Basic Techniques and the Applications of Three-dimensional Ultrasound in Obstetrics

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Three-dimensional/four-dimensional ultrasound (3D/4DUS) is a new technology to provide unique images which cannot be visualised with standard two-dimensional ultrasound. Basic 3D/4D techniques including volume acquisition, multiplanar analysis, surface rendering, volumetry, power Doppler are discussed. 3D/4DUS has found clinical applications in the evaluation of various foetal structures including face, brain, spine, skeleton, extremities and heart. The benefits and disadvantages of 3D/4DUS are reviewed.
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Introduction

The use of two-dimensional ultrasound (2DUS) in obstetrics has been well established. However, there are several drawbacks of 2DUS imaging. First, the operator has to reconstruct the three-dimensional structure mentally by combining 2DUS images and the estimated position of the ultrasound probe[1]. This reconstruction process is operator dependent. Second, the reproducibility of a given image is low at a later time. Third, it may be difficult to locate or reach some of the attempted scan planes if the foetus is in an unfavourable position[2].

With the advent of three-dimensional ultrasound (3DUS) and more recently four-dimensional ultrasound (4DUS), a lot of studies have been done to evaluate their techniques and applications in obstetrics. 3DUS allows display of multiplanar images and orientations that are difficult to obtain by 2DUS[3]. Besides, surface rendering allows curved structures or organs to be viewed in a single image[1]. Compared to 2DUS, more precise volume determinations of any organ or irregularly shaped objects can be obtained using 3DUS[4]. In addition, 3DUS volume data may be used to guide precise needle placement during intervention procedures. The entire 3DUS volume data can be stored for review in the future and to assess findings which have initially been overlooked or forgotten[3].

However, it is difficult to evaluate the net effect of 3DUS on obstetric practice and outcome[5]. Most of the studies on the use of 3DUS were not randomised controlled trials. The failure rate of using 3DUS has not been emphasised. The quality of the reconstructed multiplanar images not derived from the original plane of acquisition is generally not as good as 2DUS images[6]. There are artefacts unique to 3DUS images[7]. Extra time is required if one has to perform 3DUS as well as 2DUS examinations.

The aim of this paper was to review the techniques of 3D/4DUS and their applications in obstetrics.

Basic Techniques

Volume Acquisition

A normal 3DUS examination involves volume acquisition and display. The 3DUS transducers allow automatic volume acquisition in most commercially available 3DUS systems. After localisation of the region of interest using 2DUS real-time scans, the operator activates the volume scan and the transducer sweeps

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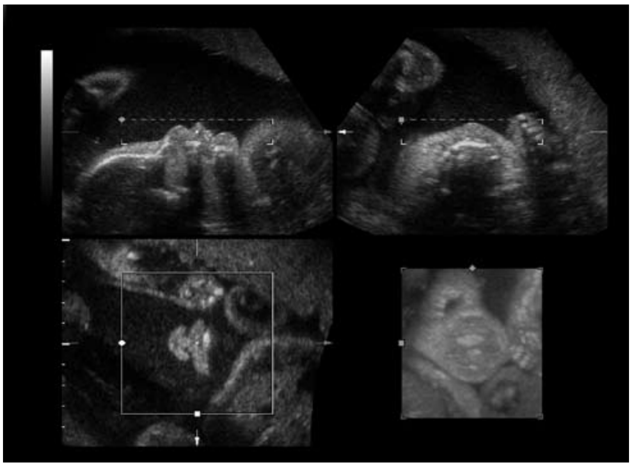

Figure 1. Three-dimensional multiplanar images (upper left, upper right, and lower left) and rendered images (lower right) of the foetal lip and palate

through the object of interest. To get a good 3D image of an object, a good 2DUS image should be obtained and an appropriate direction of view should be selected. For example, mid-sagittal view is selected for viewing the facial profile. There should be an adequate amount of liquor, but no intervening structures such as hands or an umbilical cord in front of the object. Besides, the woman should hold her breath and the operator should keep the transducer static during the acquisition process to avoid any motion artefact.

Multiplanar Images

Once the 3D volume data are stored, they can be displayed as planar and rendered images (Figure 1). Planar images are images that appear similar to conventional 2D images but can be reviewed from any orientation in the volume because the volume can be displayed in 3 orthogonal planes at right angles to each other. The addition of a 'third plane' or 'C-plane' to the examination considerably increases the chances of a thorough spatial evaluation[5]. The point where the 3 orthogonal planes intersect is marked by a dot, which is called the 'marker dot'. One can pinpoint the same exact spot or structure on the 3 planes that are being simultaneously displayed.

Surface Rendering

Surface rendering allows display of the body surface such as the face, which is the feature of 3DUS most recognisable to lay people and physicians (Figure 2)[5]. Maximum intensity or X-ray mode can be chosen to emphasise bones (Figure 3)[5], while minimal mode can be used to study blood vessels or fluid[8]. All the rendered images can be rotated to allow examination in different directions.

Figure 2. Three-dimensional rendered image of the foetal face

Figure 3. Three-dimensional rendered images (maximum mode) of the foetal upper limbs

The different display modalities enable operators to evaluate the stored volume systematically by navigating through the orthogonal planes long after the patient has left the office[5].

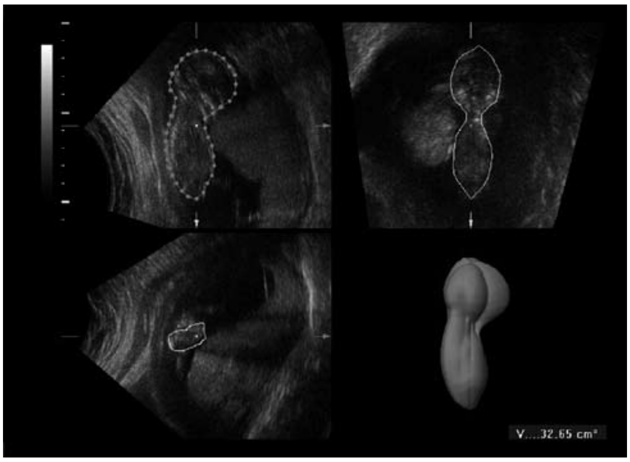

Figure 4. Three-dimensional foetal volume measurement using the rotational technique with VOCAL

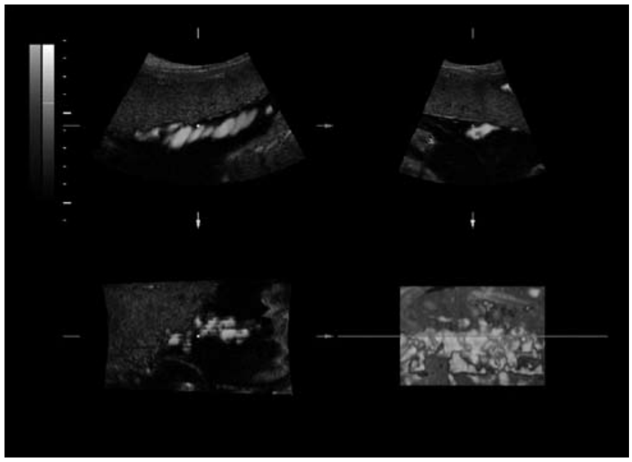

Figure 5. Three-dimensional power Doppler of umbilical cord insertion at the placenta

Three-dimensional Volumetry

It is generally accepted that 3DUS volumetry gives more precise results than 2DUS volume calculations[4]. In particular, volumetry of irregularly shaped objects benefits from 3DUS[4]. There are 2 commonly used methods for 3D volumetry: (a) multiplanar techniques, and (b) virtual organ computer-aided analysis (VOCAL) (Figure 4). 3DUS has been validated its accuracy in volume assessment, in vitro and in vivo[9-11].

Three-dimensional Power Doppler

Power Doppler ultrasound is not susceptible to aliasing, relatively angle-independent, and sensitive in detecting low-velocity blood flow, making it optimal for 3D reconstruction[12]. 3D reconstruction of Power Doppler ultrasound allows 3D visualisation of blood vessels (Figure 5) and assessment of the spatial distribution of circulation in the foetal organs, the foetal vascular system, umbilical cord and placenta[13]. Besides, the status of vascularity within a target organ or within the volume of interest can be measured because 3D power Doppler histogram analysis quantifies the Doppler signal of the volume of interest via a 3D reconstructive figure. The vascularity status is represented by 3 indices, namely vascularisation index, flow index and vascularisation flow index[14]. All these 3 indices can be calculated automatically by the VOCAL software.

Four-dimensional Ultrasound

While 3DUS is a static display of the planar and/or rendered images based upon the acquisition of a static volume, 4DUS displays a continuously updated and newly acquired volume in the planar and/or rendered images, creating the impression of a moving structure[5]. However, the frame rate of most 4DUS machines is about 4-24 per second at present and not fast enough to give real-time 3DUS images[15].

Application

First Trimester Foetal Anatomy

3DUS may assist in the evaluation of the first trimester foetus[1]. Impressive images at different embryological stages[16] and of different normal foetal structures such as the arms and face[17] can be obtained using 3DUS. The use of 3DUS in detecting a spina bifida before 10 weeks' gestation[18], alobar holoprosencepahly at 9 weeks' gestation[19] and conjoined twin in the first trimester[20] have also been reported. However, a first trimester complete anatomical survey (excluding anatomy of the heart) can be achieved in 93.7% with 2DUS compared with 80.5% using 3DUS[21]. The suboptimal image quality of 3DUS reconstructions and motion artefacts limits the diagnostic value of 3DUS in 20% of cases[21]. Although an earlier study has shown that 3DUS demonstrates higher accuracy than conventional 2DUS in the measurement of NT in the first trimester[22], this finding is not supported by a later study[1]. Volumes obtained in the longitudinal section near the midline may be used to shorten examination time. However, random volumes are not useful because of poor resolution in the C-plane.

Second and Early Third Trimester Foetal Anatomy

Several authors compared the performance of 3DUS versus 2DUS in detecting foetal anomalies, and a diagnostic advantage of 3DUS was found in 51-64% of cases[5]. However, other authors held different views. The vast majority of diagnosis described by 3DUS can reliably be made with 2DUS, and that this fact will not change in the foreseeable future[23].

The Foetal Face

Using 2DUS, a systematic examination of the foetal face requires considerable skill in image acquisition, and a diagnosis of cleft palate and lip are at times hard to make[5]. Using 3DUS, the simultaneous orthogonal planes enable the hard-to-image axial planes, and the planes for alveolar ridge and upper lip to be seen (Figure 1)[5]. Several studies have shown the beneficial effects of 3DUS over 2DUS in the evaluation of foetuses suspected of having a facial cleft[24-26]. Life-like rendered images of facial cleft were found to facilitate patient understanding[27].

The Foetal Brain and Spine

3DUS enables a reconstruction of the median plane to be made, and hence facilitates the diagnosis of agenesis of corpus callosum[28,29]. 3DUS assists in defining the severity and extent of alobar holoprosencephaly, and localisation of encephaloceles[30]. Compared to 2DUS, 3DUS allows the diagnosis of spina bifida to be made more reliably and the assessment of the level of the lesion to be determined with greater precision[31,32].

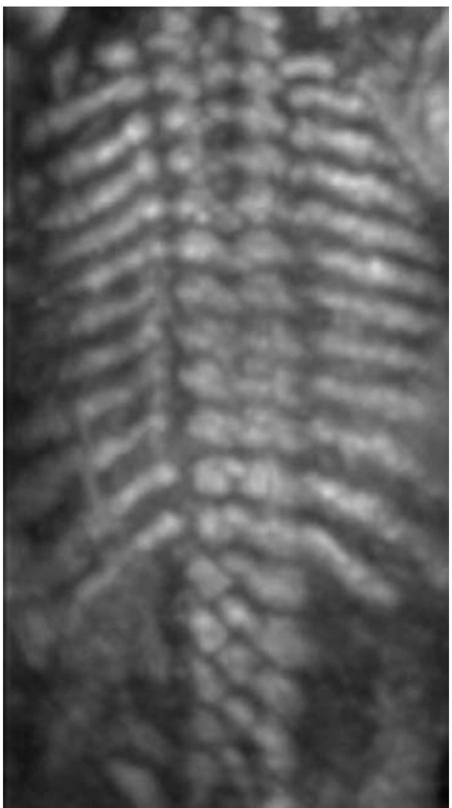

Figure 6. Three-dimensional rendered images showing the foetal spine and ribs

The Foetal Skull and Skeleton

The cranial sutures, fontanelles, vertebrae, ribs, and clavicle can be demonstrated well using 3DUS (Figure 6)[33,5]. Skeletal dysplasia can be identified with a high degree of reliability[34,35]. Besides, 3DUS provides a more comprehensive view of the skeleton than conventional 2DUS[36]. Although patient treatment is not influenced by the 3DUS results, this technique is proved to be useful by clarifying the spatial relationship of deformed limbs and by enabling the acquisition of additional information[37].

The Extremities

3DUS allows detection of club foot, polydactyly, limb contracture, micromelia, lymphangioma of the upper limb[38], and sirenomelia[39]. The 3DUS images are helpful for explanation to parents[40]. However, the assessment of the hands and feet can be limited by fast movement[41].

The Foetal Heart

The potential advantages of 3D foetal echocardiography include the ability to slice the acquired 3D volume data into an infinite number of 2D cross-sections, and the ability to reconstruct unique 3D views not seen with 2DUS[42]. In general, cardiac-gated 3DUS provides more satisfactory images of the beating heart than non-gated systems[43]. Valvular morphology and ventricular wall motion have been studied using the former system[42]. The recent advent of real-time 3DUS may overcome the need for cardiac and respiratory gating, and may minimise artefacts associated with 3D reconstruction[43].

Three-dimensional Volumetry

Several studies have been performed to assess the usefulness of 3D volumetry of different structures: gestational sac volume and pregnancy outcomes[44]; placental volume and aneuploidy[45]; foetal lung volume and pulmonary hypoplasia[46]; foetal liver volume and intrauterine growth restriction[47]; maternal cervical volume and preterm delivery[48]; volume of the thigh, abdomen and upper arm and foetal birthweight[49].

Four-dimensional Ultrasound

In 2002, Campbell[15] discussed the role of 4DUS in different areas including the study of foetal behaviours, examination of foetal extremities, maternal-foetal bonding, steep learning curve for 3D techniques, and guiding interventional procedure. It has been shown that 4DUS is superior over 2DUS for qualitative (direction), but inferior for quantitative analysis of hand movements. Besides, 4DUS is superior over 2D and 3DUS in the evaluation of complex facial activity and expression such as smiling and scowling[50].

The Bonding Effect

The ability of women, and their families to look at the 3D rendered images of the foetal body especially the face is impressive[5]. A recent prospective study on 100 women has shown that 3DUS may have a greater impact on the maternal-foetal bonding process[51]. However, a randomised study of the same size indicates that the addition of 4DUS does not change significantly the perception that women have of their baby nor their antenatal emotional attachment compared with conventional 2DUS[52].

Disadvantages

The quality of 3D images is adversely affected by foetal or maternal movements, unfavourable foetal position, advanced gestational age, multiple pregnancies, oligohydramnios, and anterior placenta[4].

Three-dimensional sonography is prone to the same types of artefact encountered in 2DUS imaging plus others unique to volume acquisition and visualisation[7]. An amniotic band can cause a shadowing artefact on the foetal face in both 2DUS and 3DUS images, and the artefact has to be differentiated from genuine facial cleft[53]. To overcome artefact, measures include acquiring optimal 2DUS images, acquiring several volumes through area of interest and multiplanar analysis, acquiring additional 3D volumes from different angles, modification of rendering parameters[7], and rescan at a later time[53].

In a study by Scharf et al[4], although 85% of 433 pregnant women were enthusiastic about 3DUS, 15% were not convinced and 5% were not able to comprehend the 3DUS images even after extensive explanation.

In conclusion, 3DUS can provide unique images in both planar and rendered format which cannot be visualised with standard 2DUS, and can assist in the examination of the foetal structures including face, brain, spine and limbs. 3DUS helps to identify the lesions more clearly and completely and make consultation with the parents more comprehensive. Compared to 2DUS, more precise volume determination of any organ or irregularly shaped objects can be obtained using 3DUS. Although 3DUS is a powerful tool, it cannot replace 2DUS but should be viewed as a complementary imaging technique.

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