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# Editorial

## Three-dimensional ultrasound in gynecology: a critical evaluation

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### INTRODUCTION

Three-dimensional ultrasound imaging has been commercially available for almost 10 years. Although this technique is no longer a novelty, debate continues about its potential clinical applications in obstetrics and gynecology. As ever, there are enthusiasts who describe many advantages of three-dimensional scanning over traditional imaging methods[1] and sceptics who see it mostly as a technology push by scientists in search of useful clinical applications[2]. There is no doubt that three-dimensional images of fetal faces *in utero* are very impressive, but the technique has yet to gain widespread acceptance amongst fetal medicine specialists. Developments in gynecological ultrasound traditionally lag behind those in obstetrics. However, with three-dimensional scanning, the pace of development has been much faster in gynecology. A few potentially useful clinical applications have been described and some of these are now gaining general acceptance[3]. I will now critically examine the clinical reports on the use of three-dimensional ultrasound published in international peer-reviewed journals so far and try to define its current role in the diagnosis of gynecological abnormalities.

### TECHNICAL CONSIDERATIONS

Three-dimensional images can be produced using a number of different methods. The simplest method is volume imaging, described by Kossoff *et al.*[4]. A cylindrical divergent lens is attached to a standard linear transducer to insonate a volume of tissue. Its only clinical application is real-time three-dimensional visualization of the fetal face and skeleton in obstetrics. The technique has not been used in gynecology because the attachment of a relatively large lens to a vaginal transducer would be difficult. Furthermore, the use of defocusing lenses decreases the quality of B-mode imaging, which is likely to affect diagnostic accuracy. The main advantage of volume imaging is the ability to produce real-time three-dimensional ultrasound images. This is of less importance in gynecology, and therefore it is unlikely that this technique will ever play a significant role in gynecological diagnosis.

More complex methods to generate three-dimensional images are based on the acquisition of a large number of consecutive tomograms through the movement of a transducer. The spatial orientation of sonograms is monitored throughout the process of acquisition and these are then stored in the computer memory as a volume set. The relative position and orientation of tomograms can be established using mechanical, electromagnetic or acoustic techniques. The volume dataset can then be examined using three methods: section reconstruction, surface rendering and volume rendering[5]. The majority of clinical studies investigating the use of three-dimensional ultrasound in gynecology have been performed using equipment designed by Kretz Technik, Zipf, Austria (Combison 530 and 730 3D Voluson). The popularity of the Kretz Technik system can be explained in part by a short volume acquisition time and fast computing, which enables almost immediate online data analysis and near real-time surface rendering. Volume acquisition with this system is performed using mechanical movement of an ultrasound transducer within the transvaginal probe. The acquired volumes are fan-shaped with a maximum angle of 130° and depth of 117 mm. This size is sufficient to include the entire uterus or a moderately enlarged ovary in a single three-dimensional volume.

An important advantage of three-dimensional ultrasound over conventional two-dimensional imaging is the ability to reconstruct and display any arbitrarily chosen section within the volume dataset. Many of these planes cannot be obtained on conventional two-dimensional sonography, as a result of the restrictions on probe movements during examination imposed by pelvic anatomy. A typical example is the examination of the uterus in the coronal plane, which can rarely be accomplished on either a transvaginal or transabdominal scan. In addition, the examination of three-dimensional volumes can be performed by displaying three orthogonal planes simultaneously, which facilitates topographic exploration of the organ of interest.

Another advantage of three-dimensional ultrasound is the ability to measure the volume of pelvic organs regardless of their shape. The accuracy of this method has been shown to be high in both *in vitro*[6] and *in vivo*[7] studies. Thus far this technique has been used to measure endometrial volume in both physiological and pathological conditions and to assess ovarian volume in women with polycystic ovarian disease[8,9].

Volume rendering is the most popular way of displaying three-dimensional volume data in obstetrics and images of fetal faces are, in the minds of many, synonymous with three-dimensional ultrasound. In gynecology this type of imaging has attracted much less interest. This may be due to the relative simplicity of uterine and ovarian anatomy, which can be easily comprehended on two-dimensional displays. The morphology of ovarian tumors is often non-specific and relying on the image analysis alone does not always provide all the information necessary for achieving a correct diagnosis. However, more recent reports indicate that surface rendering of ovarian tumors may be of diagnostic value[3].

Three-dimensional ultrasound imaging, however, is not without significant limitations, and these have largely been responsible for its slow acceptance. A major limitation is the lack of real-time information which is of particular importance in obstetrics. Fetal movements and maternal cardiac pulsation often cause extensive movement artifacts, which seriously impede the quality of three-dimensional volumes. Furthermore, fetal skeletal parts, limbs and spine, often overlie other organs of interest, causing extensive shadowing and poor quality of three-dimensional images. The large size of the fetus and smaller amount of amniotic fluid later in pregnancy also interfere with the quality of examination.

These limitations are of less importance in gynecology. The pelvic organs are relatively stationary and movement artifacts are rarely a problem. In addition, real-time information is of little value in gynecology and its absence does not significantly affect the quality of examination. With transvaginal examination the ultrasound probe can be placed very close to the organ of interest with no intervening tissue lying between them, which helps to maintain the clarity of three-dimensional images. It is almost certain that these technical differences have been responsible for the much better acceptance of three-dimensional ultrasound in gynecology.

## THREE-DIMENSIONAL ULTRASOUND OF THE UTERUS

### Diagnosis of congenital uterine anomalies

The uterus is easily accessible on transvaginal ultrasound examination due to its close proximity to the vagina and its relatively small size. This enables detection of a range of uterine abnormalities such as fibroids or endometrial polyps, which are often responsible for clinical symptoms. The limited number of scanning planes on transvaginal ultrasound examination interferes very little with the diagnosis of acquired uterine abnormalities, but it causes major difficulties in cases of congenital uterine anomalies. In order to describe a uterine anomaly it is necessary to visualize both the uterine fundus and the serosal outline in the coronal plane. This plane is rarely obtained on conventional transvaginal two-dimensional scans, and therefore invasive procedures, such as hysterosalpingography, hysteroscopy and laparoscopy, have been used routinely for the diagnosis of congenital uterine anomalies. Because of the invasive nature of these procedures, congenital uterine anomalies had only been diagnosed in women with a history of infertility or recurrent miscarriage, and their true prevalence in the general population was unknown.

The coronal uterine plane can be easily obtained in the majority of women using the section reconstruction method of a three-dimensional volume. The optimal time to examine patients for the presence of uterine anomalies is in the luteal phase of the cycle when the endometrium appears thick and echogenic and the uterine cavity can be clearly differentiated from the surrounding myometrium.

Two studies have examined the diagnostic accuracy of two-dimensional and three-dimensional ultrasound, using hysterosalpingography as a gold standard for the diagnosis of congenital uterine anomalies[10,11]. The first[10] included 61 high-risk patients with a history of recurrent miscarriage or infertility. There was complete agreement between three-dimensional ultrasound and hysterosalpingography in classifying the uterus as normal or abnormal. This result was superior to that of two-dimensional ultrasound, which also detected all cases of anomalies, but gave a number of false-positive findings.

Similar results were reported by Raga *et al.*[11] who compared three-dimensional ultrasound findings with those of hysterosalpingography and laparoscopy. There was complete agreement between three-dimensional ultrasound and hysterosalpingography in all 44 cases. In one of 12 cases of congenital uterine anomalies the description of uterine fundus on three-dimensional ultrasound examination was different from the findings at laparoscopy. The value of three-dimensional ultrasound for the diagnosis of uterine anomalies was also supported by Merz[12] who found it helpful in 20 cases of suspected anomalies.

The non-invasiveness of three-dimensional ultrasound has enabled the first large-scale screening studies of low-risk women for the presence of uterine anomalies. The reported prevalence of major uterine anomalies was 2.3%[13] which is similar to the results of other studies based on the use of combined invasive tests[14–16]. For the first time, we are also able to study the impact of uterine anomalies on reproductive outcome in the low-risk population. The initial results confirmed that the risk of first-trimester miscarriage is increased in women with a subseptate uterus, although the risk of miscarriage was much less than that suggested by previous studies of high-risk women[17].

These results indicate that three-dimensional ultrasound may be used as an alternative to invasive diagnostic methods for the diagnosis of congenital uterine anomalies. The test is relatively simple, non-invasive, fast and carries no anesthetic or surgical risks. However, it is unlikely that three-dimensional ultrasound equipment will be widely available in the immediate future. Therefore, two-dimensional ultrasound should continue to be used as the first-stage screening test. Only those women with suspected anomalies on two-dimensional scan should be referred for a detailed three-dimensional scan.

In routine clinical practice, screening for uterine anomalies should be limited at present to high-risk women with a history of recurrent miscarriage or infertility. There are several reasons for this. Firstly, using two-dimensional ultrasound as a screening test, a false-positive diagnosis of uterine anomaly occurs in approximately 6% of women, which could cause a significant workload for tertiary referral centers. In addition, there is very limited information on the reproductive risks associated with an incidental diagnosis of congenital uterine anomaly[17]. There is also no evidence that surgical correction of an incidentally diagnosed uterine anomaly is helpful.

Another problem, which should be addressed before the routine use of three-dimensional scanning for uterine anomalies is recommended, is the reproducibility of the diagnosis of uterine abnormalities. None of the studies published so far has included a formal assessment of diagnostic reproducibility. There is also no agreement on the criteria to diagnose different types of anomalies. The need to address this issue is clearly illustrated by the large variation in the prevalence of uterine anomalies between different studies using three-dimensional ultrasound. For example, in a population of women with a history of infertility, Raga *et al.*[16] found uterine anomalies in 54 of 868 cases (6.3%). Only 17 women (2%) in their population had subseptate uterus. In contrast, in a study by Kupesic and Kurjak[18,19] subseptate uterus was diagnosed in 278 of 420 infertile women (66.2%). These differences cannot be explained by the variations in study populations and it is almost certain that the researchers used different criteria to diagnose a uterine septum.

## Uterine fibroids and polyps

One of the main objectives of ultrasound examination of women with a history of abnormal vaginal bleeding is the differentiation between focal and global endometrial pathology. Women with diffuse lesions could be managed in an outpatient setting using endometrial biopsy to exclude sinister endometrial pathology. In contrast, women with focal lesions, such as polyps and fibroids, should be offered formal operative hysteroscopy and resection of the tumor. Although there are reports showing that two-dimensional B-mode transvaginal sonography is both a sensitive and specific method for the diagnosis of focal uterine pathology[20], others believe that the diagnostic accuracy could be improved by the injection of saline into the uterine cavity (saline contrast sonohysterography)[21,22]. This debate has now been extended into the field of three-dimensional ultrasound.

Bonilla-Musoles *et al.*[23] investigated 36 women with postmenopausal bleeding using conventional transvaginal sonography, hysterosalpingography, hysteroscopy and three-dimensional sonohysterography. In all four women with focal lesions, three-dimensional sonohysterography achieved the correct diagnosis, whilst conventional sonography missed two of four polyps. In another study of 23 women with endometrial polyps, La-Torre[24] showed that the specificity of the conventional ultrasound scan was only 69%. This could be improved to 88% with the use of three-dimensional ultrasound and to 100% when three-dimensional sonohysterography was used. In contrast, Ayida *et al.*[25] concluded that three-dimensional saline contrast sonohysterography does not add any further information to two-dimensional saline contrast sonohysterography; a similar conclusion was also reached by Cosmi *et al.*[26]. All of the studies investigating the value of three-dimensional sonohysterography included a very small number of patients and we must wait for much larger trials before reaching a final conclusion about the benefits of this new technique.

In recent years hysteroscopic resection of submucous fibroids has become an accepted method for treating premenopausal women with a history of abnormal uterine bleeding. The success and safety of this operation depends largely on the accurate preoperative assessment of the position of the submucous fibroid in relation to the uterine cavity. The European Society of Hysteroscopy has agreed on a classification of submucous fibroids, which takes into account the degree of intramural extension of the fibroid. All fibroids with > 50% of their volume protruding into the uterine cavity are deemed suitable for hysteroscopic resection[27]. The gold standard for assessing the suitability of a fibroid for resection is diagnostic hysteroscopy. However, hysteroscopy is an operator-dependent, subjective and invasive method with uncertain reproducibility. Vercellini *et al.*[20] examined the degree of agreement between transvaginal sonography and hysteroscopy in the preoperative assessment of submucous fibroids. The agreement between the two methods was fair (kappa, 0.48) with sonography showing a tendency to underestimate the degree of myometrial extension. However, only 69% of women deemed suitable for myomectomy, based on hysteroscopic assessment, had fibroids successfully removed using this technique. Although the reasons for this discrepancy were not discussed in the paper, it is clear that hysteroscopy may not be the best method for the preoperative assessment of submucous fibroids.

Weinraub *et al.*[28] were first to report on the technique of three-dimensional saline contrast sonohysterography with surface rendering for the diagnosis of uterine abnormalities. They showed that this technique provides a comprehensive view of the uterine surface area and it facilitates the measurement of intracavitary abnormalities and assessment of their relationship to the surrounding structures (Figure 1).

Pretorius *et al.*[29] recently compared the location of submucous uterine fibroids on three-dimensional saline contrast sonohysterography with the outcome of hysteroscopic resection of the fibroids. The resection was performed in 21/45 (47%) women with fibroids described on three-dimensional scan as being operable, and only in 2/39 (5%) women with unfavorable ultrasound findings. Although the study was retrospective and no follow-up visits were arranged to assess the completeness of fibroid resection, it provides the first objective evidence on the potential value

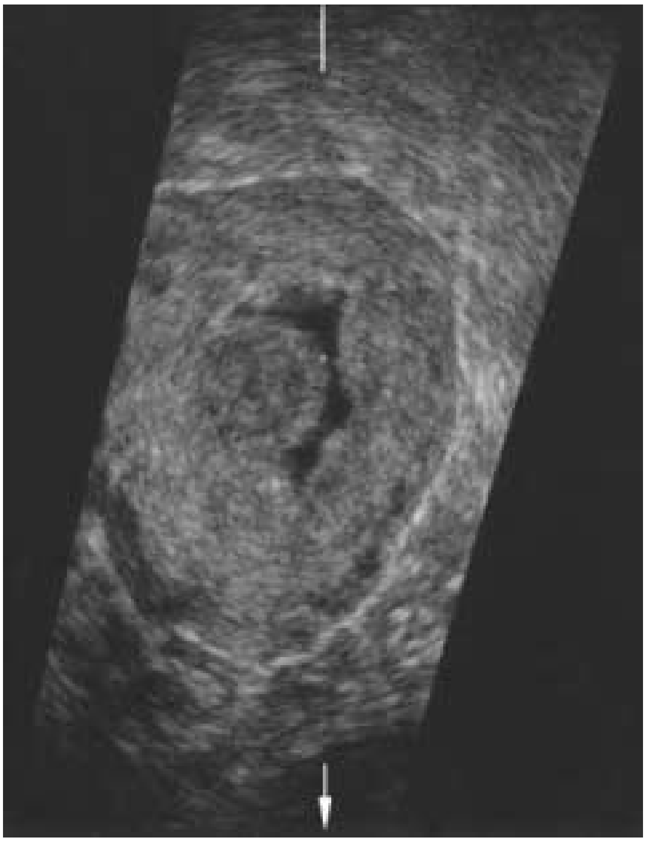

**Figure 1** Submucous uterine fibroids examined by three-dimensional saline contrast sonohysterography. The position of the fibroid in relation to the uterine cavity is clearly displayed.

of three-dimensional ultrasound in the preoperative assessment of uterine fibroids.

Another advantage of this technique is the possibility of joint reviews of three-dimensional findings by sonographers and operating surgeons, which could further improve patient selection and planning of operative hysteroscopy. In my opinion, the assessment of fibroids has the potential to become the most important indication for the use of three-dimensional ultrasound in gynecology, and I look forward to further studies which should examine its value in more detail.

## Endometrial assessment

With two-dimensional ultrasound, endometrial volume can only be estimated by measuring three perpendicular diameters and using the calculation for the volume of an ovoid. However, the shape of the uterine cavity rarely resembles the ideal ovoid and therefore measurements of endometrial volume with two-dimensional ultrasound are notoriously inaccurate[30]. Volume estimations on three-dimensional ultrasound are performed by outlining the boundaries of the organ of interest on planar reformatted sections. A number of sections 1–2 mm apart are delineated by the examiner and the volume is calculated by the in-built computer program. Two studies have been published which have shown that three-dimensional endometrial volume measurements are highly reproducible[7,31]. It is impossible, however, to assess the absolute accuracy of these measurements either *in vivo* or *in vitro*. However, the data obtained *in vitro* using phantoms reveals that measurements of small irregular volumes can be accurately performed using three-dimensional ultrasound[6].

Lee *et al.*[8] studied endometrial volume changes in 18 healthy volunteers throughout normal ovulatory menstrual cycles. The endometrial volume ranged between 0.25 and 5.5 mL with wide variations between individuals. As expected the uterus/endometrium volume ratio was highest on day 1 of the menstrual cycle and lowest in the mid-luteal phase. Potential clinical applications of endometrial volume measurements in infertile women have been examined by Schild *et al.*[32]. They compared the value of endometrial thickness and volume measurements in predicting the likelihood of successful conception in *in-vitro* fertilization (IVF) cycles after down regulation. Unfortunately, there was a large overlap between women who conceived and those who did not, and the authors concluded that volume estimation of the endometrium is unlikely to be helpful in such women. Similar findings were reported in two other more recent studies[33,34].

The value of endometrial volume measurement for the diagnosis of endometrial cancer in symptomatic postmenopausal women has been reported by Gruboeck *et al.*[31]. In a group of 103 women, the diagnosis of endometrial cancer was made with a sensitivity of 100% and a specificity of 98% using endometrial volume measurement with a cut-off level of 13 mL. This compared favorably with endometrial thickness measurement, which achieved a sensitivity of 83% and specificity of 88% at the optimal cut-off level of 15 mm. However, in a prospective evaluation of these cut-off levels in 201 patients, the sensitivity of endometrial volume measurement for the diagnosis of endometrial cancer was only 70%. The sensitivity of endometrial thickness measurement was exactly the same, although the specificity of volume measurement was better (98% vs. 88%; unpublished data). These results indicate that volume measurement may at best play a very limited role in the diagnosis of endometrial abnormalities.

Another potential application of endometrial volume measurement is in the preoperative staging of endometrial cancer. Although, there is some indication that the endometrial volume is lower in early well-differentiated cancer, more work is needed to establish the potential clinical value of this observation[31].

## Location of intrauterine contraceptive devices

Three-dimensional ultrasound offers additional information in women using intrauterine contraceptive devices (IUCDs). Using planar reformatted sections of a three-dimensional volume it is possible to visualize the IUCD fully, including the shaft and arms, in the majority of cases[35]. This enables easy identification of the type of IUCD and helps to determine the exact position of the IUCD within the uterine cavity. The visualization of the IUCD is further improved by performing the examination in volume rendering mode. This is particularly helpful when the IUCD is distorted within the uterus and the arms and shaft cannot be seen in a single plane (Figure 2).

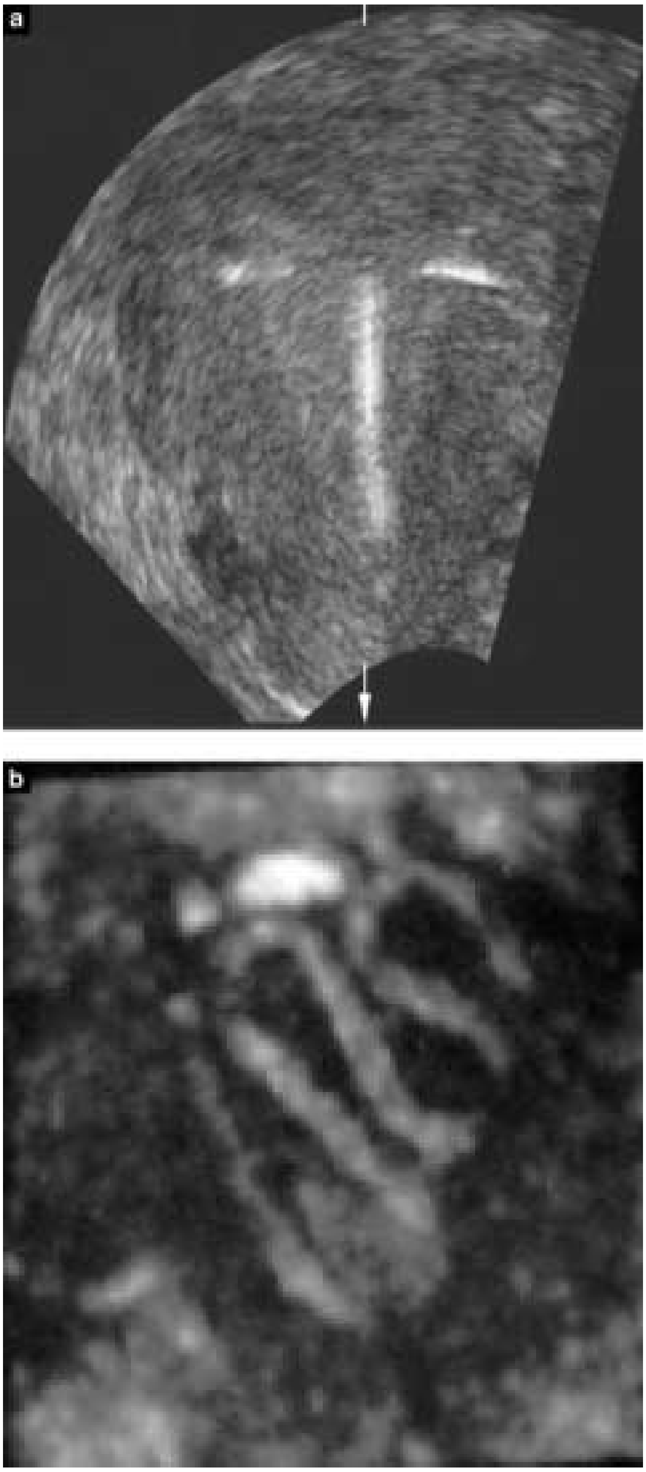

**Figure 2** Images of Gynae T (a) and Lippes loop (b) intrauterine devices obtained by three-dimensional ultrasound.

A comparative study between two-dimensional and three-dimensional sonography for the location of IUCDs was published by Bonilla-Musoles *et al.*[36]. They examined 66 women and found that the type of the IUCD was wrongly classified in 42% of cases by two-dimensional sonography when the results were compared to the findings at hysteroscopy. In contrast, there was complete agreement between three-dimensional ultrasound and hysteroscopic findings. Similarly, the location of the IUCD within the uterine cavity was established much more accurately using three-dimensional ultrasound. However, two-dimensional and three-dimensional ultrasound were equally effective in the detection of abnormal displacement of the IUCD towards the cervical canal, which is the most common reason for failure of the contraceptive. The main criticism of this study is the unusually poor performance of transvaginal two-dimensional sonography in women with IUCDs. Even so, the ability of three-dimensional sonography to describe the type of the IUCD and its exact position within the uterine cavity is unlikely to translate into any major clinical advantage. However, if the standard of routine ultrasound examination is low, the use of three-dimensional scanning may help to reduce the number of operator-dependent errors.

## THREE-DIMENSIONAL ULTRASOUND OF THE OVARIES

### Follicular development and anovulation

Two studies of IVF patients have demonstrated that three-dimensional ultrasound volume measurements correlate better with the volume of aspirated follicular fluid than do volume calculations based on conventional two-dimensional measurements[37,38]. However, no evidence has been provided so far to show that this increase in the accuracy of volume measurements would contribute to an increased success of IVF cycles. Another study showed that the visualization of the cumulus oophorus in the ovarian follicle prior to aspiration and *in vitro* fertilization correlates well with the number of retrieved oocytes[39]. The study did not, however, assess the reproducibility of three-dimensional ultrasound diagnosis of the cumulus oophorus; neither did it include a formal comparison between the different two-dimensional and three-dimensional parameters which are used to assess follicular maturity. Once this information is available, the role of cumulus visualization in IVF may be better defined.

Increased ovarian volume is one of the morphological criteria used to diagnose polycystic ovaries on ultrasound scan. A three-dimensional ultrasound study by Kyei-Mensah *et al.*[40] showed that women with polycystic ovaries have an increased stromal volume compared to women with normal ovaries, whilst the follicular volume was not different between these two groups. There was also a positive correlation found between serum androstenedione and stromal volume in women with polycystic ovary syndrome. Similar findings have also been reported by Wu *et al.*[41]. These results indicate that three-dimensional ultrasound may facilitate a more objective approach to ovarian stromal assessment and improve our understanding of the pathophysiology of polycystic ovaries.

### Adnexal tumors

A major effort has been made in the last two decades to improve the accuracy of the preoperative characterization of adnexal tumors by ultrasound[42,43]. Despite many publications, often with very encouraging results, there remains a degree of scepticism regarding the value of ultrasound for the diagnosis of ovarian cancer[44]. The main difficulty in assessing ovarian tumors lies in the wide range of their histological types and the

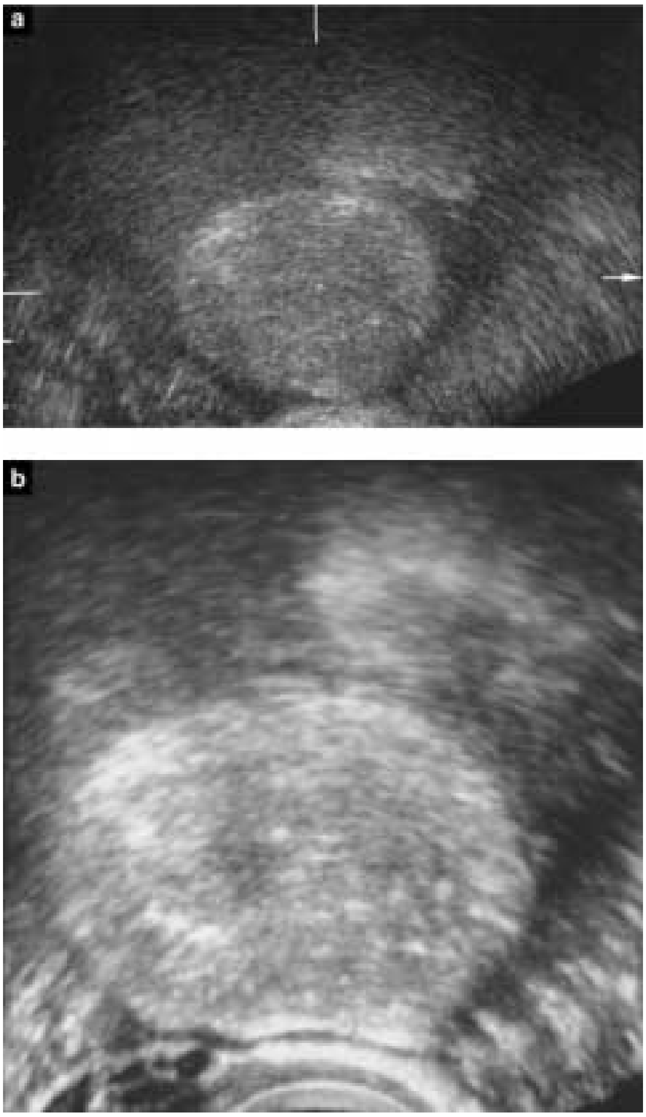

**Figure 3** A benign dermoid cyst shown on two-dimensional B-mode ultrasound (a) and on three-dimensional volume rendering mode (b). Although the internal echoes are more clearly displayed on three-dimensional ultrasound, there is little difference in the diagnostic information provided by the two imaging modalities.

variability of morphological features within the individual groups of tumors. The assessment of adnexal tumors is further complicated by the ovarian functional changes which occur during a woman's reproductive years and by tumors of low malignant potential, which share many features of both benign and malignant tumors, causing diagnostic problems to sonographers and pathologists alike. Further problems are a lack of general agreement on the description of the morphological features of ovarian tumors detected on ultrasound scan, differences in the quality of ultrasound equipment and the varying degree of operators' expertise. An international collaboration has recently been established to address some of these issues and to promote the concept of combining various diagnostic parameters to develop a diagnostic model in order to improve the non-invasive diagnosis of ovarian cancer[45].

Two studies have explored a possible role for the morphological analysis of ovarian tumors on three-dimensional ultrasound in the diagnosis of ovarian cancer[46,47]. They both compared three-dimensional ultrasound to two-dimensional scanning, rather than trying to identify the specific diagnostic features provided by either modality which discriminate best between different types of ovarian tumors. The number of invasive epithelial ovarian cancers was small, and they included only one tumor of low malignant potential and no cases of non-epithelial tumors. Both studies concluded that three-dimensional ultrasound is superior to conventional scanning in the assessment of adnexal masses. However, there were major differences between the studies in terms of patient population and the methods used to diagnose ovarian cancer. The diagnostic criteria were defined arbitrarily with no attempt to investigate their reproducibility. The study by Hata *et al.*[47] was performed transabdominally using a new '3D score', whilst Bonilla-Musoles *et al.*[46] performed transvaginal morphological analysis of tumors using their own scoring system. The main reasons for improved diagnostic accuracy of three-dimensional ultrasound were an improved visualization of echogenic foci in dermoid cysts and an increased ability to identify papillary projections arising from the cyst wall. However, one may argue that in experienced hands the diagnosis of dermoid cyst can be made reliably on two-dimensional B-mode scan and that the presence of papillary proliferation alone, being present in up to 26% of benign masses[48], is a poor discriminator between malignant and benign tumors (Figure 3).

Another technique, which may be used to examine adnexal masses, is three-dimensional power Doppler. This method was described by Kurjak and collaborators in a series of articles involving a total of 286 patients and 54 invasive epithelial cancers (18%)[49–52]. The first two studies used a complex three-dimensional scoring system to diagnose cancers, which included morphological features of the tumors depicted on B-mode imaging and the vessel architecture and branching pattern as seen on three-dimensional power Doppler. In both studies three-dimensional ultrasound achieved a sensitivity of 100% for the diagnosis of ovarian cancer and specificities of 98.8% and 99.1%, respectively[49,50].

The two subsequent studies assessed the diagnostic accuracy of three-dimensional power Doppler before and after injection of an ultrasound contrast agent[51,52]. In these studies the only criterion used to diagnose malignancy was the vascular pattern distribution as seen on three-dimensional ultrasound, with no reference to clinical, B-mode or conventional Doppler findings. In contrast to previous reports, non-enhanced three-dimensional power Doppler performed rather badly, reaching sensitivities of 58.3% and 60%, respectively. However, enhanced Doppler was 100% sensitive in both studies[51,52].

Although these results are impressive, the methods which were used are extremely complex and time-consuming. They require not only sophisticated ultrasound equipment, but also a high level of individual sonographer skill. As in other three-dimensional ultrasound studies of adnexal masses, there are no data on the reproducibility of the three-dimensional Doppler scoring systems or on the statistical methods which were used to select the individual diagnostic parameters. The acquisition times of three-dimensional power Doppler range between 30 and 60 s, which increases the likelihood of the image being affected by motion artifacts. Three-dimensional power Doppler itself is also prone to gaining artifacts, which may further compromise the quality of diagnostic information[53].

The study populations were also unusual, with no cases of borderline, non-epithelial or metastatic ovarian tumors. The absence of these 'difficult' tumors may explain to some extent the high diagnostic accuracy of three-dimensional ultrasound. It is also remarkable that amongst 232 benign lesions in this series there were only six false-positive findings. A single case of cystadenofibroma gave a false-positive result in every paper in the series, whilst an additional fibroma gave false-positive results in two studies using the contrast agent. This is slightly disappointing, as these tumors are also difficult to classify on conventional two-dimensional scans. In view of all these facts it is unlikely that other centers will successfully reproduce these results.

Despite the initial enthusiasm of dedicated researchers it is almost certain that three-dimensional ultrasound will not replace clinical assessment, two-dimensional morphology, Doppler and tumor markers for the diagnosis of ovarian cancer. Although there is no doubt that surface rendering mode provides a new and exciting insight into the morphology of ovarian cysts[54] it will take many years to acquire the necessary skills to interpret these images and even longer to define their value for the discrimination between different types of adnexal tumors. However, rather than engaging in a futile debate about the relative merits of different diagnostic techniques, efforts should focus on the identification of specific diagnostic information provided by three-dimensional ultrasound. This in combination with demographic, clinical and other diagnostic data could significantly add to our ability to correctly characterize adnexal masses.

## OTHER APPLICATIONS OF THREE-DIMENSIONAL ULTRASOUND IN GYNECOLOGY

### Tubal patency

Assessment of tubal patency is traditionally performed as part of the routine investigation of infertile couples. Until recently, hysterosalpingography and laparoscopy were the only methods which could provide reliable information about the condition of Fallopian tubes. Randolph *et al.*[55] were the first to examine the potential value of ultrasound in the assessment of tubal patency. In the last decade hysterosalpingocontrast sonography (HyCoSy) has been described as an acceptable alternative method of tubal assessment[56].

However, there are limitations with this technique, including the inability to visualize the whole tube in one scanning plane, difficulties in identifying the fimbrial end of the tube and problems in confirming the free spread of contrast fluid into the abdominal cavity. Sladkevicius[57] was the first to suggest that the use of three-dimensional power Doppler ultrasound, instead of conventional scanning, might help to overcome some of these problems. Flow of contrast through the tube is detected by power Doppler providing a tubal cast which can be captured and displayed within a three-dimensional ultrasound volume. Kiyokawa *et al.*[58] recently conducted a formal assessment of the value of three-dimensional saline HyCoSy (3D-HyCoSy) for the assessment of tubal patency in comparison to X-ray hysterosalpingography. They confirmed that the entire tubal length could be clearly seen on three-dimensional scan and that the whole procedure is faster and better tolerated than hysterosalpingography. However, a high false-positive rate of tubal occlusion, which has been reported with conventional HyCoSy, also affected the diagnostic performance of 3D-HyCoSy, decreasing the sensitivity of the diagnosis of tubal patency to 83%. In all cases in which the tubes appeared patent on 3D-HyCoSy, this was confirmed by hysterosalpingography, giving a specificity of 100%. These results indicated that a comparative study between conventional two-dimensional and three-dimensional HyCoSy was needed to see whether the theoretical advantages of the three-dimensional technique are reflected in increased diagnostic accuracy.

Such a study was conducted by Sladkevicius *et al.*[59] who used a positive contrast medium (Echovist-200) instead of normal saline to check tubal patency in 67 infertile women. They showed that visualization rates of the proximal part of the tube were similar on two-dimensional and three-dimensional ultrasound examinations. However, with three-dimensional power Doppler, free spill from the fimbrial end of the tube could be seen in 85% of cases compared to in 43% using conventional HyCoSy. Other advantages of three-dimensional power Doppler were the shorter procedure time, use of less contrast medium and the option of data storage and re-examination. In view of these promising results the authors concluded that a large-scale randomized study of three-dimensional power Doppler, X-ray hysterosalpingography and laparoscopy is justified in order to establish the role of each of these techniques in the investigation of infertile women.

### Cervical cancer

The role of ultrasound in the diagnosis of cervical cancer is limited. However, two studies have investigated the potential role of three-dimensional scanning in the assessment of this condition. Chou *et al.*[60] have shown that three-dimensional volume measurement of cervical cancer correlates better with the volume of pathological specimens compared with the volume estimates based on the measurements of three orthogonal diameters from two-dimensional scans. In another study of eight patients, Suren *et al.*[61] observed that the vascular architecture of benign and malignant cervical abnormalities appeared different on three-dimensional power Doppler. However, it remains to be seen whether either of these observations will find a role in the assessment of women with cervical disease.

### Ectopic pregnancy

Rempen[62] recently noted that the shape of the uterine cavity on three-dimensional scan is asymmetrical in women with an intrauterine pregnancy and symmetrical in those with an ectopic pregnancy. However, with the use of modern two-dimensional transvaginal probes, the diagnosis of an ectopic pregnancy should be based on the direct visualization of a gestational sac outside the uterine cavity, rather than on the assessment of uterine changes. In this context the observation by Rempen is of little clinical value, but it may be helpful in units where general standards of scanning are low, resulting in poor detection of ectopic pregnancies.

An interstitial pregnancy is located close to the uterine cavity and it is sometimes difficult to differentiate it from an intrauterine pregnancy implanted high in the lateral aspect of the uterine cavity. Examination of the uterus in the coronal plane facilitates assessment of the position of the gestational sac in relation to the uterine cavity and it may be used in rare cases when the differential diagnosis between an intrauterine and an ectopic pregnancy is difficult[63].

## CONCLUSION

Three-dimensional ultrasound is the most recent major development in ultrasound imaging, providing a new and unique way of displaying ultrasound data. In view of this it is almost certain that the option of three-dimensional imaging will be integrated in all future top-of-the-range ultrasound machines. However, three-dimensional ultrasound is not going to fundamentally change the way in which ultrasound examination is performed; neither will it cause a revolution in ultrasound diagnosis.

The development of three-dimensional ultrasound will probably follow a similar pattern to that of color Doppler, which provides useful additional information to B-mode imaging in many cases, but is rarely critical in reaching the correct diagnosis. Experience with three-dimensional ultrasound in gynecology so far has shown that the greatest diagnostic improvements should be expected in the diagnosis of uterine pathology and tubal patency. This is encouraging as color Doppler has made little impact on the diagnosis of uterine abnormalities, and the ultrasound assessment of uterine morphology has not significantly changed since the introduction of static B-mode imaging into clinical practice many years ago. However, it will take a few more years before the place of three-dimensional ultrasound in gynecological diagnosis can be defined more precisely.

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