between the bilateral carotid arteries (Fig. 2C).
2. In ductal arch view, the cross-section of the left bronchus can be confirmed between the arch and right pulmonary artery (Fig. 3A).
3. In oblique three-vessel view, the right bronchus can be seen on top of the ascending aorta coursing toward the azygos vein (Fig. 3B).
4. In the plane including the ascending aorta up to the brachiocephalic artery, the left bronchus can be seen coursing toward the left lung close to the left atrium (Fig. 3C).

#### Shortcuts to Identify the Fetal Trachea and Bronchi

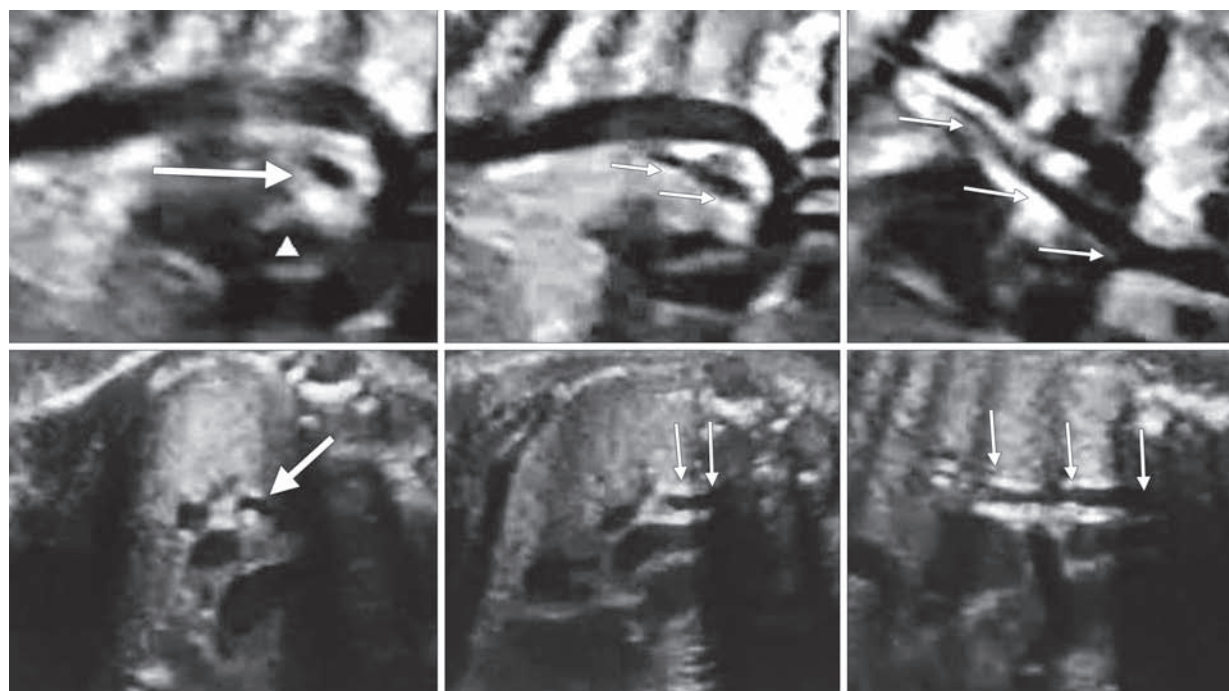
1. *Trachea*: In either cross-section of the fetal neck or three-vessel tracheal view, the trachea is clearly identified. In the former, the cross-section of the trachea is located between the bilateral common carotid arteries. In the latter, the cross-section of the trachea can be identified in the right-posterior side of the middle transverse aorta. To confirm the trachea, its connection to the larynx and pharynx is ascertained in longitudinal section.
2. *Left bronchus*: In both the aortic and ductal arch views, the cross-section of the left bronchus can be confirmed inward of the arches. Specifically, in the aortic arch view, the left bronchus is located slightly occipito-posterior to the right pulmonary artery inside the arch, and in ductal arch view, it is seen between the ductus arteriosus and right pulmonary artery.
3. *Right bronchus*: In the three-vessel view, the cross-section of the right bronchus is observed on the right side of the first curvature of the ascending aorta coursing toward the azygos vein.

When detected, the image is confirmed to be the airway tract by tracing the tubular structure up to the



**Figs 3A to C:** (A) In ductal arch view, between the ductus arteriosus (•) and right pulmonary artery (▲), the left bronchus (arrow) is located, (B) the right bronchus (arrow) courses toward the azygos vein (small arrows) in oblique three-vessel view and (C) in the plane that includes the ascending aorta up to the brachiocephalic artery, the left bronchus (arrows) courses close to the left atrium toward the left lung (\*: Ascending aorta; ▲: Brachiocephalic artery)





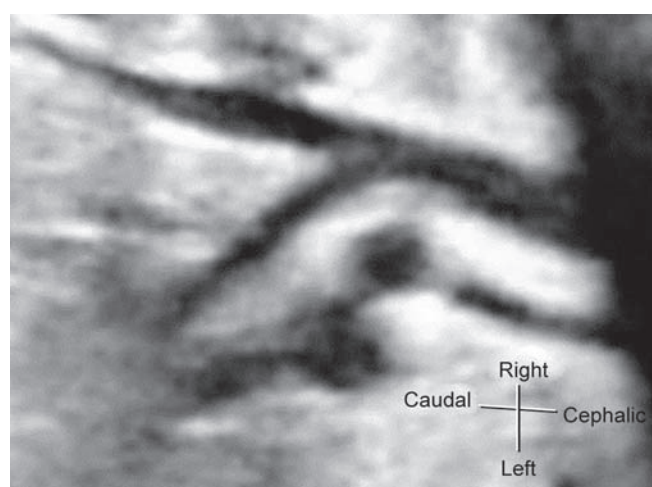
**Fig. 4:** Upper row: Cross-section of the left bronchus (arrow) located slightly occipito-posterior to the right pulmonary artery (▲) inside the aortic arch can be traced to the tip of the bronchus (small arrows) by manipulation of the transducer. Lower row: Cross-section of the right bronchus (arrow) in three-vessel view changes to the tubal image (small arrows) with slight rotation of the transducer

laryngeal cavity and following up to the tip of the bilateral bronchi (Fig. 4). In the coronal view, the whole 'Y-shaped' image of the airway tract can be obtained (Fig. 5). To exclude the blood vessels, the absence of blood flow signals in the trachea and bronchi should be reconfirmed using color Doppler sonography.

### Detection Rate and Measurements for Inner Diameter of Fetal Trachea and Bilateral Bronchi

Richards et al<sup>3</sup> first reported the sonographic observation and measurement of the pharynx and upper portion of the trachea in normal fetuses. They described that the proper timing for observation of the upper portion of the fetal trachea was between 20 and 30 weeks of gestation. In general, fetal airway detection depends on the fetal position. When the fetal backbone is positioned anteriorly, the aortic or ductal arch view is hard to depict. However, the three-vessel-tracheal view is easy to detect in any fetal positions by wider repositioning of the transducer. The tracing approach from the trachea in this view has a high detection rate. Accordingly, in our data, the detection rate of the trachea and bilateral bronchi showed 100% from 26 to 41 weeks of gestation irrespective of fetal position; although, the whole 'Y-shaped' optimal image provided overall detection rate of 89.7%.<sup>2</sup>

The inner diameters of the trachea and bilateral bronchi measured at the level of the transverse aortic arch and bifurcation is shown in Table 1. The mean diameters of the trachea, left bronchus, and right bronchus increased

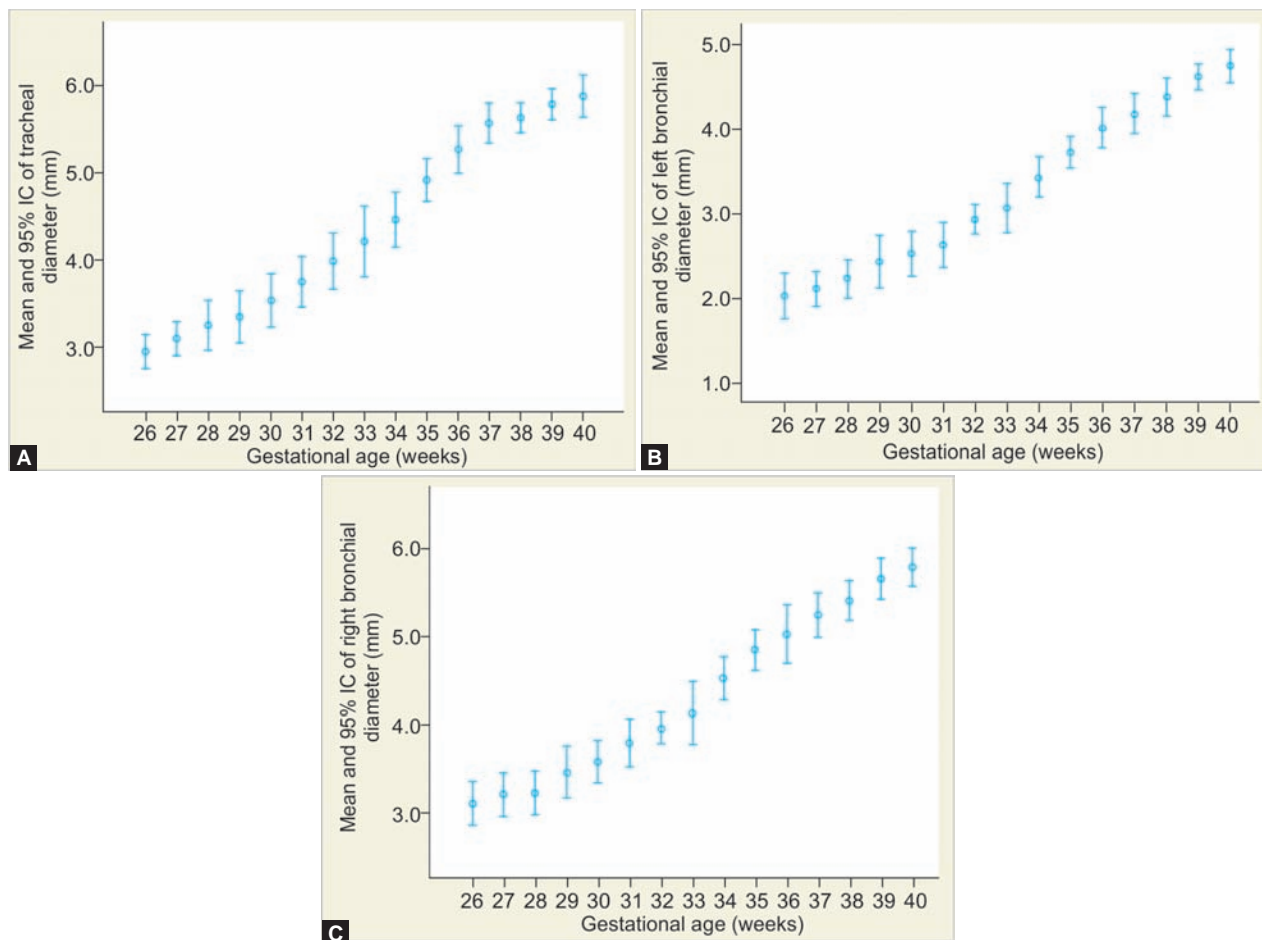


**Fig. 5:** The whole 'Y-shaped' image of the fetal respiratory tract. The right bronchus is more linearly extended from the trachea than the left bronchus

gradually from 2.9, 2.0, and 1.9 mm at 26 to 27 weeks to 6.0, 4.7, and 4.6 mm at 40 to 41 weeks of gestation, respectively. After 36 weeks, the inside diameters of the trachea and each bronchus exceeded 4.5 and 3.0 mm in all cases, respectively. The estimated mean and 95% confidence intervals in normal fetuses are shown in Figures 6A to C.

### Details of Fetal Airway Image

The bronchus consists of three macroscopic parts, namely MB, LB and SB. In the fetus, the morphological characteristics of the bilateral MB can be clearly



**Figs 6A to C:** Relationship between the inner diameters of the trachea and bilateral bronchi and the gestational age in normal fetuses: (A) tracheal, (B) left bronchus and (C) right bronchus. Bar presents the estimated mean value and 95% confidence intervals

**Table 1:** Detection rates and inner diameters of the high airway in normal fetuses

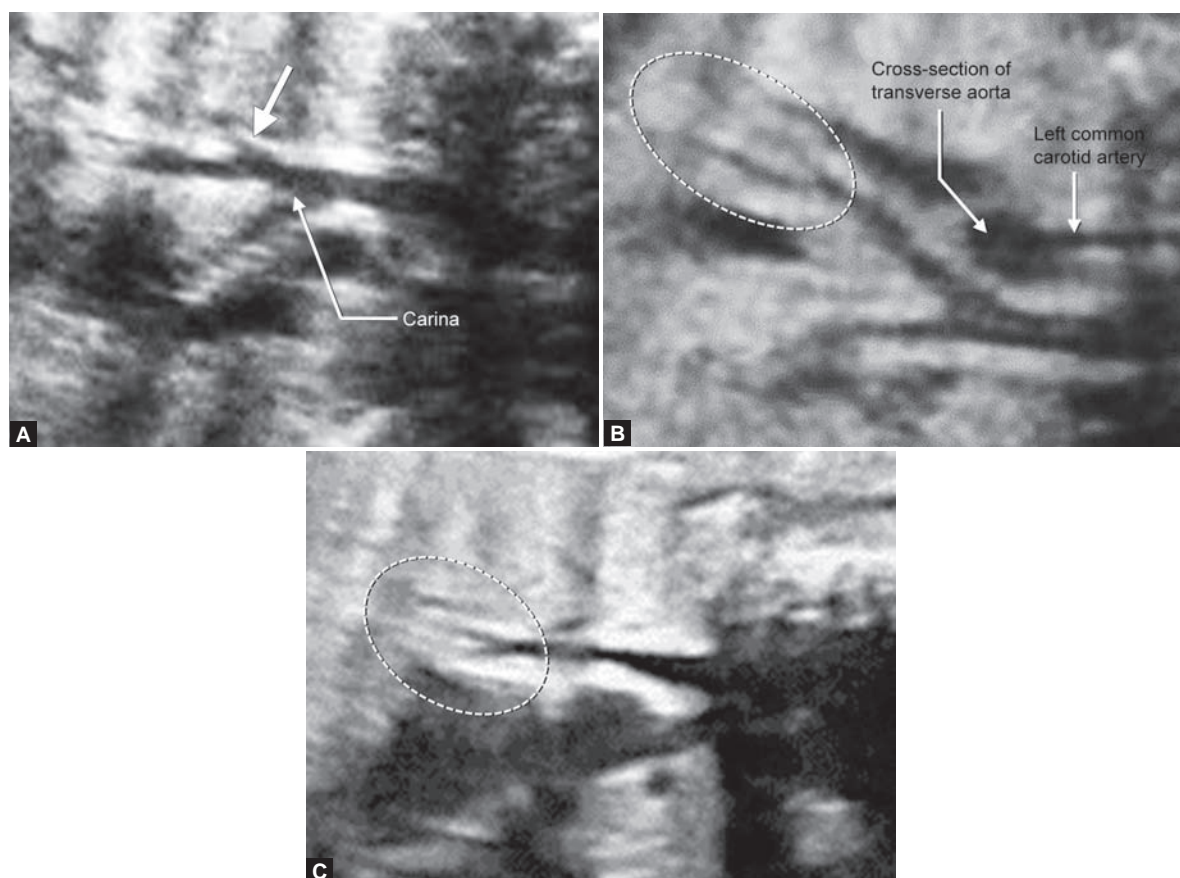
Gestational age	No. of cases	Detection rate (%)	Inner diameters (mm)		
			Trachea	Left bronchus	Right bronchus
26-27	5	100	2.9 ± 0.12	2.0 ± 0.08	1.9 ± 0.24
28-29	4	100	3.2 ± 0.17	2.1 ± 0.96	2.1 ± 0.14
30-31	5	100	3.7 ± 0.24	2.4 ± 0.29	2.3 ± 0.21
32-33	9	100	4.0 ± 0.43	2.9 ± 0.16	2.9 ± 0.16
34-35	7	100	4.6 ± 0.46	3.6 ± 0.38	3.5 ± 0.46
36-37	8	100	5.4 ± 0.53	4.1 ± 0.41	4.0 ± 0.47
38-39	7	100	5.8 ± 0.55	4.5 ± 0.60	4.4 ± 0.50
40-41	5	100	6.0 ± 0.54	4.7 ± 0.44	4.6 ± 0.54
Mean ± SD					

demonstrated ultrasonographically. In the whole 'Y-shaped' image, the right MB depicts the anatomical characteristic of a more linear extension from the trachea than the left MB (Fig. 5), and the first LB branches shortly near the carina to the right upper lobe (Fig. 7A). The left bronchus runs under the cross-section of the transverse aorta, which branches out to the left common carotid artery (Fig. 7B). The SB can also be depicted in both bilateral bronchi (Figs 7B and C).

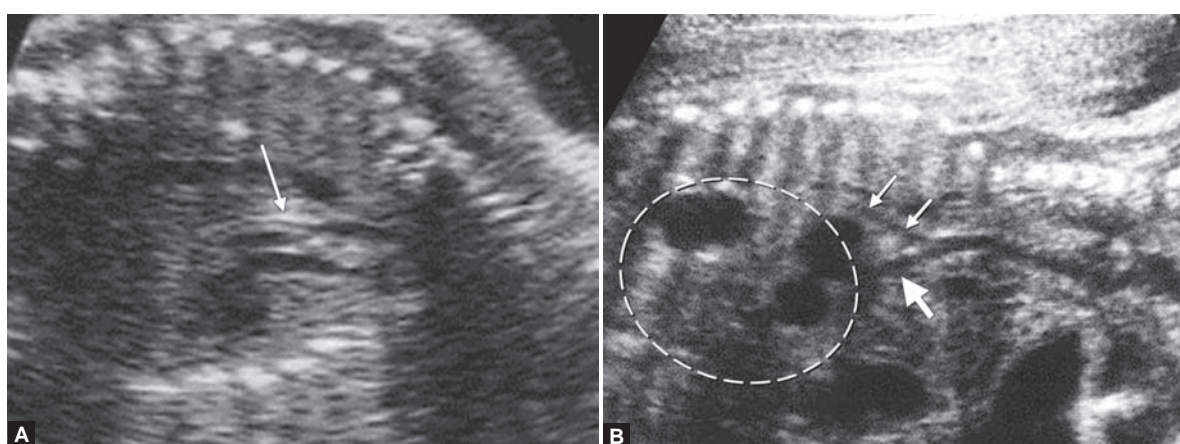
### Abnormality of Fetal Airway Tract

Airway tract abnormality is one of the life-threatening conditions in the neonates. In the case of congenital diaphragmatic hernia (CDH), anatomical abnormalities of the tracheobronchial tree on the affected side were identified in 17.9 and 38.4% of neonates with a significant decrease in survival rate.<sup>4</sup> In cases of congenital high airway obstruction syndrome (CHAOS), outstanding findings, such as large echogenic lungs with compressed heart, dilated airways distal to the obstruction, and flattened or inverted diaphragms, are easily observed.<sup>5</sup>

However, partial deformities without major findings are most likely to be missed in a fetus. In the case of vascular ring, including right aortic arch with aberrant right subclavian artery, double aortic arch, and left pulmonary artery sling, just a tiny indentation by the abnormal artery makes critical stenosis on the trachea.<sup>6,7</sup> Similarly, in a typical case of tracheal agenesis, the only indicative finding during pregnancy is polyhydramnios.<sup>8</sup> Therefore, detailed examination for abnormal fetal conditions, including congenital cardiac abnormalities, inevitably requires additional assessment of airway condition.



**Figs 7A to C:** (A) The first lobar bronchus (arrow) that branches shortly around the carina to the right upper lobe is noted, (B and C) the segmental bronchi (broken circles) of both the left (B) and right (C) bronchi are identified clearly. Left bronchus runs under the cross-section of the transverse aorta that branches to the left common carotid artery (B)



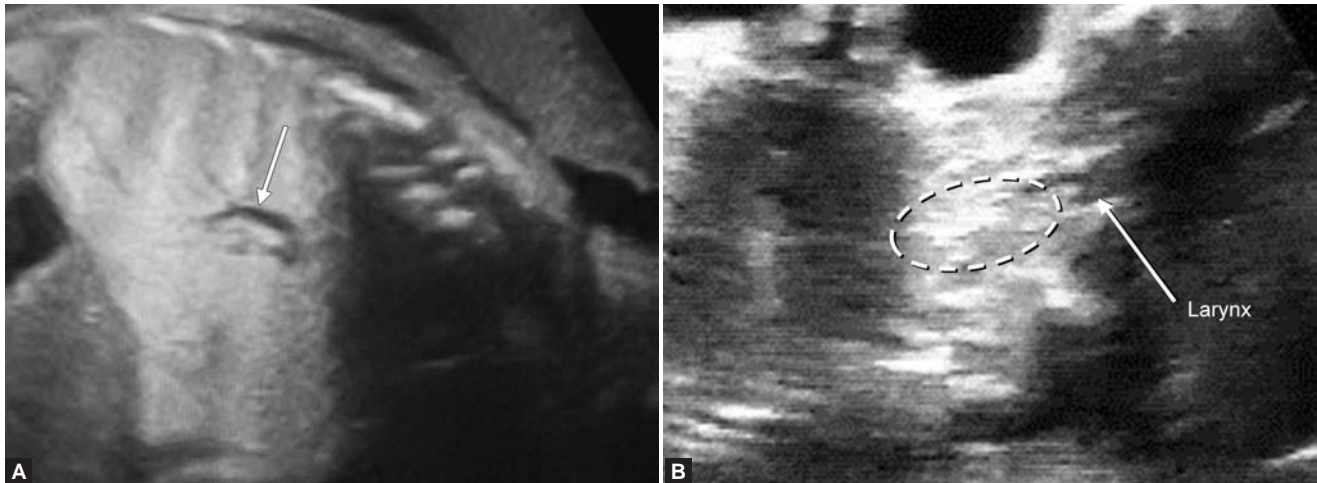
**Figs 8A and B:** Abnormal findings of fetal airway tract with intrathoracic space-occupying lesion: (A) In congenital diaphragmatic hernia (CDH), the left bronchus (arrow) shows abrupt stenosis after the tracheal bifurcation and (B) in congenital cystic adenomatoid malformation (CCAM) of the right lung, the right bronchus abruptly ends due to mass compression and (arrow). Small arrows and broken circle indicate the left bronchus and mass lesion of CCAM, respectively

Actual abnormal findings that can be possibly obtained through ultrasound are as follows: (1) absence of a structure in the original location caused by agenesis or deviation, (2) narrowing caused by compression, collapse, stenosis, or hypoplasia and (3) distal dilatation caused by regional occlusion. These findings are feasible enough to suspect the underlying abnormal change in the fetal airway tract.

Figures 8A and B show the fetal airway tract with intra-thoracic space-occupying lesion of CDH and congenital cystic adenomatoid malformation (CCAM). Bronchial narrowing and abrupt ending of the bronchus caused by compression and collapse are observed.

Figures 9A and B show the fetal airway tract affected by stenotic anomaly in cases of CHAOS and tracheal agenesis. In the former, distal bronchial dilatation caused





**Figs 9A and B:** Abnormal findings of fetal airway tract with airway anomaly: (A) in congenital high airway obstruction syndrome (CHAOS), dilated bronchus (arrow) and expanded high echogenic lung are noted and (B) in tracheal agenesis, absence of trachea below the larynx (broken circle) is distinct

by regional stenosis is obvious. In the latter, tracheal absence in the original location is noted.

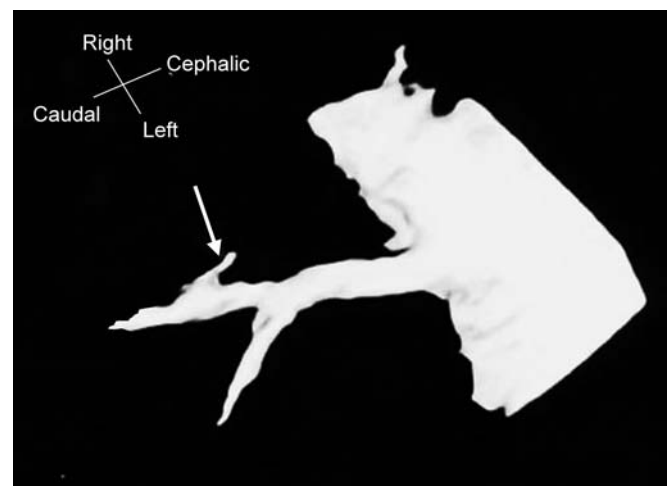
### Three-dimensional (3D) Sonographic Image of Fetal Airway Tract

With respect to 3D visualization of the airway tract, Chen et al<sup>9</sup> reported the neonatal tracheobronchial 3D image using CT scan and described the prevalence of airway tract anomalies. Nelson et al<sup>10</sup> first reported the prenatal application of 3D inversion mode to visualize the fetal cardiac structure.

For a successful visualization of the tracheobronchial 3D image, acquisition of high-quality datasets from 2D 'Y-shaped' airway images is necessary. Prior to acquisition, 2D images for the 3D datasets must be optimized by adjustment of frame rate and contrast resolution. Acquisition angle and time were set ranging from 25° and 7.5 seconds in the second trimester to 35° and 15 seconds in the third trimester.

Seeking for the understandable fine stereotypic image, 3D inversion mode has been applied to visualization of fetal organs. In the inverted mode, anechoic structures appear echogenic in the rendered image by gray-scale inversion of voxels in the rendering image with adequate post-processing adjustments. Figure 10 demonstrates a well-delineated 'Y-shaped' 3D image, which is derived successfully from the fetal airway tract using 3D inversion mode. The right upper LB branching from the right MB near the carina is noted.

In the case of left CDH, the tip of the left bronchus spreads widely and suddenly breaks off at the middle (Fig. 11). In the case of left atrial isomerism, equally wide spreading angles of the bilateral bronchi and lack of right upper LB are noted, which characterize left isomerism in the right bronchus (Fig. 12).

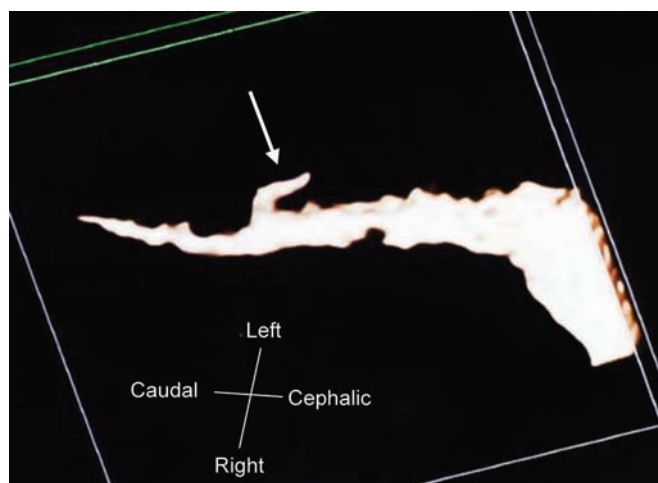


**Fig. 10:** Inverted 3D image of whole 'Y-shaped' image of fetal airway tract. The first lobar bronchus (arrow) that branches from the right main bronchus near the carina is noted

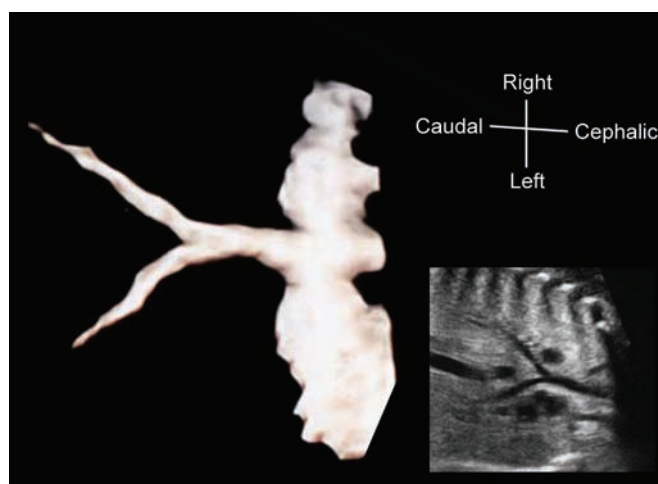
### Simultaneous Visualization of Fetal Trachea and Esophagus

Congenital esophageal atresia and/or tracheoesophageal fistula are common congenital anomalies. Also, tracheobronchial malacia and stenosis are associated with esophageal atresia.<sup>11,12</sup> Simultaneous visualization of the fetal trachea and esophagus can provide helpful information in order to effectively manage the affected neonate.

In the case of esophageal atresia with Gross type C, Quarello et al<sup>13</sup> reported the 'tracheal print' sign in relation to simultaneous visualization of the fetal esophagus and trachea. The optimal plane for simultaneous visualization is a slightly right-sided section from the aortic arch view in relation to a right-sided backbone (Figs 13A and B). In the case of esophageal atresia, this optimal plane is useful for understanding the anatomical relation between the partially dilated esophagus and the trachea. Figure 14



**Fig. 11:** Inverted 3D image of fetal airway tract in case of left diaphragmatic hernia. Tip of the left bronchus (arrow) spreads widely and suddenly breaks off at the middle



**Fig. 12:** Inverted 3D image of fetal airway tract in case of left atrial isomerism (LAI). Equally wide spreading angles of the bilateral bronchi and lack of right upper LB are noted, which characterize left isomerism in the right bronchus. Right low: Corresponding 2D image of fetal airway tract

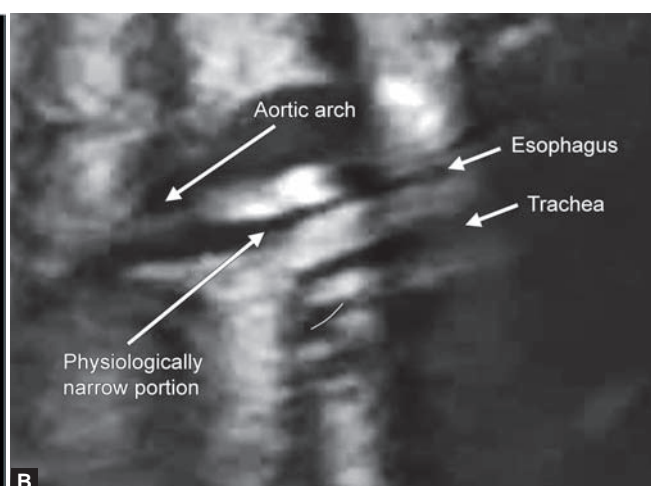
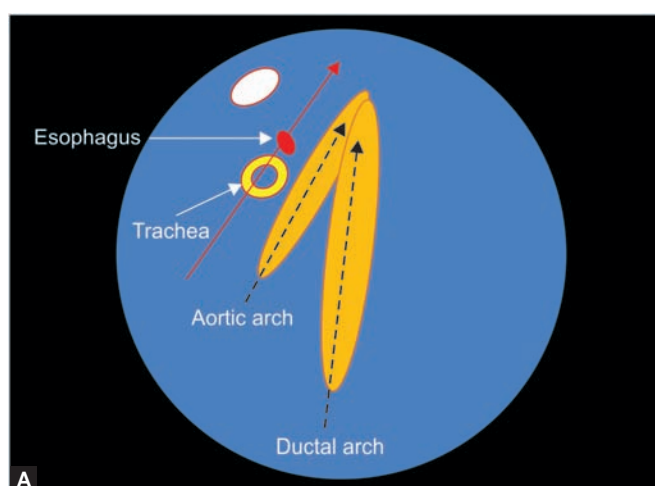
shows esophageal atresia (Gross C) presenting as an anechoic, dilated, blind-ending proximal esophageal pouch behind the trachea.

### Fluid Flow in Fetal Airway Tract

Fluid flow waveforms can be obtained from the fetal airway tract, including the oral cavity, nasal cavity, larynx, and trachea (Figs 15A to C). Among them, the tracheal flow is well-investigated using pulsed Doppler ultrasound. Gilles et al<sup>14</sup> reported that Doppler ultrasound waveforms of fetal tracheal fluid flow demonstrate the cyclic respiratory profiles allowing a noninvasive approach for semiquantitative evaluation of prenatal respiratory activity. In the cases of pulmonary hypoplasia and CDH, the tracheal fluid flow was investigated in relation to prognosis.<sup>15,16</sup> The assessment of fluid flow in fetal airway tract may allow more detailed evaluation of an obstructive or malformative disease by identifying alterations in respiratory function.

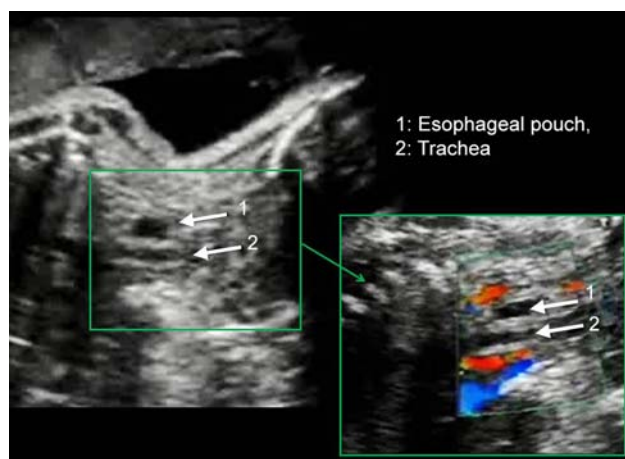
### CONCLUSION

To identify the fetal airway tract prenatally, the planes of view for fetal cardiac screening are feasible. The representative planes to demonstrate the fetal respiratory tract are three-vessel-tracheal view for short-axis view of the trachea, aortic arch view or ductal arch view for the short axis view of the left bronchus, and three-vessel or left ventricular outlet tract plane for short axis view of the right bronchus. Fetal airway tract visualization is possible for prenatal screening and investigation. It is of great advantage for neonatal respiratory management to obtain precise information on fetal airway condition prenatally.



**Figs 13A and B:** (A) Illustration of three-vessel-tracheal view showing the optimal plane for simultaneous visualization of the fetal trachea and esophagus. Slightly right-sided slice section (long arrow) from aortic arch view in relation to right-sided backbone is favorable, (B) fetal intrathoracic image including both trachea and esophagus

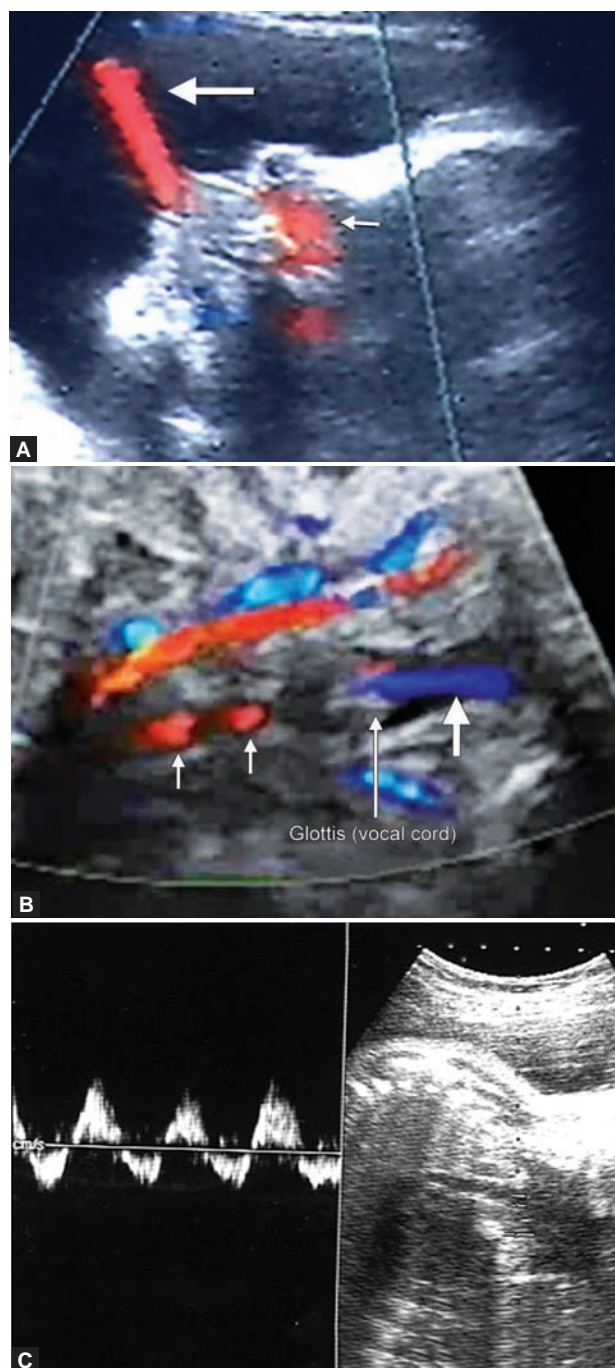




**Fig. 14:** Intrathoracic image in case of fetal esophageal atresia with long gapping Gross type C. Dilated, blind-ending proximal esophageal pouch is noted behind the trachea

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**Figs 15A to C:** (A) Oral flow (arrow) and nasal flow (small arrows) in fetus, (B) laryngeal flow (arrow) and tracheal flow (small arrows) in fetus and (C) pulsed Doppler waveforms of fetal tracheal flow

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