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The current status of three-dimensional ultrasonography in gynaecology

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REVIEW ARTICLE

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Ultrasonography (US) is the most recent cross-sectional imaging modality to acquire three-dimensional (3D) capabilities. The reconstruction of volumetric US data for multiplanar display took a significantly longer time to develop in comparison with computed tomography and magnetic resonance imaging. The current equipment for 3D-US is capable of producing high-resolution images in three different planes, including real-time surface-rendered images. The use of 3D-US in gynaecology was accelerated through the development of the endovaginal volume transducer, which allows the automated acquisition of volumetric US data. Although initially considered an adjunct to two-dimensional US, 3D-US is now the imaging modality of choice for the assessment of Müllerian duct anomalies and the location of intrauterine devices.

Keywords: Ultrasonography; Imaging, three-dimensional; Gynecology; Müllerian ducts; Intrauterine devices

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Introduction

Ultrasound is the most recent cross-sectional imaging modality to acquire three-dimensional (3D) capabilities. In comparison with computed tomography (CT) and magnetic resonance imaging (MRI), the ability to perform multiplanar reconstruction from volumetric ultrasound data was developed significantly more slowly. Current equipment, however, is able to produce high-resolution diagnostic images in three dimensions, including real-time surface-rendered images, whereas CT and MRI still have limited real-time imaging capabilities.

The application of 3D ultrasonography in gynaecology was accelerated with the development of the endovaginal volume transducer. Although initially considered an adjunct to two-dimensional (2D) transvaginal ultrasonography, 3D ultrasonography is now the imaging modality of choice for the assessment of Müllerian duct anomalies and the location of intrauterine devices (IUDs). Its applications in clinical practice continue to expand as new volumetric data manipulation capabilities are added.

Background and Transducer Technology

Scientific experiments and studies on the 3D display of ultrasound images have been carried out by researchers in different parts of the world since the 1970s. However, 3D ultrasound only became commercially available in 1989 when Kretztechnik (Austria) launched a machine using a specially built volumetric transducer [1]. The volumetric transducer contained a built-in motorised mechanism to move the enclosed transducer over the region of interest, acquiring the images in a single sweep. The same transducer is also used for conventional 2D scanning. Subsequent development led to other ultrasound machines that use conventional transducers for manual acquisition of volumetric data with or without position-sensing devices. These resulted in less optimal image quality compared to the automated or volumetric transducers and are being phased out. More recently, fully electronic matrix array transducers capable of producing 3D images without the use of any moving parts have been introduced.

Volumetric scanning capabilities initially developed for the convex transducer have been gradually introduced to linear and endocavity transducers, expanding the use of 3D ultrasound in other areas such as the abdomen, the breast, and the female pelvic area. These transducers can acquire volumetric data within only a few seconds for each plane.

Image Display

Although much of the initial interest in 3D ultrasonography, particularly in obstetrics, was focused on the display of surface-rendered images, the applications of 3D ultrasonography gradually expanded to domains such as multiplanar reconstructions, tomographic slicing, volume calculations, image manipulation, and other forms of image rendering.

Depending on the equipment and the selected display format, the initial images from 3D ultrasonography are usually displayed in three planes: the plane of volume acquisition and two orthogonal planes (Fig. 1). Depending on the type of acquisition, the rendered image may be shown as well. The optimal display of the coronal plane of the uterus usually requires some manipulation of the data set. One technique was described by Abuhamad et al. [2]. The coronal plane, or C-plane (Fig. 2), is the best anatomical view of the uterus, as it provides information on the shape of the uterine fundal anatomy and the endometrial cavity, which is essential for the evaluation of the most common Müllerian duct anomalies and the position of an IUD in relation to the uterine cavity.

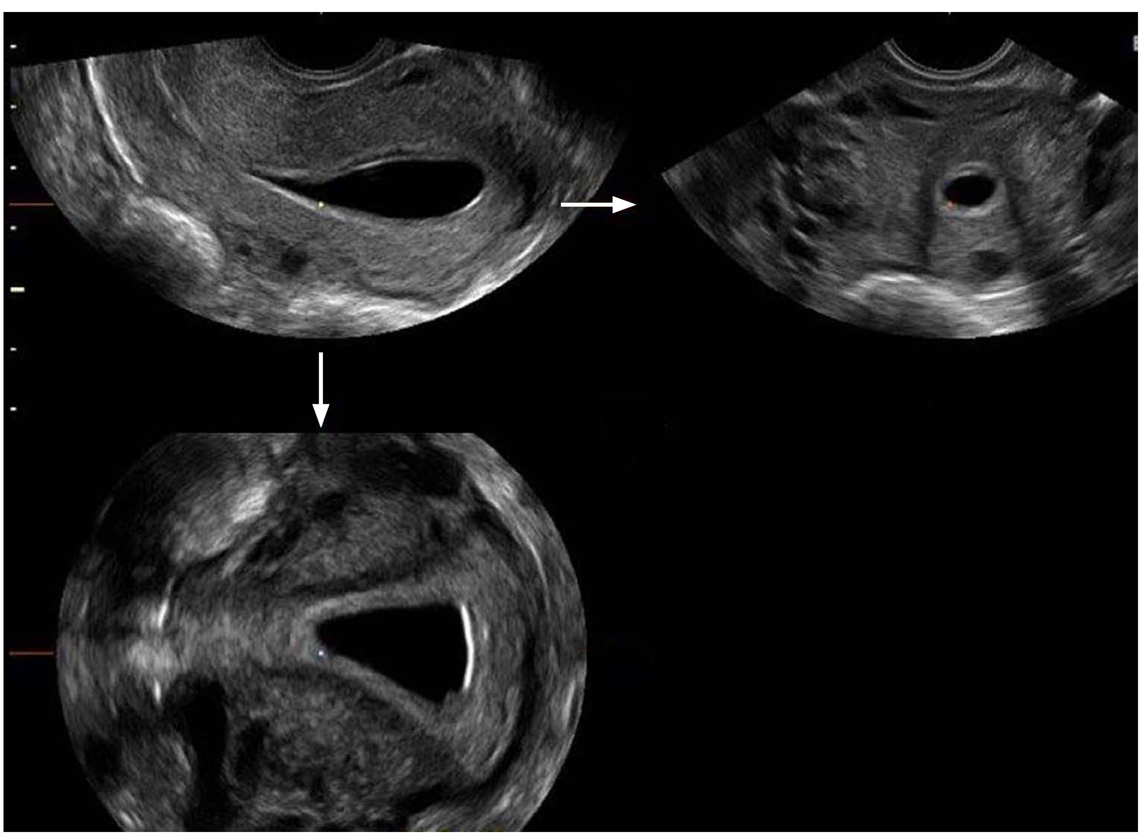


Fig. 1. **Three-dimensional transvaginal ultrasonography of a 26-year-old woman.** Images are displayed in three planes including the plane of acquisition (upper left) and two reconstructed orthogonal planes derived from the volumetric data (upper right and lower left).

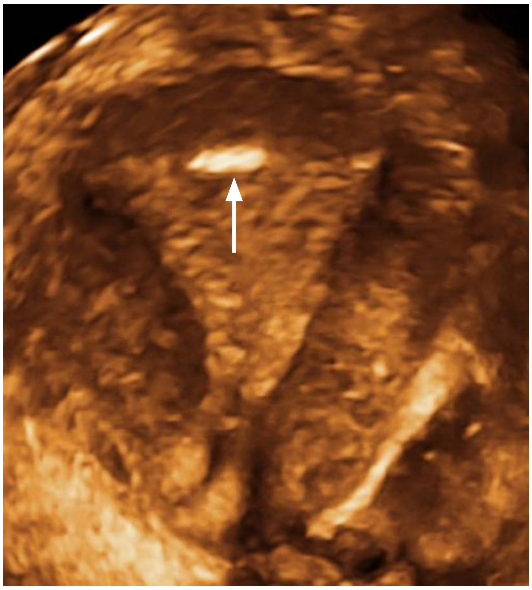


Fig. 2. Coronal or C-plane of the normal uterus (rendered image). The reconstructed coronal plane shows the outer uterine fundal anatomy and the endometrial configuration of a normal uterus. The arrow indicates an air bubble introduced during saline infusion.

Improvements in data acquisition and processing allow for almost isometric reconstruction of the data to useful images in planes other than the one originally acquired. A number of proprietary software programs have been developed for the manipulation of volumetric data. Depending on the manufacturer, the volumetric data may be reprocessed into slices (Fig. 3) similar to those used in CT and MRI. Such capabilities allow for a more efficient workflow, as volumetric data can be obtained through standard acquisition methods, and image analysis may be performed off-line.

Data may also be analysed for information such as volume and vascular density. Software developments combined with faster processors have allowed faster reconstructions and reinterpretation of data.

Examples of image manipulation include the inversion mode, in which fluid-containing structures are made echogenic or opaque and solid structures are substracted [3], allowing concurrent display of the cystic structures in a single image. Other examples of image manipulation using the volume data include volume contrast imaging, in which data acquired from a thick slice is reconstructed over a 2D display to improve the contrast between tissues, allowing better

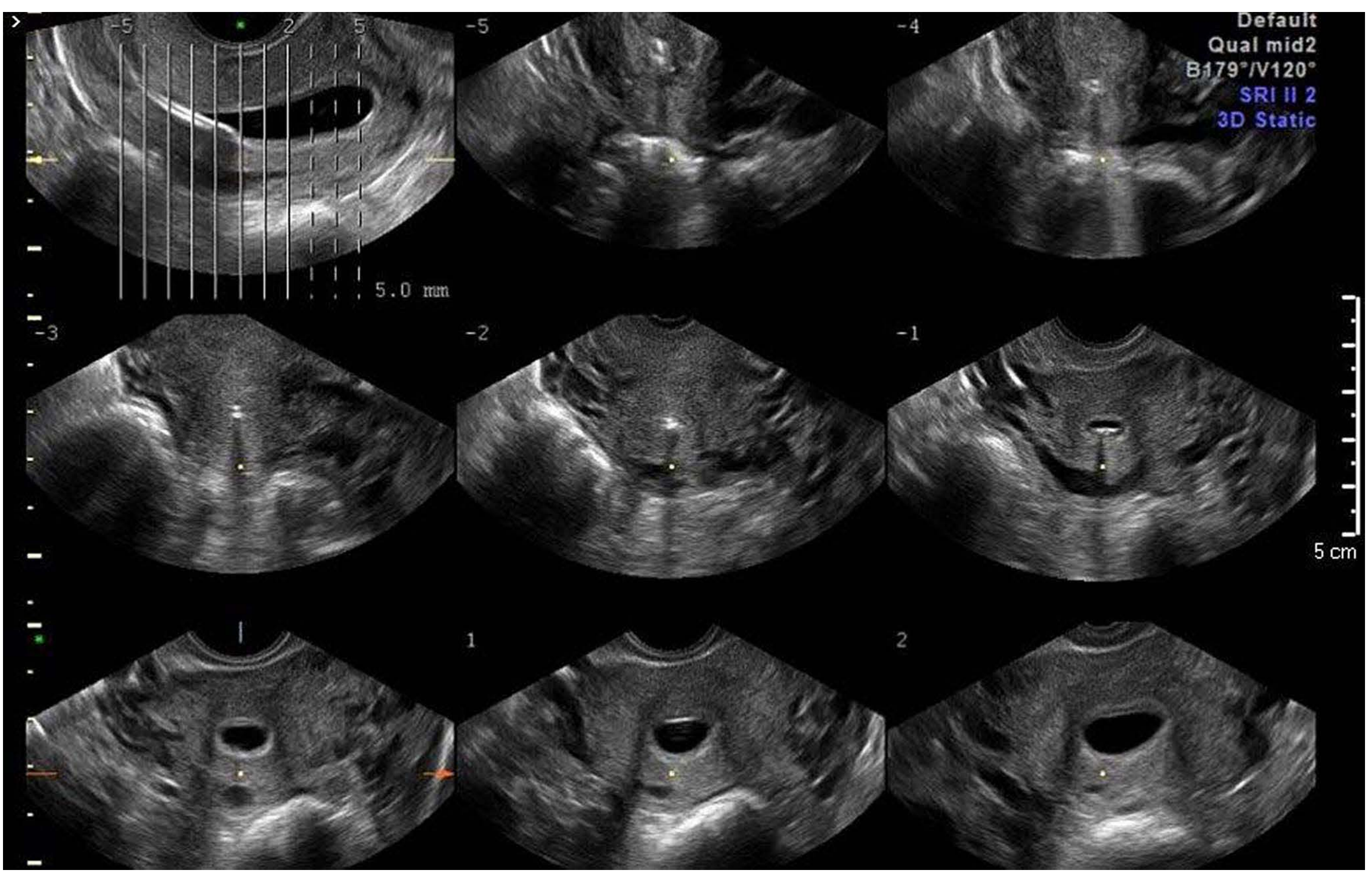


Fig. 3. Tomographic axial sections from transvaginal three-dimensional (3D) ultrasonography of the uterus in a 26-year-old woman. Reprocessed volumetric data from 3D ultrasonography is displayed here in 5-mm thick tomographic axial sections.

distinction between the different tissue types. The surface rendering mode is less frequently used in gynaecology than in obstetrics, as the structures of interest are normally not covered by fluid.

Further improvements in transducer technology have enabled real-time 3D displays. More recently, special effects such as a virtual "light source" have been incorporated to produce photorealistic effects in images. Although this is used predominantly in obstetric ultrasounds, its use has also been reported in gynaecological ultrasonography [4].

Gynaecological Ultrasonography

Ultrasonography is the imaging modality of choice for the evaluation of many gynaecological problems. The role of 3D ultrasonography in gynaecology includes the assessment of Müllerian abnormalities, IUDs, the endometrium, polyps, the location of a pregnancy, and the mapping of uterine leiomyomata, ovarian follicles, adnexal lesions, and the pelvic floor.

Although 3D ultrasonography is considered a useful adjunct and problem-solving tool in many conditions, it has become the modality of choice for the evaluation of Müllerian abnormalities and IUDs. An additional benefit of using 3D ultrasonography is finding anomalies not detected on 2D studies. In a study by Benacerraf et al. [5] on 66 patients, the reconstructed coronal view of the uterus provided additional information not seen on 2D ultrasonography, and improved the confidence of the diagnosis of suspected anomalies in 24% of patients. Using a technique described by Abuhamad et al. [2], the additional findings detected on 3D ultrasonography were a polyp or submucous fibroid, three arcuate uteri, and a subseptate uterus that were not detected using 2D ultrasonography.

Ultrasonographic Technique

3D ultrasonographic assessment of the female pelvis is ideally performed using a volumetric endovaginal transducer. This allows the acquisition of high-resolution images of the uterus and adnexal structures. The ultrasonographic volumetric data of the uterus is usually acquired in the midsagittal plane using an automated transducer. The sweep angle should be chosen to acquire the full width of the uterus.

Müllerian Duct Anomalies

Müllerian anomalies, also known as congenital uterine anomalies, result from varying degrees of non-fusion or partial fusion of the Müllerian ducts, inadequate resorption of the septum in fused ducts, unilateral or bilateral failure of the development of the ducts, and hypoplasia. A classification of congenital uterine anomalies (Table 1) was published by the American Fertility Society in 1988, and remains the most widely accepted to date [6]. However, certain anomalies do not fit into any of the classes, such as uterus didelphys with obstructing vaginal septum or bicornuate uterus with cervical or vaginal aplasia. These anomalies cannot be straightforwardly classified using this system [7].

While the majority of women with Müllerian duct anomalies have little problem conceiving, they experience a higher rate of adverse reproductive outcomes [8]. This includes higher rates of miscarriages, preterm labour, abnormal foetal lie, and shoulder dystocia. A study by Woelfer et al. [9] on 1089 women who underwent 3D transvaginal ultrasonography showed higher rates of first-trimester pregnancy loss in women with septate uteri, and higher rates second-trimester pregnancy loss and preterm labour in those with arcuate uteri than in women with normally shaped uterine cavities.

Müllerian duct anomalies may be detected through imaging modalities such as hysterosalpingography, 2D and 3D ultrasonography, and MRI. Invasive procedures, such as laparoscopy and hysteroscopy, are also used, but usually in conjunction with therapeutic procedures. In comparison to MRI, ultrasonography is a cost-effective imaging technique for diagnosing Müllerian duct anomalies. Unlike MRI, 3D ultrasonography is not affected by bowel peristalsis and produces higher-resolution images.

3D ultrasonography shows good concordance with hysterosalpingography and laparoscopy [10,11], as well as with MRI [12]. The acquisition of 3D ultrasound volumetric data requires only a fraction of the time that MRI requires for pelvic scanning. MRI may still be used as a problem-solving tool after ultrasound assessment for patients who are unable to undergo a transvaginal scan, in cases of uterine agenesis, or in cases of vaginal obstruction.

Hysterosalpingography is a well-established imaging technique for assessing uterine cavity and tubal patency. Congenital anomalies such as uterus didelphys, unicornuate uterus, and arcuate uterus can be confidently diagnosed with the procedure. As only the uterine cavity, and not the outer contour of the uterus, is evaluated,

Table 1. American Fertility Society classification of Müllerian duct anomalies

Class	Anomaly	
I	Hypoplasia, agenesis	Vaginal, cervical, fundal, tubal, combined
II	Unicornuate	Communicating, non-communicating, no cavity, no horn
III	Didelphys	–
IV	Bicornuate	Complete, partial
V	Septate	Complete, partial
VI	Arcuate	–
VII	Diethylstilbestrol drug-related	–

hysterosalpingography has a diagnostic accuracy of only 55% for differentiating septate from bicornuate uteri [13]. In contrast, with the addition of conventional ultrasonography, an accurate diagnosis was made in 90% of cases [13,14]. It is of critical importance that these two types of Müllerian anomalies are accurately diagnosed due to differences in their clinical management. Although surgical intervention is usually not performed for bicornuate uteri, when performed, a transabdominal approach is used. In contrast, a hysteroscopic approach is used for septate uteri.

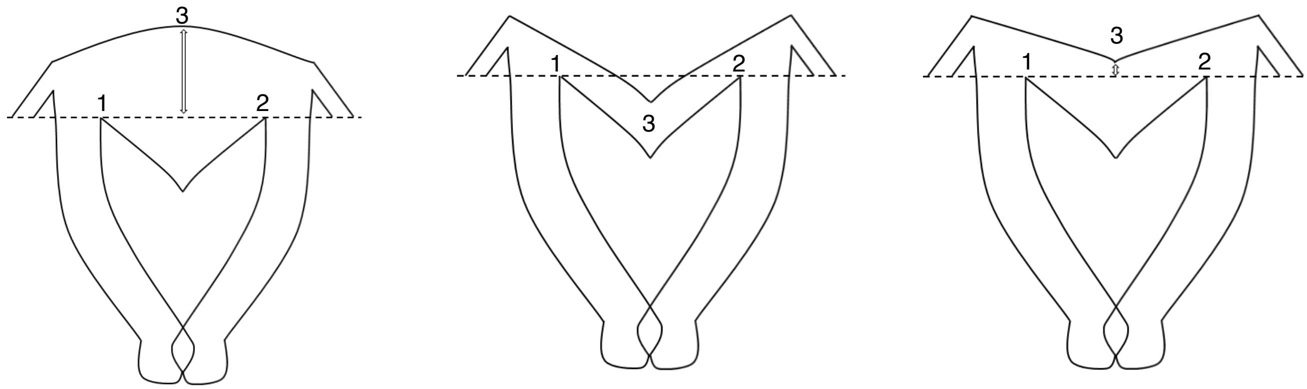
Fig. 4. **Coronal image of an arcuate uterus.** A reconstructed coronal image of the uterus in a 34-year-old woman obtained during three-dimensional sonohysterography shows the arcuate configuration of the fundal part of the endometrial cavity.

3D ultrasonography can provide the information needed to differentiate between these two conditions. Using the volumetric data acquired from 3D ultrasonography, the uterus is displayed in its coronal plane, facilitating visualisation of the uterine fundal contour and uterine cavity in the same plane. This is useful for the detection and characterisation of Müllerian anomalies. Whilst the separate endometrial cavities of bicornuate and septate uteri (class IV and V) are usually apparent on 2D ultrasonography, it is usually impossible to visualise the configuration of the uterine fundus. In arcuate (Fig. 4) or septate uteri (Fig. 5), the fundus may be flat, convex, or show minimal indentation, whereas a bicornuate uterus would have a deeper indentation (Fig. 6). The uterus is considered bicornuate if the fundal indentation is less than 5 mm above the level of the uterine ostia or extends below the level of the uterine ostia (Fig. 7A–C) [15,16].

Generally, class I and III anomalies can be diagnosed through 2D ultrasonography. Another Müllerian anomaly that is more easily recognised using 3D ultrasonography is the unicornuate uterus (Fig. 8). 3D ultrasonography also allows better assessment of unilateral hypogenesis or agenesis in such cases. In some cases of Müllerian duct anomalies where duplication of the cervix is also in question, acquisition of two sets of volumetric data has been suggested: one

Fig. 5. **Septate uterus in a 47-year-old woman.** A coronal image of the uterus shows the presence of a septum (asterisk) separating the endometrial cavity into two sides. The uterine fundus is convex.

Fig. 6. **A bicornuate uterus with pregnancy in the right horn in a 32-year-old woman.** A coronal image shows a bicornuate uterus with separation of the outer fundal contour into two uterine horns containing separate endometrial cavities and a pregnancy (arrow) in the right uterine horn.



A B C

Fig. 7. **Schematic diagrams of the criteria for ultrasound differentiation between bicornuate and septate uteri.**
A–C. The diagrams show that bicornuate and septate uteri are distinguished based on the fundal contour and the distance of the fundus/fundal indentation (3) from the level of the uterine ostia (1, 2). A. Diagram shows a septate uterus with a convex outer fundus. B. In a bicornuate uterus, the fundal indentation lies below the ostial level. C. In a septate uterus with fundal indentation, the distance between the apex of the fundal indentation and the ostial level should be 5 mm or more. The dotted line indicates the ostial level.

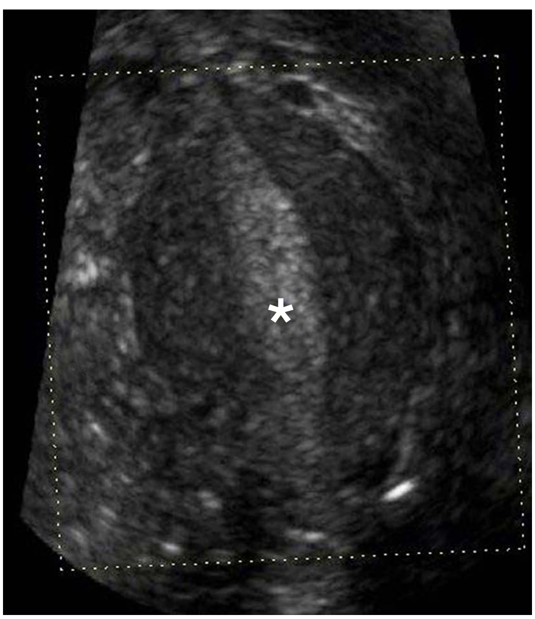


Fig. 8. **Unicornuate uterus with a single right horn.** A coronal image of a unicornuate uterus in a 25-year-old woman shows an almost tubular endometrial cavity (asterisk) and a single right uterine cornu.

set for the uterine body and another set for the cervix.

In order to assess the configuration of the uterine cavity, it is important to perform the study during the luteal or secretory phase of the menstrual cycle when the endometrium is thicker and most echogenic. Visualization on the 3D coronal plane is poor when the endometrium is less than 5 mm in thickness [5].

Studies on the role of 3D ultrasonography in Müllerian anomalies have shown a high degree of concordance in the interpretation of findings amongst readers in differentiating between septate and bicornuate uteri [17].

Sonohysterography

Sonohysterography may be performed with the infusion of saline or water, or the instillation of gel, to evaluate the uterine cavity for endometrial polyps, submucosal fibroids, adhesions, and other mucosal anomalies. It is more accurate than conventional transvaginal ultrasound. It is less invasive and more comfortable than hysteroscopy, with comparable accuracy in detecting intracavitary lesions [18–20]. The addition of 3D ultrasound allows evaluation of the uterine fundus and the overall configuration of the endometrial cavity. Surface rendering of the endometrial lining presents another way to visualise mucosal folds and endometrial polyps (Fig. 9).

A study by Ghate et al. [21] did not find any additional benefits from 3D ultrasound apart from the ability to evaluate the uterine fundal contour. Depending on the type of anomaly assessed, 3D sonohysterography may or may not be of additional clinical utility. In a study that compared 3D sonohysterography with diagnostic hysteroscopy, Lagana et al. [22] found better concordance in diagnosing polyps (77.78%), myoma, mucus accumulation, and Müllerian anomalies (100%), and poor concordance in assessing endometrial thickening (0%) and Asherman's syndrome (50%).

In another study by Opolskiene et al. [23] on 54 patients with post-menopausal bleeding who underwent both 3D sonohysterography and hysteroscopy, 3D ultrasound was not found to be advantageous in detecting focal lesions or irregularity of the

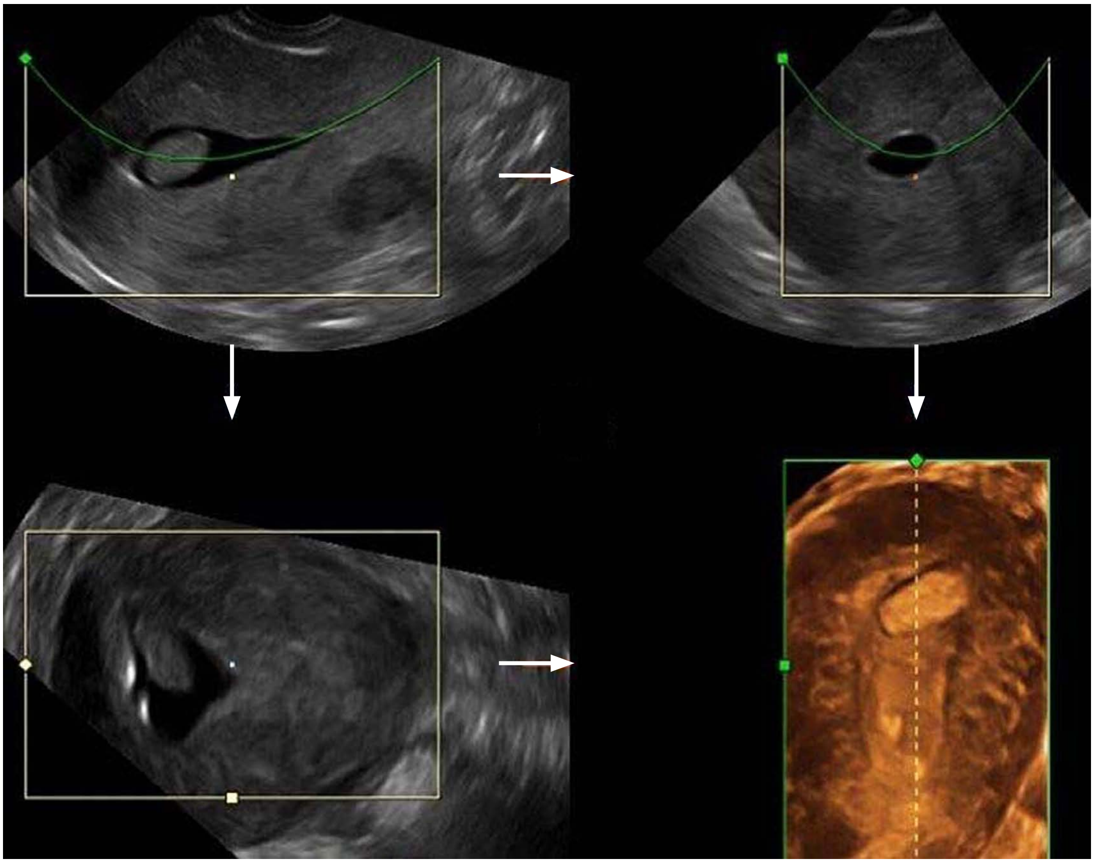


Fig. 9. **Multiplanar display of uterine volumetric data with surface rendering of the endometrial polyp.** A multiplanar display of the images obtained from sonohysterography in a 42-year-old woman shows the plane of acquisition (upper left), two reconstructed orthogonal planes (upper right and lower left) and the three-dimensional rendered image (lower right) of the endometrial polyp arising from the left uterine cornu.

Fig. 10. **A T-shaped intrauterine device (IUD) in the correct intrauterine position.** A coronal image of the uterus shows a T-shaped IUD in the appropriate position enveloped within the endometrium.

endometrium.

On the other hand, a study by Ludwin et al. [24] found substantial interrater and intrarater agreement and correlation with hysteroscopy in 3D sonohysterographic evaluation of the uterine cavity in patients who had undergone hysteroscopic metroplasty, which is a minimally invasive procedure that removes the uterine septum. Patients may therefore be spared a second-look hysteroscopy if the results are normal, reserving hysteroscopy for those who require interventions.

Intrauterine Devices

Abnormally positioned IUDs may be associated with a higher incidence of failed contraception, pain, and bleeding. Upon visualisation, a correctly positioned IUD should be enveloped within the endometrial echo with both arms extended towards the uterine cornua and its stem above the level of the isthmus (Fig. 10) on the C-plane. The stem and arms should not extend into the myometrium. Malpositioned IUDs are better visualised on 3D ultrasonography than on conventional 2D ultrasonography (Fig. 11A, B).

In a study of 167 patients with IUDs who underwent 3D ultrasonography, Benacerraf et al. [25] found a malpositioned IUD in 16.7% of the patients, and they were all visible on the 3D reconstructed coronal view. In the same study, they found that 2D ultrasonography failed to demonstrate the abnormal location of the side arms. By reconstructing the dataset in various scan planes, 3D ultrasound allows for full visualization of the device, its type, and its position or malposition in most cases. Whilst copper T devices are well visualised on 2D studies, visualisation of the less conspicuous levonorgestrel-releasing IUDs (Mirena, Bayer Healthcare, Whippany, NJ, USA) is significantly improved with 3D ultrasonography [26].

The type of an IUD is better identified through 3D ultrasonography. Another method that may be used to identify an IUD is through positioning of the Z-plane just below the endometrium or acoustic shadows of the IUD (Fig. 12) [27]. Due to the numerous advantages in imaging IUDs, 3D ultrasonography is considered the modality of choice for the assessment of IUDs [28].

Uterine Fibroids

Uterine myomas, or fibroids, are a common cause of uterine enlargement. They are usually classified according to their location as intramural, subserosal, and submucosal. Submucosal fibroids (Fig. 13) are a common cause of abnormal uterine bleeding, subfertility, and early pregnancy loss. Minimally invasive surgery for the treatment of uterine fibroids requires an accurate assessment of their location. Transcervical resection of submucosal uterine fibroids, a hysteroscopic procedure, enables the removal of fibroids without open surgery. The careful selection of patients is essential, as not all submucosal fibroids can be removed using this technique. Assessing suitability for hysteroscopic resection requires evaluating the size of the fibroid, the size of the intramural component, and the degree of protrusion of the fibroid into the endometrial cavity [29]. Submucosal fibroids may be classified based on their protrusion into the endometrial cavity [30]. They are classified into three groups: type 0 (fibroid polyps), type I (<50% contained within the myometrium), and type II (>50% contained within the

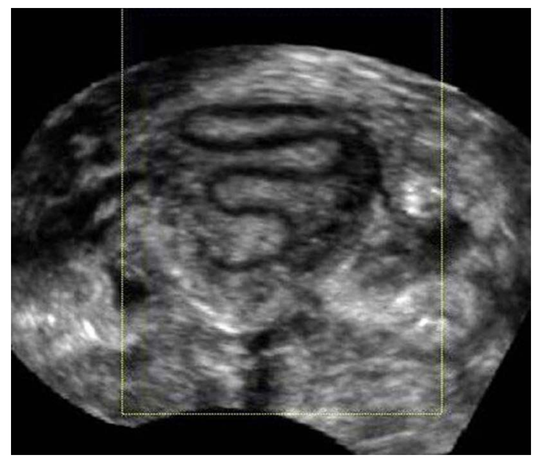
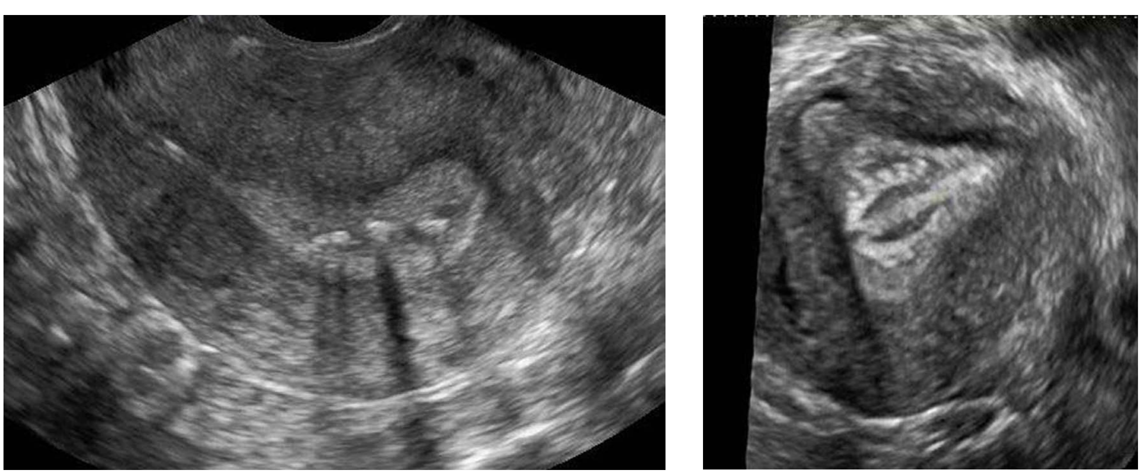


Fig. 12. Image of the acoustic shadow from an intrauterine device (IUD) (Lippes loop). The type of IUD was identified by its acoustic shadow in a 41-year-old woman by placing the Z-plane just below the endometrial echo. Reconstruction to the coronal plane shows the acoustic shadow of the IUD, revealing the type of IUD.



A B

Fig. 11. A malrotated intrauterine device (IUD) (Multiload) on two-dimensional (2D) ultrasonography and three-dimensional (3D) ultrasonography.
Sonograms of a 39-year-old woman show the improved visualisation of a malrotated IUD (Multiload), a copper IUD, using 3D ultrasonography. 2D ultrasonography (A) demonstrates parts of the IUD, whereas the coronal image reconstructed from 3D ultrasonography (B) shows the entire IUD and its relationship to the endometrial cavity.

myometrium). 3D saline sonohysterography shows good overall agreement with diagnostic hysteroscopy in assessing the type of submucosal fibroids [31].

Assessment of Pregnancy Location

Whilst most pregnancy locations may be easily confirmed with 2D ultrasonography, some pregnancies present greater challenges. Early diagnosis aids the proper management of such pregnancies, which is critical for ectopic pregnancies. The differences among interstitial ectopic pregnancies, angular pregnancies, and pregnancies in the septate uterus may be very subtle on 2D ultrasonography, but is better assessed with 3D ultrasonography [32]. 3D ultrasonography can be very helpful in confirming the position of an interstitial pregnancy, demonstrating its location away from the endometrial cavity and its relationship to the uterine cornu (Fig. 14). Angular pregnancies can be easily mistaken for interstitial pregnancies, as the overlying myometrium can be less than 5 mm [32]. An angular pregnancy refers to an intrauterine pregnancy that has implanted at one of the lateral angles of the uterine cavity, medial to the utero-tubal junction. Although such pregnancies can descend into the main uterine cavity and develop to full term, they are associated with a higher risk of adverse outcomes. 3D ultrasonography can better demonstrate the intrauterine location of such pregnancies and distinguish them from interstitial pregnancies.

Automated Volume Measurement and Assessments

Depending on the ultrasound equipment, automated or semi-automated volume measurements from 3D ultrasound datasets may be used to evaluate structures such as the ovaries and their follicles. Accurate measurements of follicular size are essential in patients who undergo assisted reproduction in order to monitor follicular development, to time the administration of medication for oocyte maturation, or for oocyte retrieval. Studies using automated volume calculation software (e.g., SonoAVC, GE Medical Systems, Zipf, Austria) have shown good correlations between 2D measurements and those obtained from 3D ultrasound datasets [33,34]. Such automated/semi-automated capabilities (Fig. 15) allow for improvements in workflow and efficiency. Volumetric measurements of the endometrium and cervix have also been reported in the literature [35,36].

Other Applications of 3D Ultrasonography in Gynaecology

Several studies have explored the use of endometrial volume and 3D vascular indices (vascularization index, flow index, and vascularization flow index) to discriminate between benign and malignant endometria in patients who present with post-menopausal vaginal bleeding [37–42].

Volume-contrast imaging has been reported to improve the assessment of myometrial invasion by endometrial cancer [43]. Volume contrast imaging, which combines the display of a thick-slice volume dataset with 2D images, improves the distinction between endometrial and myometrial tissues. Another application of 3D ultrasonography is in the evaluation of pelvic floor muscles [44].

Benefits and Limitations

With 3D volume acquisition of ultrasound data, the workflow may

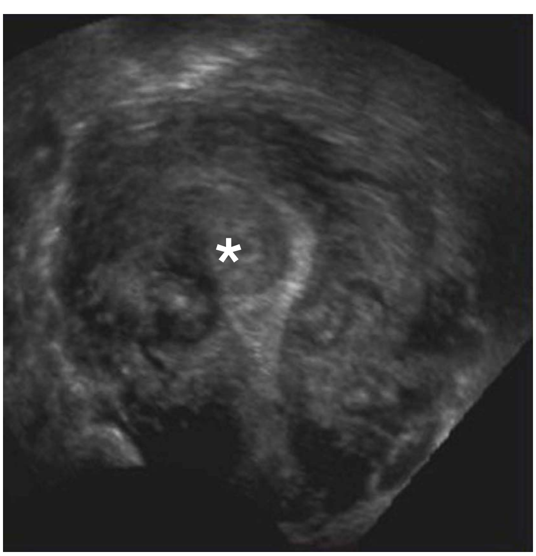


Fig. 13. **C-plane image of the uterus with a submucosal fibroid.** A reconstructed image of the uterus in a 52-year-old woman shows a submucosal fibroid (asterisk) arising from the right uterine wall, located predominantly within the endometrial cavity.

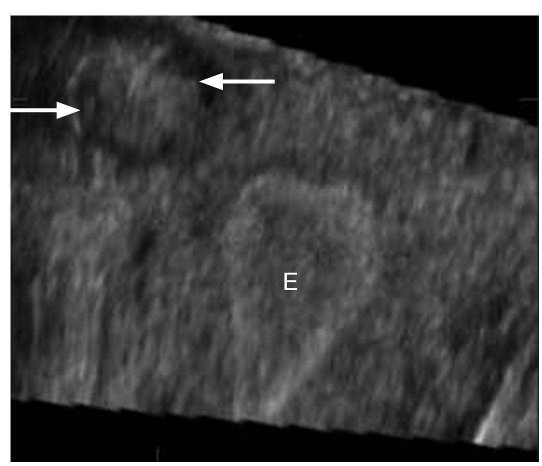
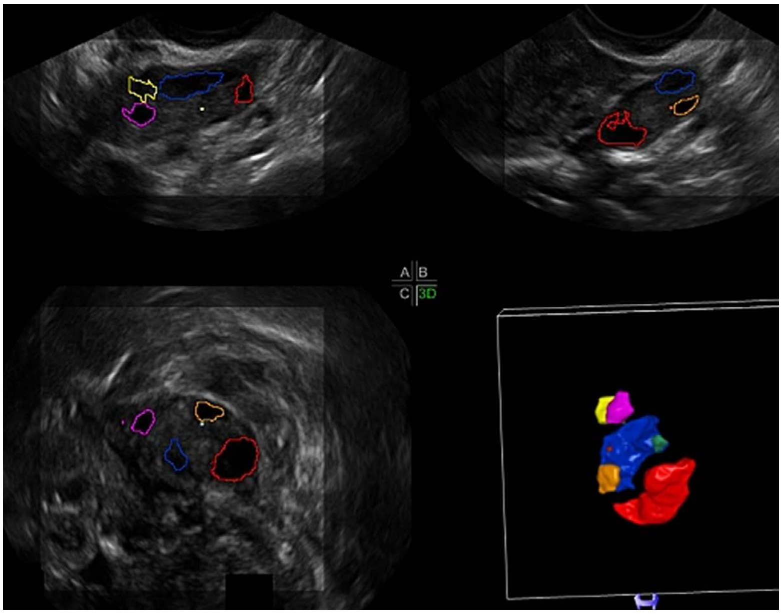


Fig. 14. **C-plane image of a uterus with a right interstitial ectopic pregnancy.** A reconstructed coronal image of the uterus shows a right interstitial ectopic pregnancy (arrows) located in the myometrium and separate from the endometrial cavity (E).



Ovary: Left
Total No. 7

No.	d(V) (mm)	dx (mm)	dy (mm)	dz (mm)	mn.d (mm)	V (cm^3)
1	9.2	19.2	9.0	5.8	11.3	0.41
2	8.2	15.4	9.1	5.2	9.9	0.29
3	5.1	6.7	5.7	3.8	5.4	0.07
4	4.6	6.0	4.4	4.0	4.8	0.05
5	4.4	6.4	4.8	3.0	4.7	0.04
6	2.4	3.7	3.4	1.5	2.9	<0.01
7	1.3	1.5	1.3	1.3	1.4	<0.01

A B

Fig. 15. Three-dimensional (3D) sonogram of the left ovary.
The images show a 3D multiplanar display of the left ovary with the follicles automatically identified, separately color-coded, and rendered opaque after subtraction of the grey scale (A). The sizes of the follicles and their volumes were tabulated using automated volume calculation (B).

be redesigned to improve efficiency. Benacerraf et al. [45] showed that the examination time may be reduced by using standardised volume acquisition protocols that were subsequently evaluated off-line.

As well as the benefits and capabilities of 3D ultrasonography, the sonologist should also be aware of the presence of artefacts and its physical limitations. These limitations reflect the inherent physics of ultrasound. However, artefacts can sometimes be useful, as in the use of the acoustic shadow for the evaluation of IUDs.

Standardisation of Practice

Practitioners of 3D ultrasonography need to learn not only acquisition techniques, but each software module used. Even sonographers and sonologists who are experienced in 2D imaging undergo a learning curve with 3D methodology [46]. With large volumes of ultrasound data and latitude in demonstrating multiplanar images, spatial orientation can be challenging for less experienced practitioners. The orientation of structures (i.e., ventral, posterior, right, and left sides) no longer corresponds to the edges of the display screen, but to the object itself. With current equipment, the orientation of the display is still dependant on the operator. Proposed guidelines for the standardised display of 3D images have been published by the International Society of Ultrasound in Obstetrics and Gynecology 3D Focus Group with the aim of providing some degree of standardisation of image display [47].

Conclusion

The proven efficacy of 3D ultrasonography for the diagnosis of Müllerian duct anomalies, locating IUDs, as well as adjunctive roles in ultrasound studies for the assessment of infertility and the preoperative evaluation of submucosal uterine leiomyomata, has made it a cost-effective first-line imaging technique.

As 3D ultrasonography capability is becoming a standard feature of many mid-range to high-end ultrasound machines, ultrasound practitioners should develop the necessary proficiency and skills to take advantage of its applications.

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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