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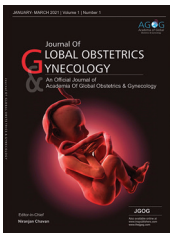
Review Article



Application of Three-dimensional Ultrasound in Obstetrics

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ABSTRACT

Ultrasound today is an indispensable tool to the obstetrician. It has been labeled as the greatest find of the millennium after anesthetics and forceps. To conceive an obstetric unit without ultrasound in this modern era is unthinkable. The rapid strides in real-time sonography and advances in color Doppler have today made it possible to study fetal blood flows, placental perfusion, and predict P.I.H. and I.U.G.R. Color has also made us time the delivery in IUGR cases. Today with the advent of the three-dimensional (3D) imaging a new dimension in obstetrics surface volume imaging, E-Ray mode has now made us study fetal surface and fetal anatomy and has improved the fetal anomaly pick up. An additional advantage has been the start of maternal fetal bondage by seeing the fetus in 3D and live 3D (4D) mode. This study has been carried out since last 6 months to study the feasibility and efficacy of 3D in routine obstetric practice in India.

Key words: 3D- Ultrasound, Color Doppler, IUGR

INTRODUCTION

Three-dimensional (3D) ultrasound involves imaging of the distribution of ultrasonic echo information in 3D space, while conventional ultrasonography applies to this imaging on a two-dimensional (2D) plane. Now 3D ultrasound is being regarded as the future of ultrasound system after color Doppler system. Voluson 530 D was the first, the only real-time digital 3D system as well as a very powerful digital CFM, and it shows the value of future diagnostic oriented system.[1]

Kretztechnik started in 1974 with the first developments dedicated to 3D ultrasound. A cylindrical-shaped transducer incorporating 25 elements mounted on a drum performed a volume scan consisting of 25 parallel slices. Today, we have many advanced 3D and 4D machines available with artificial intelligence and silhouette imaging.

It was in 1989 in Paris at the French congress of Radiology when Kretztechnik presented the first commercially available ultrasound system featuring the 3D-voluson technique (voluson-volume sonography) [Figure 1].

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In 1991, Nelson and Pretorius discussed the potential advantages of 3D ultrasound and its usefulness for fetal studies.[2] All the studies mentioned above used systems developed by the authors. The most recent development is real-time 3D ultrasound using a defocusing lens, without computer processing.[3,4]

Now addition of 4D has made possible to study 3D in live mode and understanding fetal behavior better in utero.

TECHNIQUE OF 3D

Continuous research and development of this technology led to diagnostic applications in various medical fields. The voluson system is based on several main components:

- Dedicated voluson transducers providing a fully automatic scan of a user-defined region of the patient's body. For different applications various transducers ranging from 3.5 to 10 MHz are available
- A special electronic memory to store the ultrasound data as a geometrically correct volume block
- A digital 3D scan converter for lossless and fast image processing.

Immediately after the volume scan is finished (0.5–5 s), the monitor displays three orthogonal planes, longitudinal, transverse, and coronal planes [Figure 2]. Each of these planes can be moved within the volume block for detailed analysis, either by parallel shifting (tomographic slicing) or by rotation around any of the three spatial axes. It is now possible to image reconstructed 3D

image in real time (4D) and also render in silhouette imaging and transparent modes. Furthermore, possible to add color and edit the gray image to highlight only the vasculatures.

3D ULTRASOUND IN OBSTETRICS

Early pregnancy ultrasound is performed using transvaginal probe in the first trimester.

Fetal biometry in the first trimester is often used for the estimation of gestational age. Lasser *et al.*[5] examined 144 first-trimester fetuses by transvaginal ultrasonography and showed that gestational age can be estimated much earlier and more accurately than with the transabdominal approach.

However, with the use of conventional transvaginal ultrasonography, it is sometimes difficult to obtain an optimal plane for crown-rump measurement for diagnosis. 3D ultrasound overcomes this problem and increases the accuracy of fetal biometry. Furthermore, live 3D can depict fetal movements and shilloute imaging can highlight the sac and YS and fetus much better.

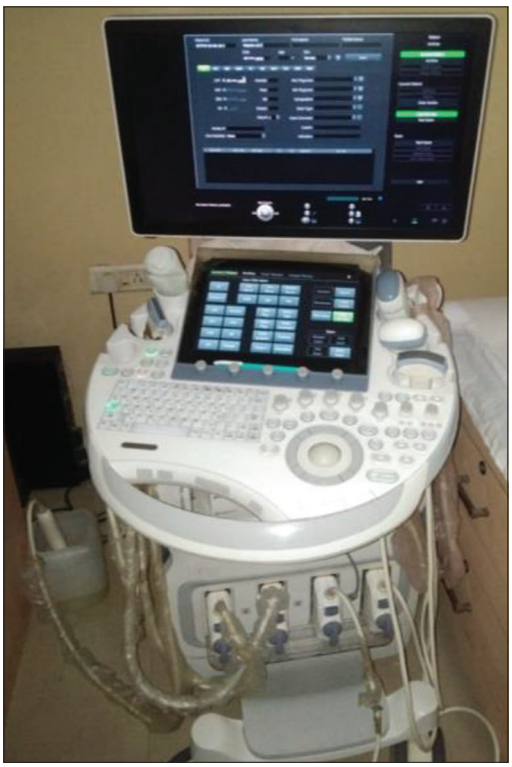

Figure 1: Ultrasound machine

3D ultrasound with transabdominal scanning in and after the late first-trimester with conventional 2D Ultrasound Scan, a general impression of fetal posture can be obtained, but it cannot be described precisely. Surface rendering in 3D ultrasound overcomes this problem.[6-8]

Early Pregnancy

The embryonic period extending from conception up to 9 weeks of gestation is very important as most major anatomical structures are formed and developed during this period. The first trimester 3D ultrasound is performed by transvaginal probe.

It is expicially useful over 2D scan in multiple gestations to identify the number of sacs, thick exact location, and viability. The gestation sac volume can also be measured accurately and may be useful indicator for outcome of pregnancy.

Steiner *et al.*[9] determined gestational sac volume in the first trimester by tracing the contour of the gestational sac using transabdominal 3D ultrasound. The normal anatomy and major anomalies can be better and earlier diagnosed by 3D TVS. 8 weeks onward the limbs and by 11 weeks the hands anf feet can be clearly visualized to rule out possible anomalies such as phocomelies amniotic band syndrome. Fetal face and spine can be well visualized from 12 weeks onward and some major anomalies such as anencephaly, encephalocele, sacral agenesis, proboscis, and anophthalmia can be ruled out. In the late second and third trimester, the volume of amniotic fluid decreases relative to fetal size and it becomes increasingly more difficult to obtain 3D images of the whole body of fetus by surface rendering.

T.V.S. 3D ultrasound can also be effectively used to asses cervical in competence in early pregnancy and to decide about the guidelines for Mc Donald stitch application or Pessary (Arabian Pessary) [Figure 3].

Fetal Head

Blaas and associates[10] obtained 3D images and calculated the volume of the brain cavities at 7–10 weeks of gestation. Contours

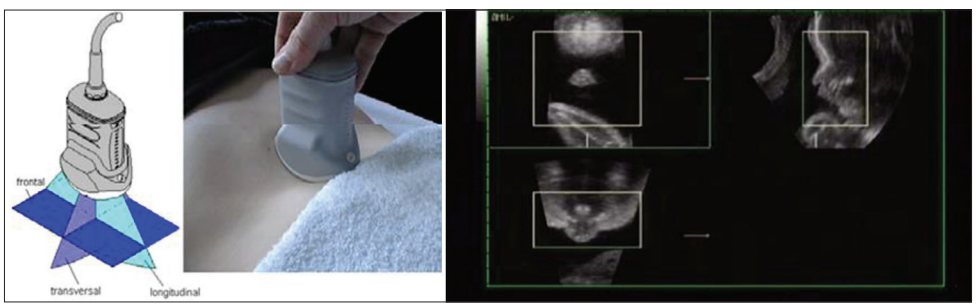

Figure 2: Multiplanar volume analysis

of the brain cavity were interactively drawn in successive 2D slices and displayed as 3D images [Figure 4].

Diagnosis of structural abnormalities such as anencephaly, encephalocele, or choroid plexus cyst can be made by 2D ultrasound. However, the defects can be better described by displaying orthogonal Triple planes simultaneously[11] [Figure 5].

The corpus callosum, which is difficult to see with 2D ultrasound, may be depicted with 3D ultrasound by constructing a section horizontal to the abdominal wall.[12]

Abnormal development of cranial sutures is seen in many dystrophic syndromes and metabolic disturbance. With 2D ultrasound, curvilinear cranial structures such as cranial sutures and fontanelles cannot be properly evaluated. This is easier with 3D Ultrasound using a volume rendering method such as the maximum intensity method[13] or defocusing lens (real-time 3D ultrasound).[14]

Fetal Face

3D ultrasound provides clear surface[4,6,8,14-17] images of the fetal face non-invasively. Images from different directions can also be obtained from 3D data,[6] with 3D ultrasound, the lips,[18] upper gum,[18] nose, and eyelids can be observed well and morphological

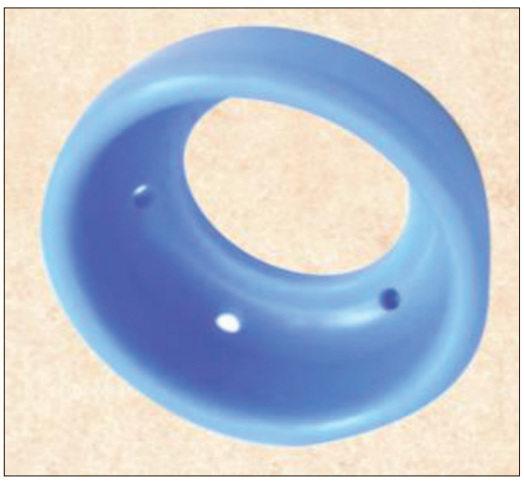

Figure 3: Arabian pessary

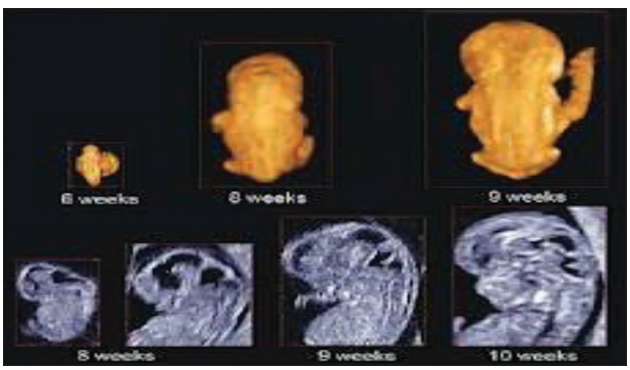

Figure 4: Brain cavities in early pregnancy

anomalies such as single hostric,[18] flat nose,[18] proboscis.[19] Cleft lip,[17-19] hypotelorism,[18] or hypertelorism can be better seen with 3D ultrasound[8,14,17] and a low set dysplastic ear can be readily diagnosed.[17] The facial origin of a fetal teratoma was confirmed on a transparent rational display.[11] Facial defects are one marker of chromosomal abnormalities[20] and 3D ultrasound may be useful for increasing the selectivity of screening [Figure 6].

Fetal Skeleton

The fetal skeleton can be observed by volume rendering, with techniques such as the transparent method and maximum intensity method.[11,15,16]

If the vertebral column is pathologically curved laterally, it is impossible to display the whole vertebral column in one tomogram. Anomalies such as scoliosis,[17] kyphosis, lordosis, and spina bifida may be overlooked by 2D ultrasound. The advantage of 3D ultrasound is the ability to visualize both curvatures at the same time [Figure 7].

Budorick *et al.*[21] reviewed the ultrasonography of the fetal spine and pointed out that the curvature of the spine, continuity of vertebral bodies and cost overtebral junctions could be observed more clearly with 3D ultrasound using the depth-cued maximum intensity method, than with 2D ultrasound [Figure 8].

The fetal thorax, ribs, vertebrae, clavicles, and sternum[22] are observed with 3D ultrasound, which is useful for diagnosing a small thorax and skeletal dysplasia related to pulmonary hypoplasia.

Fetal Cardiovascular System

In 3D ultrasound examination of the adult heart with regular rhythm, 3D data are generally acquired over a period of many heart beats, monitored by an electro cardiogram (ECG). Nelson *et al.* solved this problem using the movement of a heart wall/valve instead of the ECG, and constructed 3D images of the fetal heart without distortion due to beating [Figure 9].[23]

Smith and associates[24] developed a 2D array probe for obtaining 3D data in real-time and applied it to the fetal heart and real-time 3D ultrasound with simultaneous multisection display.

Fetal Abdomen

By surface rendering, abnormalities of the abdominal wall such as omphalocele[15,17] and gastroschisis are well demonstrated. It is possible to construct any slice nearly parallel to mother's abdominal wall in arbitrary section on orthogonal triple-section display, thus making it to observe the esophageal-gastric junction and pylorus.

3D ultrasound confirms suspected, multicystic dysplastic kidney as well as renal agenesis and the pelvi-ureteric junction[12] and ureterovesical junctions are easily observable.

Nagata *et al.*[25] developed a method for 3D reconstruction of the fetal stomach mathematically from one ultrasonogram of a longitudinally transected stomach, using the symmetry of the stomach about the central asis. The inner volume of the stomach can be measured directly from 3D data.

The volume of the bladder is also measurable.

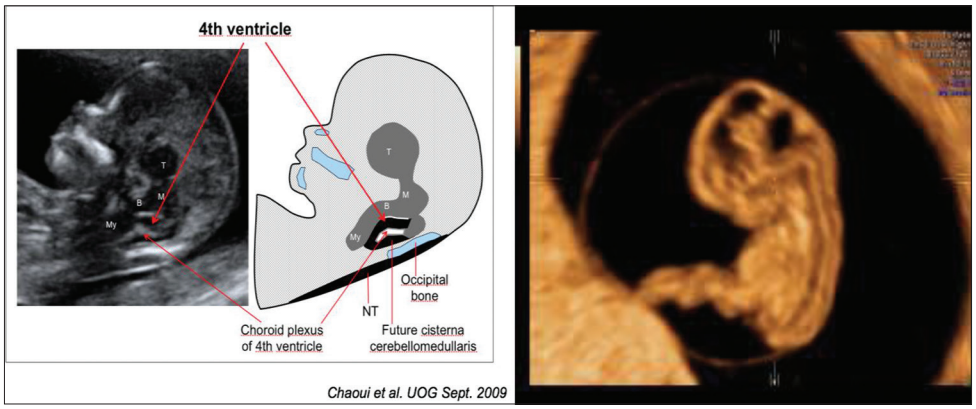

Figure 5: Orthogonal planes

Figure 6: Facial profile in Acrania/Anencephaly

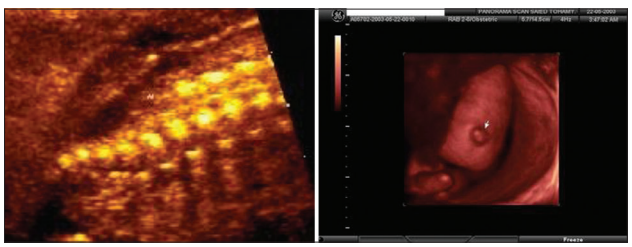

Figure 7: Three-dimensional spinal anomaly

Figure 8: Spina bifida – sagittal view

Fetal Limbs

Surface-rendered images in 3D ultrasound give clear displays of distortions of the normal anatomical axis such as club foot (talipes equinovarus)[17] and rocker-bottom feet as well as limb abnormalities such as phocomelia.[26] With 3D ultrasound, fingers are well observed[4,15] and it is thus useful for detecting overlapping fingers6, polydactyly[27] and missing phalanx or digits syndactyly [Figure 10].

With 3D ultrasound, two orthogonal sections can be displayed together. The section at the exact midpoint of the limb can be obtained with good reproducibility. Favre *et al.*[28] determined thigh circumference at the midpoint of the femur and arm circumference using 3D ultrasound and proposed a new formula for fetal weight estimation.

Fetal External Genitalia

External genitalia can be observed and malformations of the genitalia such as hermaphroditism[15] and bipartite scrotum[29] can be seen clearly by 3D ultrasound.

Estimation of Fetal Weight

Placental weight and amniotic fluid volume.

If the fetal volume can be measured accurately with 3D ultrasound, a more accurate fetal weight estimation may be possible.

With 3D ultrasound not-only fetal volume but also placental volume and amniotic fluid volume could be measured *in vivo*.

Fetoplacental Circulation

3D ultrasound shows the distributions of blood flow in the placenta. Thus, it facilitates the diagnosis of not only morphological abnormalities but also abnormalities of the distribution of blood flow [Figure 11].

LIMITATIONS OF 3D ULTRASOUND

1. The influence of movement of the object on 3D images, distortion is caused, if fetus or mother moves during the acquisition of 3D data. The movement of object, either of fetus or mother, during acquisition of 3D data, causes distortion of image formed. Hence, 3D data acquisition should be carried out — during periods of fetal rest. Merz *et al.*[17] state that

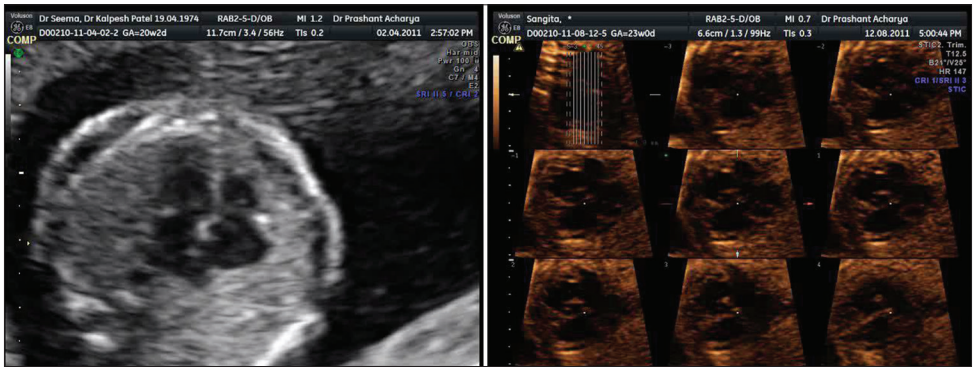

Figure 9: Fetal heart in two-dimensional and three-dimensional CT slice mode

Figure 10: Congenital talipes equinovarus, bilateral with associated fetal malformation

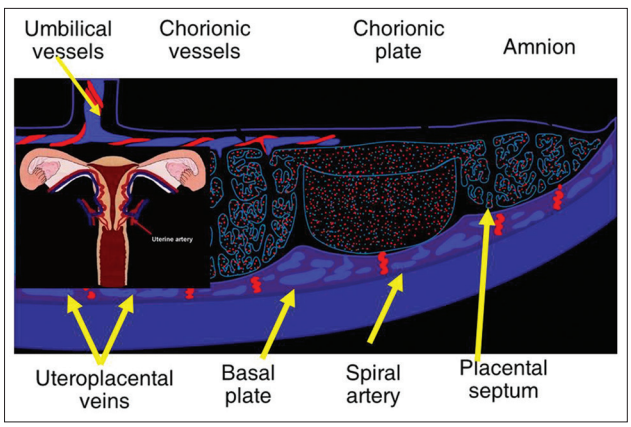

Figure 11: Uteroplacental blood flow

conventional 2D ultrasound is superior to 3D ultrasound for the assessment of cardiac anatomy

2. Artifacts and other problems in 2D also exist in 3D
3. The 3D image is not always useful for diagnosis. In cases of severe obesity or in patients with oligo hydramnios, fetal imaging not only with 2D ultrasound but with 3D ultrasound is also difficult.

Close proximity of the uterine wall or placenta to the fetus may cause overlapping and non-visualization of some fetal parts

4. Preprocessing for 3D image construction is time consuming
5. Scanning range is too narrow, only portions of fetal images can be obtained in the third trimester.

Figure 12: Feta facial expression

DISCUSSIONS

Today with high resolution 2D conventional ultrasounds makes it possible for us to detect a lot of congenital defects; however, the examiner has to mentally form a 3D impression of the fetal anatomy while scanning, this can be sometimes very difficult specially in small surface defects and also in complex malformations.

3D ultrasound allows visualization of their dimensional sculpture like images of the fetus within a few minutes.

4D allows live imaging in 3D and gives fetal neurophysiology assessment and fetal face expressions [Figure 12].

CONCLUSIONS

3D ultrasound is very useful diagnostic method in obstetrics. However, 3D ultrasound is not yet a substitute for conventional 2D ultrasound and both methods should be used together to get accurate and efficient ultrasonic diagnosis, especially of lesions of fetal surface.

SEE and HEAL WITH SOUND
TURN ON THE COLOR TO IMPROVE YOUR IMAGE
MOVE TO THE 3RD and 4TH DIMENSION

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