3D and Thoraco-abdominal Malformations

E Viora, A Sciarrone, S Bastonero, G Errante, S Stillavato, M Campogrande

Centro di Ecografia e Diagnosi Prenatale, Ospedale S. Anna, Torino, Italy

Correspondence: Dr Elsa Viora, Centro di Ecografia e Diagnosi Prenatale, Ospedale Sant'Anna
Corso Spezia 60, 10126 Torino, Italy
Tel.+390113134392, Fax +390113134720, e-mail eviora@etabeta.it

Abstract: There are few 3D well-documented studies about thoraco-abdominal malformations, except for the evaluation of fetal lung volume.

Three-dimensional ultrasound provides additional diagnostic information for the evaluation of fetal thorax both for the diagnosis of skeletal anomalies and the biometric measurements of lungs.

3D adds few information about the diagnosis of gastrointestinal malformations, but 3D images are an effective tool to make a careful advice with parents and pediatric surgeons, especially in fetuses with anterior wall defects.

Until now its use must be reserved in a research setting and offered to high-risk patients in order to understand which role 3D may play in the study of thoraco-abdominal malformations as a screening or diagnostic tool.

Key words: 3D ultrasound, Fetal thoracic malformations, Fetal abdominal malformations, Prenatal diagnosis.

INTRODUCTION

Potential benefits of 3D ultrasound in obstetrics, especially in the prenatal diagnosis of fetal malformations, have been reported or proposed. In fact the possibility of reviewing volume data sets of fetal organs, of rotating the acquired volume so that the structures can be visualized from different point of view and studied with different planes of section are certainly new and important methods of analysis.

The use in medical practice requires the knowledge not only of real diagnostic possibility in a clinical setting, but also the scientific evidence that 3D adds diagnostic information to what is provided by two-dimensional ultrasound.

The aim of this article was to review current knowledge related to the use of 3D in the prenatal diagnosis of thoraco-abdominal malformations and especially to assess the usefulness of 3D in the diagnosis and clinical evaluation of these malformations and what additional information it can give.

FETAL THORAX

In this paper we include in fetal thorax only lungs and skeleton structures. Fetal heart is presented in another review article of the same issue.

LUNG ANOMALIES

Lung hypoplasia is a severe anomaly associated with an high mortality rate; a lot of parameters have been evaluated in order to diagnose lung hypoplasia during pregnancy. Fetal lung measurements have been performed also by 3D with two different techniques: multiplanar and VOCAL (Virtual Organ Computer-Aided Analysis). Kalache *et al* observed that both can be used to measure lung volume and such data have been confirmed by other authors. An advantage of VOCAL is the possibility of evaluate more accurately the contours of lung, especially when they are irregular, such in presence of diaphragmatic hernia. Multiplanar mode is faster and the data sets are better if acquired by transverse scan of fetal thorax.

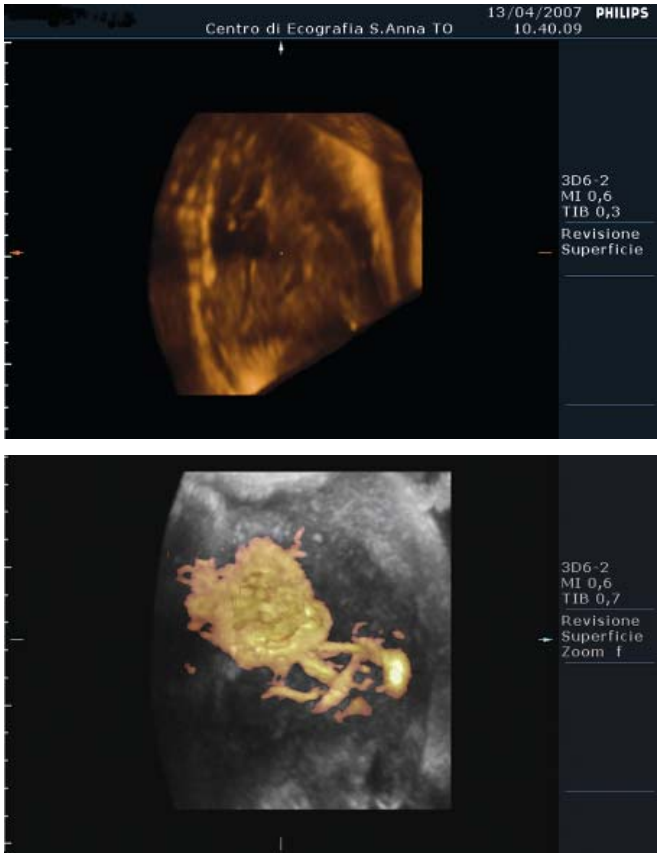
Nomograms of pulmonary volume by 3D have been proposed by different authors. Ruano *et al* have calculated lung volume by the VOCAL technique in 109 healthy fetuses and they have confirmed that the observed-expected fetal lung volume ratio was lower in fetuses affected by diaphragmatic hernia when compared with normal fetuses.

Until now no study have been performed to evaluate potential additional information of the three-dimensional ultrasound in the diagnosis of congenital diaphragmatic hernia in a general population (Figs 1A and B).

Ruano *et al* have evaluated the potential of 3-dimensional power Doppler imaging to predict neonatal outcome and pulmonary arterial hypertension (PAH) in 21 fetuses with congenital diaphragmatic hernia (CDH) compared with 58 controls between 20 and 40 weeks. Among CDH cases, the vascular indices were significantly lower in fetuses who died ($P < 0.05$), and in fetuses with neonatal PAH ($P < 0.05$). The severity of neonatal PAH was also associated with a progressive reduction in prenatal vascular indices ($P < 0.05$). In conclusion, all vascular indices seem to be constant throughout gestation. In isolated CDH, perinatal outcome and postnatal PAH can be predicted using the vascular indices assessed by 3D power Doppler histogram.

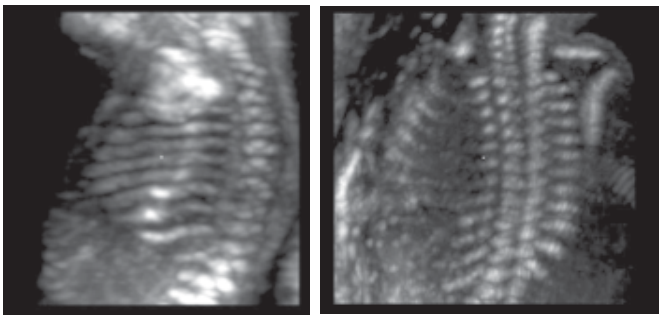
Thoracic Skeleton Malformations

The skeleton of fetal thorax is visualized with difficulty by 2D because the thorax is a complex structure with multiple



Figs 1A and B: A fetus with congenital diaphragmatic hernia diagnosed by 2D. 3D images show the left hepatic lobos partially herniated in the thorax (A), while Power Doppler with transparent mode (B) consent to identify hepatic vessels that are dislocated

Fig. 2: A normal thoracic cage in a fetus at 21 weeks' gestation: vertebrae, ribs, scapulae and clavicles are seen



Figs 3A and B: Images of scapula in a normal fetus at 21 weeks' gestation which show relationships between the ribs, clavicles and scapula: scapula corresponds approximately to the first 4 ribs

curvilinear bones so bidimensional scan is not so appropriate and it is difficult to visualize the spatial relationship between the bones each other. The thoracic skeleton can be examined by 3D using multiplanar display and volume rendering with the maximum-intensity mode (the so-called skeletal mode) or a combination of both.

The rotation of volume data sets can be used to demonstrate the spatial relationship between the spine and the rib cage (Fig. 2).

In our experience, fetal thoracic skeleton can be easily studied by 3D. Volume acquisition is fast and it doesn't increase the examination time. The structural surveys were complete in about 15 minutes using 3D reconstructed volumes, but the evaluation time of volume data sets may be decreased significantly if the acquisition of volumes is standardized to minimize artefacts and produce uniform images.

Multiplanar mode with *maximum intensity weighting* (MIW) allows a precise study of the vertebras and the sternum. The volume must be acquired with a longitudinal scan of the fetus with the spine proximal to transducer to study the vertebrae and with chest directed toward the transducer to evaluate the sternum.

The scapulae and clavicles can be easily visualized by multiplanar mode, but the relationships between the thoracic bones, especially with ribs and scapulae, are better observed by rendering mode (Figs 3A and B).

Esser and Kalache (2006) described a case of trisomy 21 with absence of the 12th rib diagnosed by 3D: such thoracic anomaly is reported by pediatrician literature in children with trisomy 21.

In our experience, we have observed two fetuses affected by trisomy 21 with only eleven ribs (Fig. 4).

Spondylocostal dysostosis is a rare congenital disorder characterized by vertebral segmentation and asymmetrical rib anomalies. It has been observed by 3D ultrasound and two cases were described in the 2006: one by Sallout and Pretorius and one by Wong *et al*.

We have diagnosed two cases of thoracic hemivertebrae in fetuses at 20-21 weeks' gestation.

One fetus, referred for suspect of congenital cardiac disease, was affected by tetralogy of Fallot: an evaluation of fetal thorax

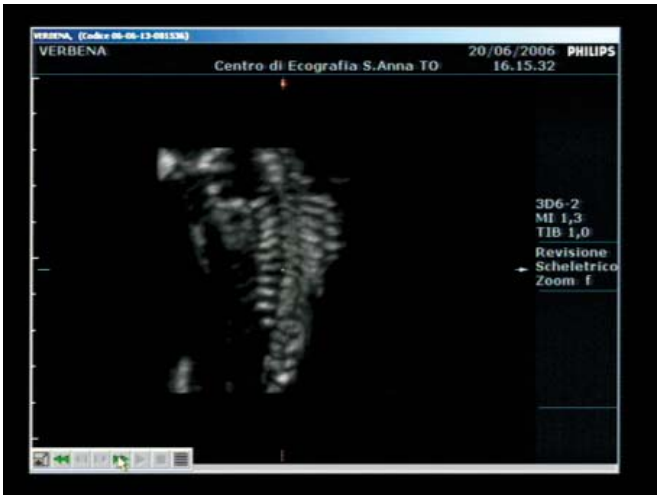


Fig. 4: 3D ultrasound allows to observe the absence of one rib in a fetus affected by trisomy 21

by 3D has shown the presence of only eleven ribs with fusion of four ribs in one side and two hemivertebrae (Fig. 5) confirmed after birth by radiological exam.

In another fetus at 22 weeks' gestation, referred for ventriculomegaly, a 3D scan of fetal thorax revealed the presence of hemivertebrae (Figs 6A and B).

FETAL ABDOMEN

Some structures located in the abdomen (stomach, kidneys) can be visualized by 3D ultrasound and anomalies of such organs can be observed also by 3D.

Gastrointestinal Malformations

Few studies have evaluated the potential use of 3D in the prenatal diagnosis of gastrointestinal malformations. Only case-reports or case-series have been reported.

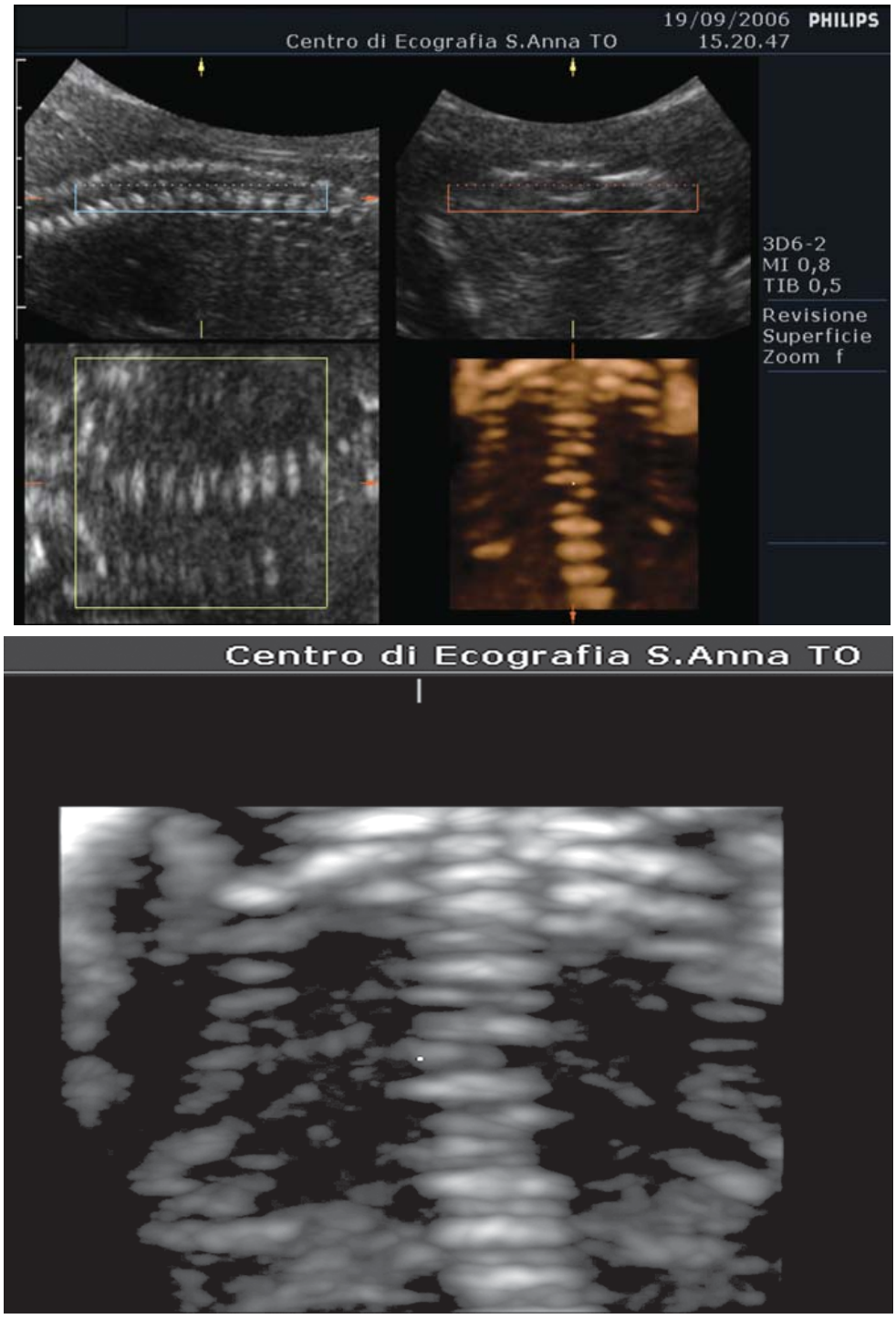
Lopez Ramon Y Cajal C *et al* have observed one case of duodenal atresia with polyhydramnios in which 3D ultrasound has allowed a better definition of stomach and duodenal dilatation and the anatomic relationship each other. The images have aided in the counseling with the couple and pediatric surgeons.

Yagel S *et al* have reported a case of esophageal atresia whose diagnosis has been improved by 3D scan.

Bonilla-Musoles F *et al* have compared 2D and 3D in 11 fetuses with abdominal defects using multiplanar mode. According to these authors, 3D ultrasound has given additional information to improve the counseling with the couple and pediatric surgeon.

In conclusion, we think that 3D ultrasound does not provide significant additional information over 2D in the diagnosis of

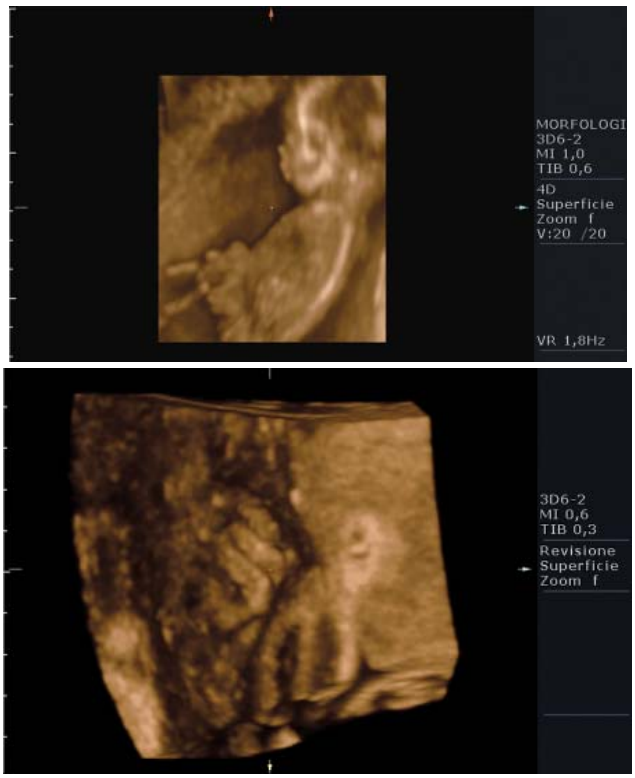
Figs 5A to C: Fetus at 21 weeks' gestation with eleven ribs, fusion of four ribs and hemi vertebrae (A and B); the same case in a radiological image after birth (C)



Figs 6A and B: 3D multiplanar (A) and rendering mode (B) scan of thoracic vertebrae in a fetus of 22 weeks' gestation with hemi vertebrae

gastrointestinal malformations, but it may be an effective tool to make a careful advice with parents and pediatric surgeons in the fetuses with anterior wall defects (omphalocele and gastroschisis) (Figs 7 and 8).

Fig. 7: Surface rendering in a fetus affected by omphalocele



Figs 8A and B: Images of a fetus with gastroschisis at different gestational age

Urogenital Fetal Anomalies

There are few reports of the diagnosis of urogenital malformations; they are essentially about normal anatomy, some cases of multicystic kidney and one case of kidney tumor.

Chang *et al* have retrospectively compared 2D and 3D in 28 fetuses affected by multicystic kidney. According to their experience, multiplanar mode adds information especially in associated anomalies.

A 3D scan can be useful in cases with solid renal masses. Schild has observed a case of renal tumor of 69 × 50 × 49 mm; by color Doppler a rich vascularization is present. A presumptive diagnosis of Wilms' tumor is performed and is confirmed after birth. The advantage of 3D scan was in the multiplanar evaluation of the mass, of her edges and of the adjacent organs. *Inversion mode* may be useful in the study of cystic lesions and tubular structures (ureters, intestine), but at now no clinical works have been made by using this technique.

In our experience 3D adds few information in the diagnosis of multicystic kidney (Fig. 9) and of obstructive uropathy, even images are undoubtly very suggestive.

Three-dimensional ultrasound may provide additional about adjacent organs and about the relationships each other.

In our experience, in one fetus with distended bladder and dysplastic kidneys at 20 weeks' gestation, 3D ultrasound allows a better definition of the relationships between the hyperechoic renal images and the anechoic structure situated in the fetal pelvis that was interpreted as a cloaca (Figs 10A and B).

Prenatal diagnosis of isolated unilateral kidney agenesis may be difficult by 2D ultrasound, but Benacerraf *et al* reported one case in which the absence of one kidney, associated to other malformations, was not diagnosed also by 3D. In our experience, in cases relieved by bidimensional sonography, 3D images were certainly more suggestive, especially in third trimester (Fig. 11).

The visualization by surface rendering of external genitalia is better if compared to 2D ultrasound. Some case of prenatal diagnosis of hypospadia have been reported and also in our experience 3D images may improve the multidisciplinary counseling with couple (Figs 12A and B).

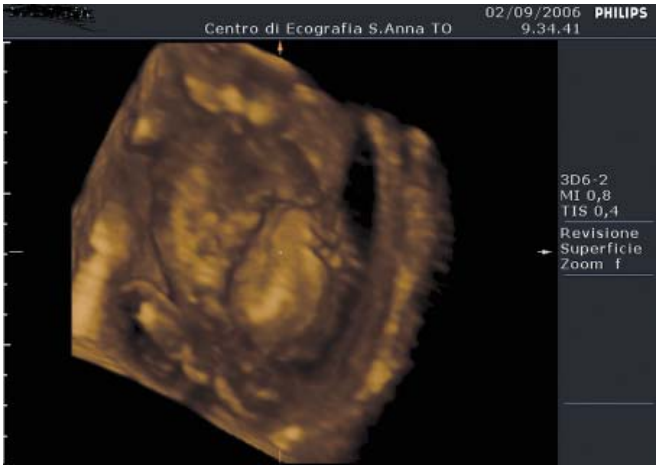
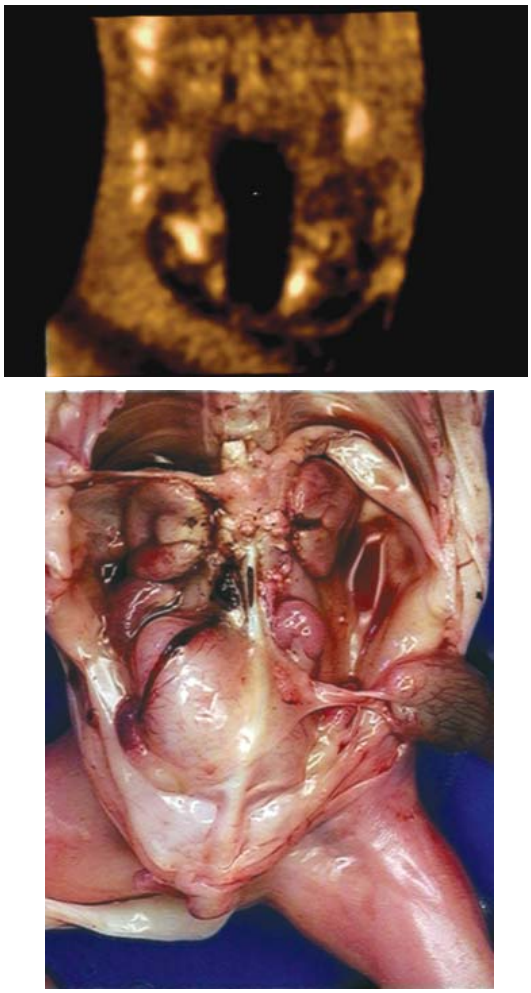


Fig. 9: Surface rendering of a fetal multicystic kidney



Figs 10A and B: 3D (A) and autoptic (B) images of a fetus at 20 weeks' gestation with anechoic structure situated in the fetal pelvis that was interpreted as a cloaca and dysplastic kidneys that appear hyperechogenic

Fig. 11: A fetus with unilateral kidney agenesis: a coronal scan in which normal kidney is present on the right of the image, while the contralateral renal fossa is empty

Figs 12A and B: Hypospadia: images by rendering (A) and multiplanar mode (B) in a fetus in the second trimester

CONCLUSIONS

Prenatal ultrasound examination is an essential and reliable method for detecting thoraco-abdominal malformations and 3D sonography can improve the specificity of the exam.

Surface rendering adds additional information in the study of fetal masses, external genitalia and may be used also in the anterior defects of abdominal wall to improve prenatal counseling not only with the couple, but also with pediatric surgeon.

With multiplanar view we could measure structure volume (for example lungs or kidneys' mass) and compare its increase in following ultrasounds, and with 3D power Doppler it is possible to observe the whole mass vascularization, estimating also small-calibre vessels.

Thoracic skeleton can be evaluated both by multiplanar and rendering mode using appropriate algorithms to view fetal bony structures.

It is often reported that 3D proves to be easy to use and less operator-dependent than bidimensional ultrasound, but it is only partially true, at the present state of art, because the operator must have both experience in acquiring volume, evaluation of the acquired volume and a knowledge of the ultrasound and radiological (for the skeletal part) aspects of the suspected anomalies.

The great advantage of 3D is that the volume data sets can be recalled, examined and interpreted off-line by other operator without need of the patient so this reduces direct and indirect costs, including the anxiety of the pregnant women; also the re-examination after birth can provide much more information with additional views improving the diagnostic ability and it can be used as a training tool.

For its clinical use, it must be underlined that some thoracic bones can be evaluated with bidimensional ultrasound. However, some malformations (scoliosis, ribs fusion or hemivertebrae) are certainly studied in a more precise way by 3D that allows to visualize contemporarily the different bones of thoracic cage and the spatial anatomic relationships.

On the other hand, three-dimensional ultrasound adds few information about the diagnosis of gastrointestinal malformations, but 3D images were an effective tool to make a careful advice with parents and pediatric surgeons, especially in fetuses with anterior wall defects. In fetuses with urogenital malformations, 3D can allow a better definition of renal masses and external genitalia anomalies.

From this review of the current state of knowledge and in our experience, we believe that 3D can improve prenatal diagnosis of some thoraco-abdominal malformations and some conclusive considerations can be made.

First, we think that rendering mode may allow a better definition of:

- Anatomic spatial relationship between the spine and the rib cage
- Visualization of clavicles and scapulas
- Evaluation of abdominal masses diagnosed by 2D
- Anomalies of genitalia, for example hypospadia.

Second, multiplanar mode is useful in the evaluation of thoracic vertebrae and sternum.

Obviously all 3D analysis tool must be used complementary, also with power Doppler, in order to obtain much more information as possible.

There are few 3D well-documented studies about thoraco-abdominal malformations, except for the evaluation of fetal lung volume, and further investigations are warranted.

Until now 3D ultrasound use must be reserved in a research setting and offered to high-risk patients in order to understand which role three-dimensional ultrasound may play in the study of thoraco-abdominal malformations as a screening or diagnostic tool.

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