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REVIEW ARTICLE

Current Role of 3D/4D Sonography in Obstetrics and Gynecology

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ABSTRACT

Modern 3D/4D sonography provides a routine method not only for storing single image planes as in 2D ultrasound but also for storing complete sets of volume data in the computer memory. Once acquisition is completed, all volumes can be accessed from the memory and normal and abnormal findings in both obstetrics and gynecology can be demonstrated in different display modes. Furthermore digital storage of volumes permits virtual examinations by reloading of volumes and navigating through them in the absence of the patient.

This review article would like to give an illustration of the latest technologies in 3D/4D ultrasound in obstetrics and gynecology.

Keywords: 3D ultrasound, 4D ultrasound, Obstetrics, Gynecology, Display modes, Fetal malformations.

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INTRODUCTION

In 1989, the first commercially available ultrasound scanner (Combison 330) was launched by Kretztechnik AG, Austria.[1] Despite the fact that many physicians were initially skeptical regarding the clinical use of this technique, three-dimensional/four-dimensional (3D/4D) ultrasound has found widespread acceptance since the time of the First World Congress for 3D Ultrasound in Obstetrics and Gynecology held in Mainz, Germany, in 1997.[1] The American Institute of Ultrasound in Medicine held a consensus conference in 2005, in which 3D ultrasound was shown to be able to image a huge number of conditions, both in obstetrics and gynecology.[2] In the meantime 3D/4D ultrasound has evolved into a powerful technique that can be integrated in every routine ultrasound examination. The most recent 3D/4D ultrasound technology facilitates 3D/4D ultrasound examinations even for the less experienced sonographer, while giving the examiner the opportunity to identify normal and abnormal fetal structures in the most appropriate imaging mode.[1] However, 3D/4D technology is not only useful for prenatal diagnosis[1-19] but also for gynecological ultrasound[20-32] and breast ultrasound[33-38] as well.

TECHNICAL ASPECTS

Generally, a 3D ultrasound examination consists of four main steps:[3] data acquisition, 3D visualization, volume/image processing, and storing of volumes, rendered images or image/volume sequences (Table 1).

3D/4D transvaginal transducers (5-9 MHz) are used for volume acquisition in early pregnancy and in gynecology. 3D/4D abdominal probes (4-8 MHz) are necessary in later pregnancy and in huge or highly located gynecologic tumors. Examinations of the breast require a different 3D/4D transducer with 6 to 12 MHz. While 3D ultrasound is only able to provide the operator with static pictures, 4D ultrasound allows the demonstration of 3D images in real time.

Currently several display modes can be used to demonstrate the ROI in 3D and 4D (Table 2). This allows the operator to choose always the most appropriate mode for the visualization of normal or abnormal findings in obstetrics (Figs 1A to F) and gynecology.

With the latest development, known as the HDlive technique (Voluson E8, GE), a step toward even more realistic visualization of the fetus can be achieved. HDlive uses a movable virtual light source that can illuminate the examination object from all sides[39] (Figs 2 and 3). The brightness and shadow of the fetal surface are calculated from the reflection and scattering behavior of the structures in relation to the light direction, i.e. the original ultrasound grayscale values no longer apply. The human skin-based color spectrum and the movable virtual light source allow

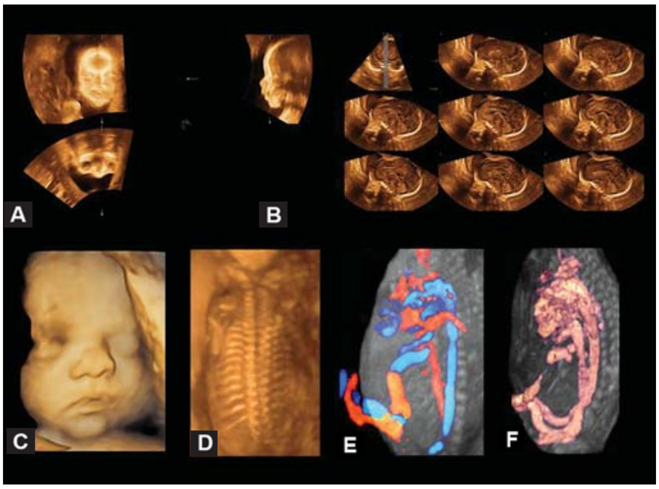
Table 1: Steps involved in transvaginal and transabdominal 3D/4D ultrasound (Adapted after Merz E[3])

Data acquisition
- Orientation in the 2D image
- Definition of the region of interest (ROI)
- Volume acquisition

3D/4D visualization
- Multiplanar display
- Tomographic display
- Surface-rendered image (surface mode, light mode, HDlive mode)
- Transparent display (maximum mode, X-ray mode)
- Glass body display (combination of surface or transparent rendering and color Doppler)
- Animated display (rendering of image sequences)

Volume/image processing
- Electronic scalpel
- Filtering
- Contrast and brightness control
- Color selection

Storage of volumes or rendered images/image or volume sequences



Figs 1A to F: Different display modes in 3D/4D ultrasound. (A) multiplanar view (fetal face), (B) tomographic view (fetal brain, sagittal planes), (C) surface view (face), (D) transparent view (spine), (E) glass body view with color Doppler (blood circulation), (F) glass body view with power Doppler (blood circulation)

Fig. 2: HDlive view, demonstrating an embryo at 8+5 gestational weeks

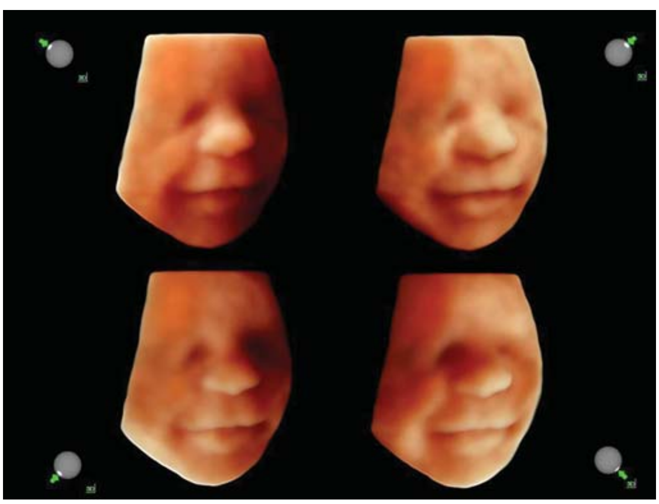


Fig. 3: HDlive view of a fetal face at 32 weeks of gestation. Depending on the position of the movable virtual light source, particular anatomical facial structures are visualized in a more accentuated manner

Table 2: Overview on 3D/4D visualization modes

3D	*4D*
Multiplanar mode	Multiplanar mode
Multislice/TUI mode	Multislice/TUI mode
3D surface mode	3D surface mode
Transparent mode	Transparent mode
Glass body mode	Glass body mode
Inversion mode	Inversion mode
VCI mode	VCI mode
OmniView mode	OmniView mode
3D-animation (cine) mode	STIC mode
HDlive mode	HDlive mode

Table 3: Applications of 3D/4D ultrasound in gynecology (After Merz E[22])

Uterus
- Endometrial evaluation
- Investigation of uterine anomalies
- Localization of intrauterine devices

Ovary
- Folliculometry
- Investigation of ovarian masses
- Ovarian blood flow

Fallopian tube
- Assessment of tubal patency
- Investigation of postinflammatory tubal changes and tubal masses

Rest of the true pelvis
- Investigation of endometriotic lesions

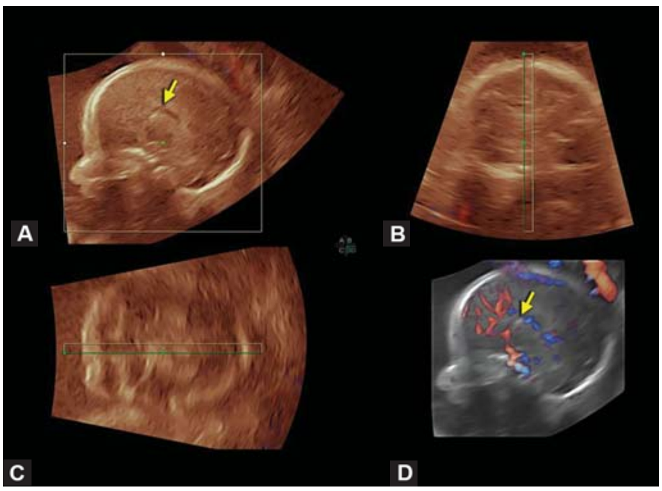
Pelvic floor
- Surface rendering of the pelvic floor

almost photographic imaging of fetuses. In the case of optimal positioning of the virtual light source, this technique can be used to detect normal anatomical structures in early and late pregnancy (facial features, facial expression) as well as pathological changes, particularly surface defects, with greater detail and clarity than possible with the previous 3D surface technique. The virtual light source can be positioned in the front of as well as behind the object allowing impressive translucent images of embryos or fetuses. This technique provides such extraordinarily realistic imaging of fetuses that it is almost impossible to differentiate between actual photographs and ultrasound scans.[39]

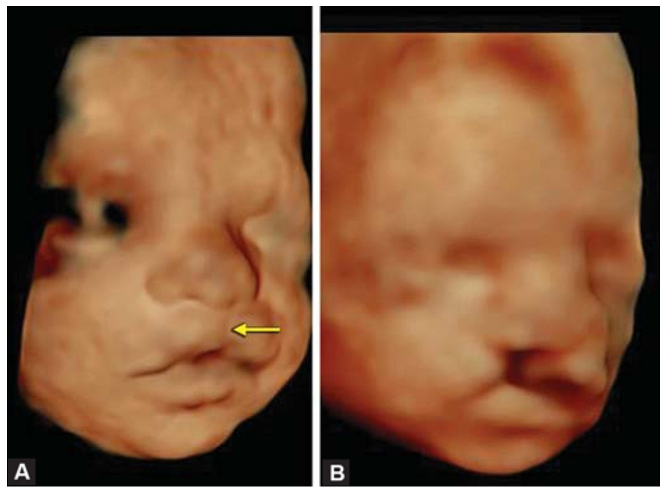
APPLICATION OF 3D/4D SONOGRAPHY IN OBSTETRICS

3D and 4D ultrasound play an important role in early demonstration of normal and abnormal findings in the first, second and third trimester. The various display options give the operator the possibility to choose that display mode which gives the best overview of the ROI (Figs 1A to F). A basic requirement for all 3D surface rendering is the presence of an adequate fluid pocket in front of the structure being imaged.[3] The embryonic and fetal circulation can be demonstrated by application of the glass body mode, a combination of gray scale 3D ultrasound and color respectively power Doppler (Figs 1E and F).

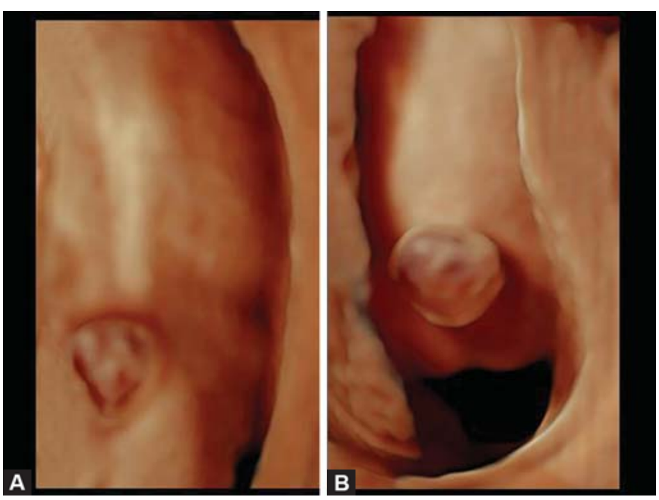
With the interactive display of 3D images, the examiner can demonstrate all types of visible abnormalities in the most appropriate mode, showing the extent of the lesion in all dimensions. In the first trimester this can be the triplanar demonstration of a true midsagittal section which is necessary for an exact nuchal translucency (NT) measurement.[40,41] In the second and third trimesters the multiplanar display mode is helpful identifying a flat fetal profile or micrognathia[4,7,42] or pathologic brain structures like partial or completely absent corpus callosum (Figs 4A to D)[43] or slightly dilated ventricles.[7,44,45] Surface rendered images give a precise demonstration of all the defects concerning the fetal surface like in facial defects (Figs 5A and B)[4,7,46-50] neural tube defects (Figs 6A and B),[7,51] abdominal defects (Fig. 7),[7] abnormalities of the gender (Fig. 8)[52] and defects of the limbs including hands and feet (Figs 9 and 10).[7] In case of cutting organs with the electronic scalpel,[53] the surface mode can also provide the examiner with impressive 3D images of inner fetal surfaces (Fig. 11).[7] The transparent mode provides a view of the fetal skeleton with demonstration of abnormal ossification, e.g. abnormalities of the skull, spine,[7,54] chest, pelvic bones and the long limb bones.[7,55] 3D and 4D fetal echocardiography using STIC technique and in particular color STIC allows the examiner to view complex anomalies of the fetal heart and to control the cardiac blood flow during the different heart cycles (Fig. 12).[11,12]



Figs 4A to D: (A-C) Multiplanar view of corpus callosum agenesis (←), 24 weeks of gestation. (A) Median plane, (B) coronal plane, (C) transverse plane, (D) glass body rendering, showing missing pericallosal artery (←)



Figs 5A and B: (A) Surface view (HDlive) of a fetus with superficial cleft lip (←), 27 weeks of gestation. (B) surface view (HDlive) of a fetus with unilateral right sided cleft lip and palate, 25 weeks of gestation



Figs 6A and B: (A) Surface view (HDlive) of a fetus with lumbar myelocele, 23 weeks of gestation. (B) surface view (HDlive) of a fetus with lumbar myelomeningocele, 18 weeks of gestation


Fig. 7: Surface view (HDlive) of a fetus with gastroschisis, 21 weeks of gestation

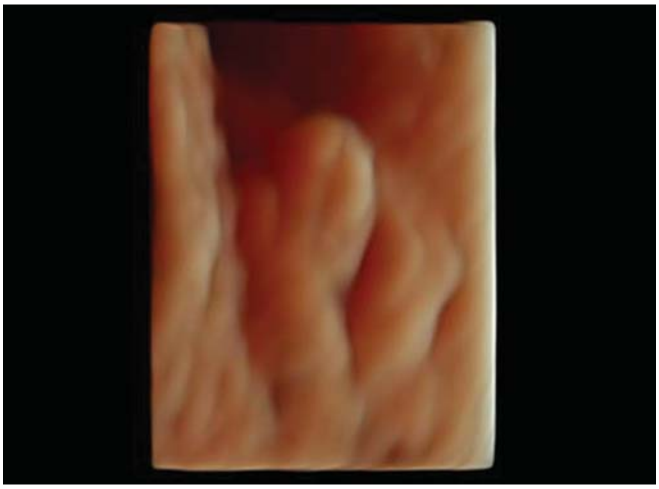
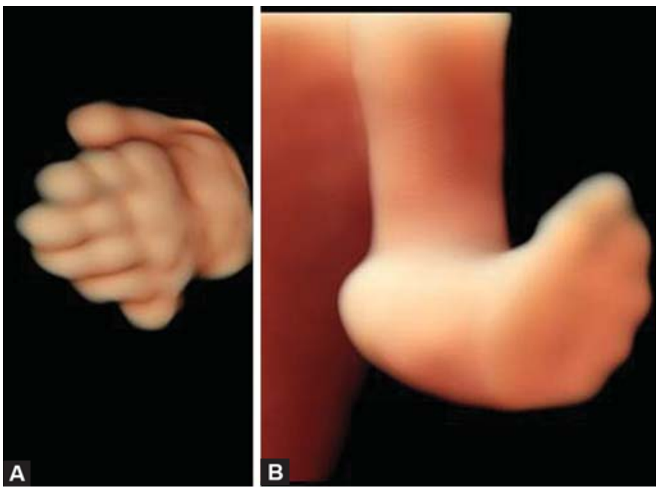


Fig. 8: Surface view (HDlive) of a female fetus with hyperplasia of the clitoris, 23 weeks of gestation

Fig. 9: Surface view (HDlive) of a fetus with Pena-Shokeir syndrome, 18 weeks of gestation. The arms are in a fixed flexed position, while the lower limbs show extension contractions and a deviation of the foot axis. Narrow thorax with pulmonary hypoplasia. Polyhydramnios



Figs 10A and B: (A) Surface view (HDlive) of a fetus with postaxial hexadactyly, 14 weeks of gestation. (B) surface view (HDlive) of a club foot (view from planar), 24 weeks of gestation

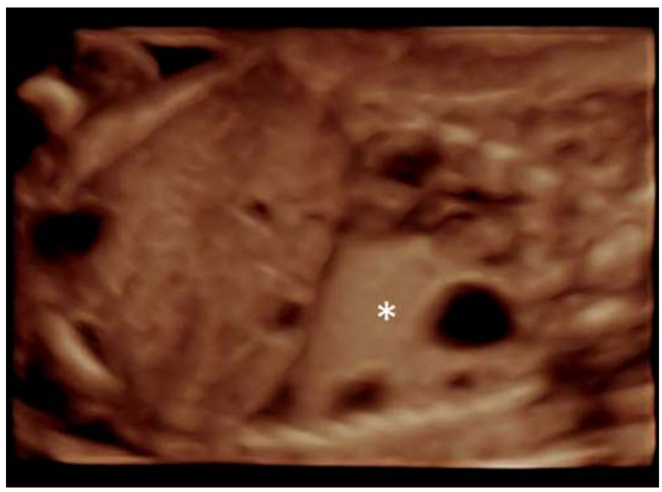


Fig. 11: Surface view of the inner surface of the trunk (HDlive), showing lung sequestration with macrocystic adenomatoid lung malformation (CCAM) (*), 23 weeks of gestation

APPLICATION OF 3D/4D SONOGRAPHY IN GYNECOLOGY

Scanning of the pelvis with an endovaginal 3D/4D probe opens up new diagnostic possibilities (Table 3).

The main advantage of transvaginal 3D/4D ultrasonography is the ability to generate transverse sections of the true pelvis in addition to conventional sagittal and coronal scans.[22] Also, the examiner can scroll through a stored volume millimeter by millimeter in all three planes and can rotate the volume in all three directions. This makes it possible not only to determine the maximum extent of an abnormal finding, but also to define the precise topographic location of the lesion in all three planes.[22] The ability to display all three orthogonal planes simultaneously on the monitor also enables a precise volumetric analysis.[56] This is particularly important in the determination of tumor

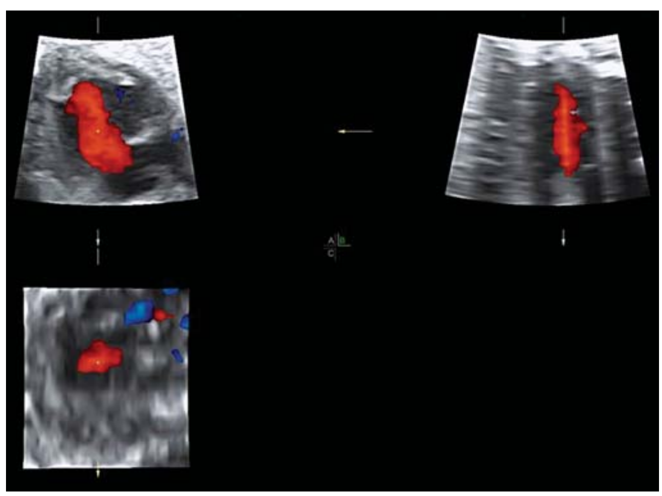


Fig. 12: Single ventricle, 27 weeks of gestation. STIC technology in combination with color Doppler shows the blood flow in all three perpendicular planes at the same time. Due to an atretic mitral valve only a flow to the right chamber can be observed

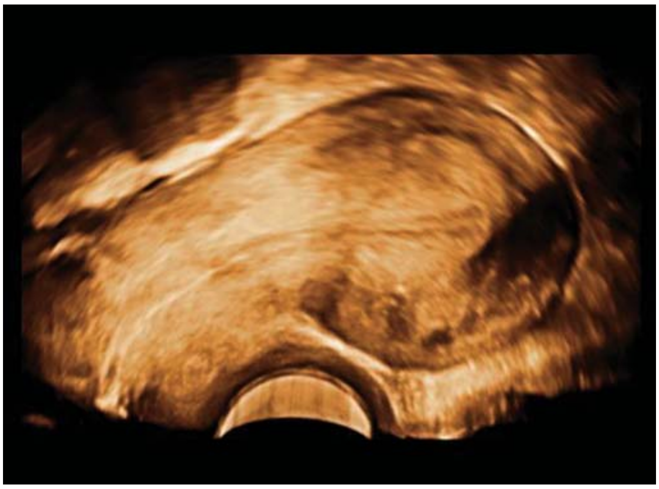


Fig. 13: Surface view of the endometrium in an anteverted and anteflexed uterus. The right side of the uterus was removed electronically

Figs 14A to C: Surface-rendered coronal view of the endometrium after rotation of the uterus in an upright position and removing the front part of the myometrium electronically. (A) Normal shape of the endometrium, (B) septated uterus, (C) bicornuate uterus with fundal indentation

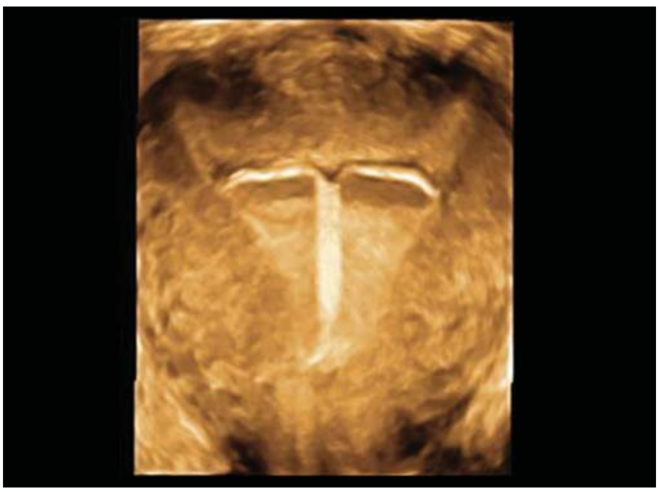


Fig. 15: Correct position of a Copper-T IUD. Surface-rendered coronal view of the IUD after rotation of the uterus in an upright position

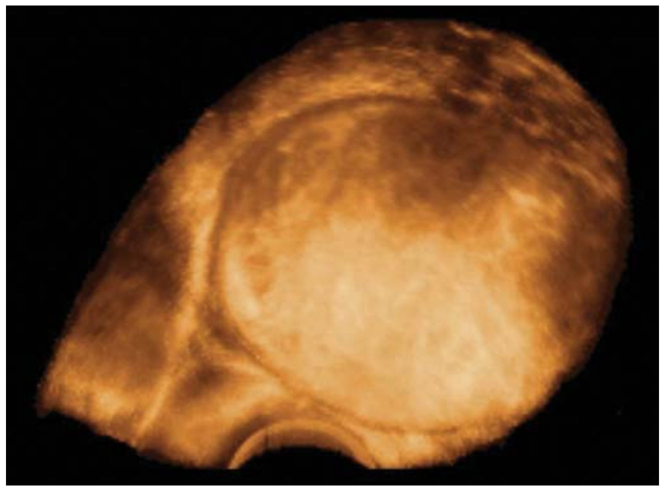


Fig. 16: Sagittal surface-rendered image of a large submucous fibroid

volumes.[57] Moreover, the ability to render a 3D surface view or transparent view can produce a direct, lifelike image of organs such as the uterus (Fig. 13) or adnexa.[22]

The uterus can always be rotated in the stored image in an upright position to display the endometrium in the exact coronal plane. This enables a clear diagnosis of uterine anomalies (Figs 14A to C).[20,32,58] In contrast to hysterosalpingography which allows only an evaluation of the uterine cavum, 3D sonography reveals a clear picture of the inner and outer contour of the myometrium. Endometrial volumetry may be done in *in vitro* fertilization therapy and in patients with suspected tumors. The exact coronal section makes it also possible to check precisely the position of an intrauterine device[59,60] (Fig. 15). In the investigation of uterine tumors, fibroids can be accurately localized and their volume can be precisely determined[22] (Fig. 16). Glass-body rendering enables the operator to demonstrate uterine vascularity in three-dimensions. In particular neovascularization can be shown in endometrial (Fig. 17) and cervical cancer (Fig. 18).[22,25,26]

The ovaries can be depicted with the multiplanar and the surface mode. Both can be used to evaluate follicular maturation in spontaneous and stimulated cycles[22] (Fig. 19). The surface mode can be used to demonstrate cystic or solid tumors of the ovary (Figs 20 to 25) and tumors of the fallopian tube (Fig. 20B). The glass body mode can provide impressive 3D views of the vascularity of benign tumors and neovascularity of borderline and malignant tumors of the ovary[22] (Fig. 23).

In reproductive medicine hystero-contrast sonography is the main procedure for evaluating the uterine cavity and the fallopian tubes as well.[27,61,62]

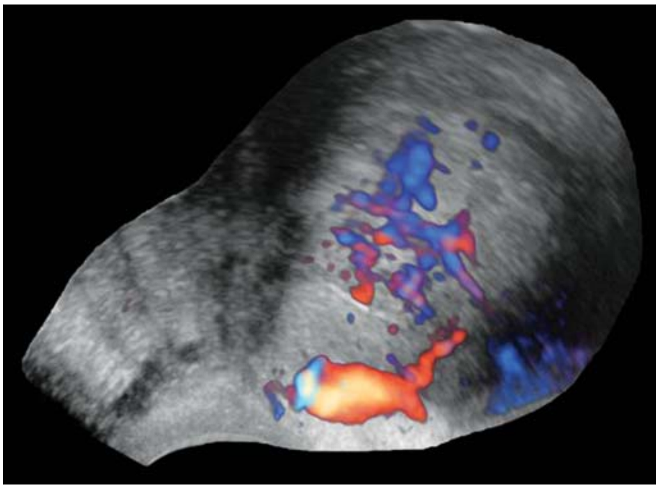


Fig. 17: Glass body rendering (transparent and color Doppler display) of an endometrial carcinoma showing conspicuous neovascularization within the endometrium. Sagittal view

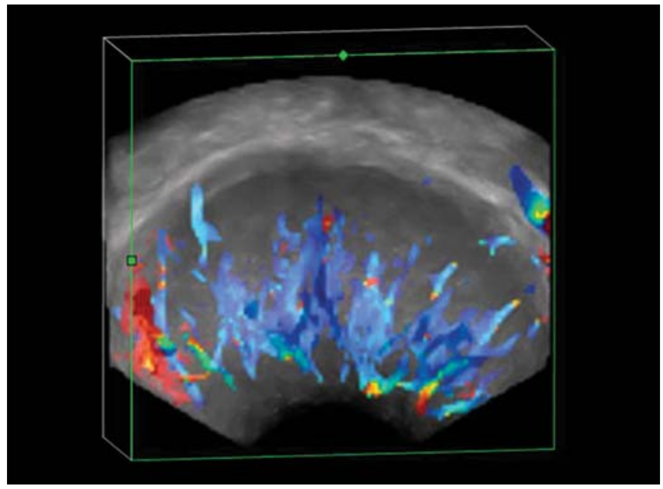


Fig. 18: Glass body rendering of cervical carcinoma with eye-catching neovascularization throughout the cervix. Transverse view of the cervix

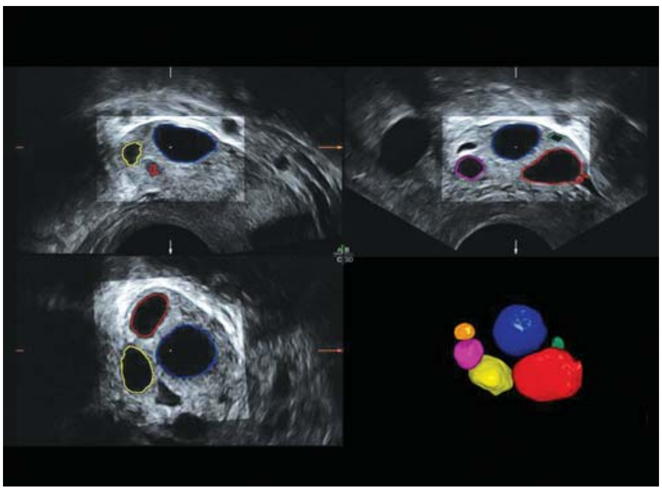
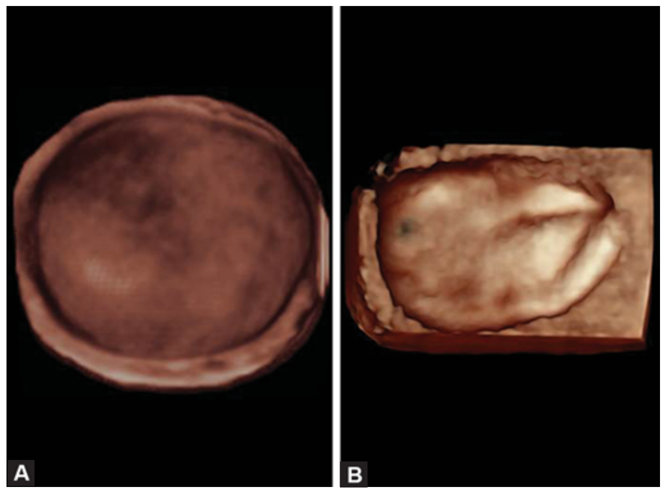


Fig. 19: Multiplanar demonstration of a stimulated ovary following HMG therapy. The SonoAVC technique allows automatic volume calculation of the follicles that are shown in different colors (lower right)



Figs 20A and B: (A) Surface-rendered view of a round unilocular ovarian cyst with smooth margins of the cyst wall. (B) Surface-rendered view of hydrosalpinx. The 3D display clearly distinguishes the more longitudinal cystic structure from an ovarian cyst. HDlive images

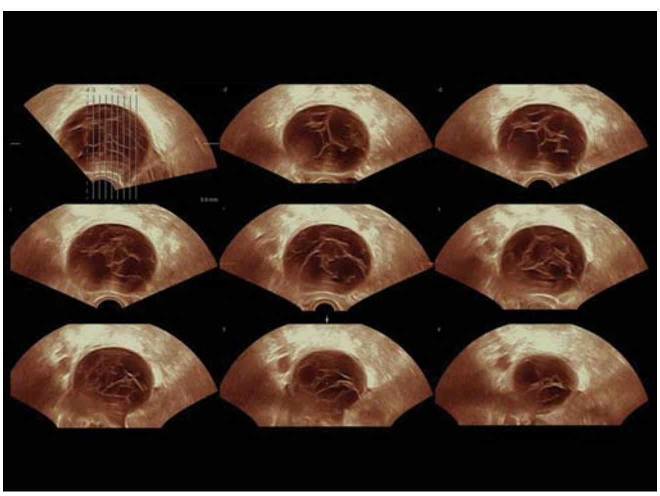


Fig. 21: Tomographic display of a mixed cystic mass with smooth margins: Corpus luteum cyst with intracystic hemorrhage. The distance between the parallel slices is 5 mm

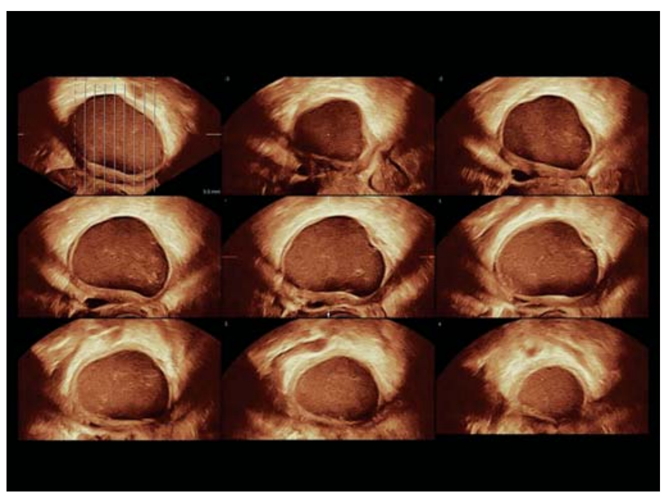


Fig. 22: Tomographic display of a unilocular cystic mass with fine internal echos and a thick wall: endometriotic cyst

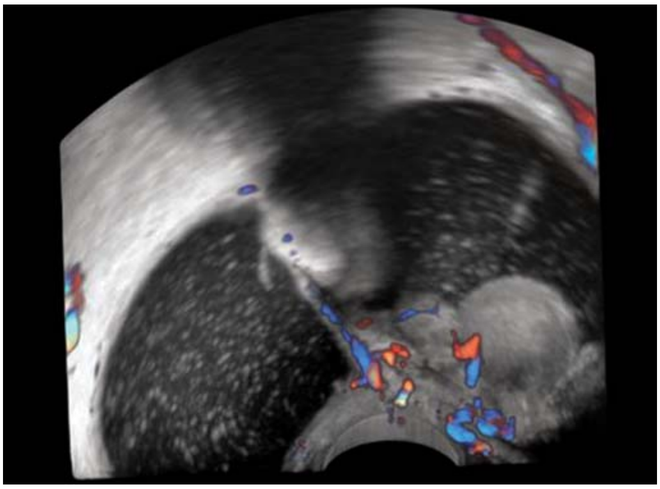


Fig. 23: Glass body rendering of a mucinous cystadenoma showing hyperechogenic internal echos and some vascularization in the more solid area and in the septum

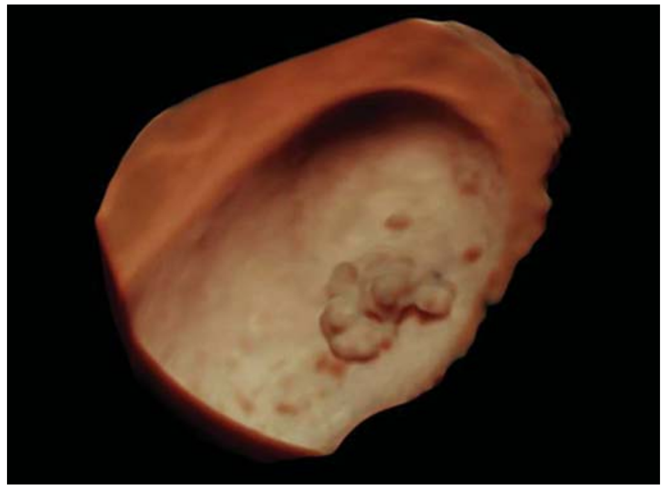


Fig. 24: Surface-rendered image of a cystic ovarian borderline tumor with a proliferative focus on the inner wall of the cystic mass (HDlive)

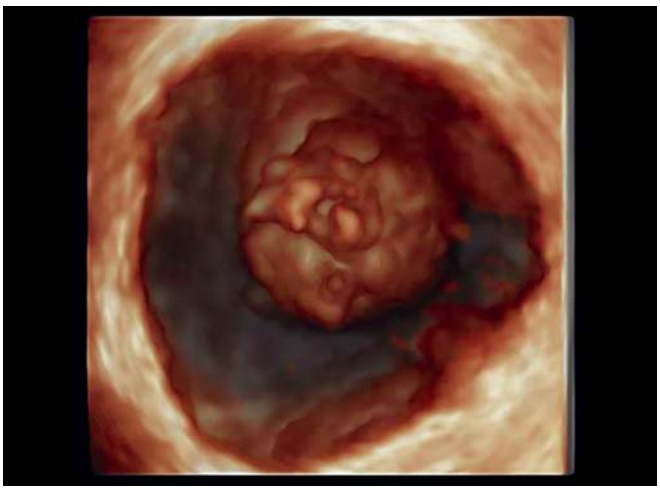


Fig. 25: Surface-rendered image of an ovarian cancer (HDlive). Within the cystic mass an irregular solid structure can be seen

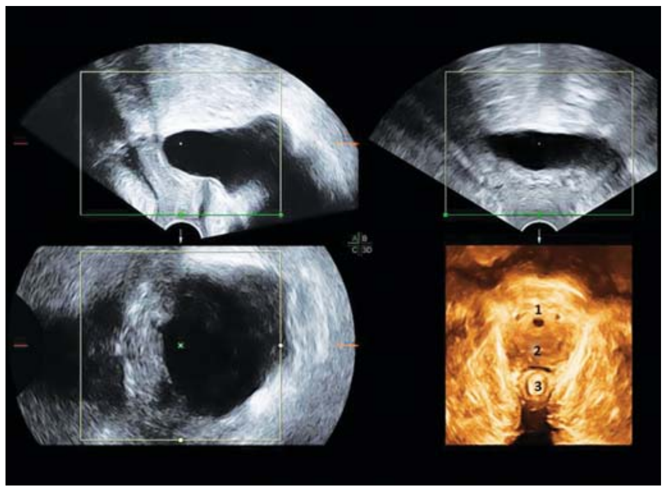


Fig. 26: Multiplanar (three orthogonal images in gray scale) and surface-rendered image of the pelvic floor, viewed from below (lower right). 1: urethra; 2: vagina; 3: rectum

3D ultrasound can be also used to obtain sonographic views of the normal (Fig. 26) and abnormal pelvic floor.[21,30,63,64]

CONCLUSION

Twenty-four years after the first introduction of 3D ultrasound into the clinical field of obstetrics and gynecology, 3D/4D sonography has experienced a wide spreading around the world. The easy handling of the ultrasound equipment, the variety of display modes after volume acquisition, the possibilities of volume manipulation and the advantage of storing volume data without any loss of quality provide the operator with an exceptional flexibility in daily routine examination. This is not only true in obstetrics but also in gynecology. However, 3D/4D ultrasound in obstetrics has the advantage that the fetus is surrounded by amniotic fluid and that the demonstration of the outer surface of the fetus provides us with phenomenal images that are comparable to the pictures known from the textbook of embryology.

Future 3D/4D developments will be dependent from the progress in computer and transducer technology.

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