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REVIEW ARTICLE

Volume Ultrasound in Uterine and Tubal Evaluation

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ABSTRACT

After the development of the new technologies and rendering modes, it became possible to acquire valuable diagnostic images of the female genital organs. There appear to be few differences in the diagnostic accuracy of standard 2D *vs* 3D images in detecting pelvic pathology, but 3D scanning can improve efficiency by reducing scanning time and therefore improving patient throughput. Furthermore, 3D ultrasound is able to rapidly acquire and store ultrasonographic data that can later be retrospectively analyzed with little loss of information. The most important advantage is the visualization of the coronal plane. It is therefore likely that the application of 3D ultrasound scanning will increase in the future for diagnostic purposes, particularly when the purchase cost of ultrasound equipment falls. The purpose of this review is to highlight the benefits of volume ultrasound in evaluation of uterine and tubal pathology.

Keywords: 3D ultrasound, Sonohysterography, Endometrium, Leiomyoma, Müllerian anomalies, Tube.

INTRODUCTION

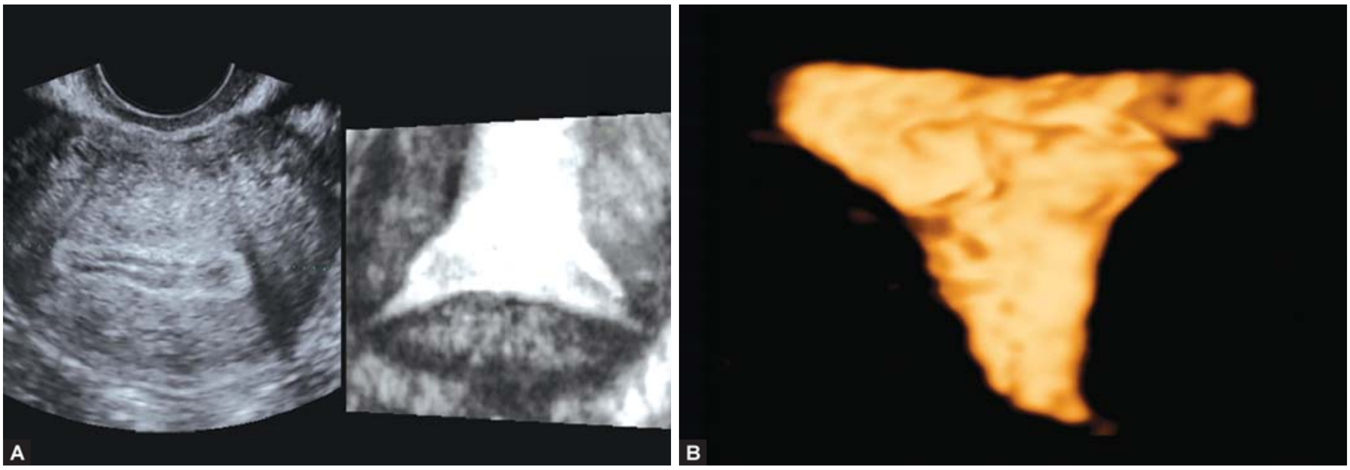
Over the past decades, there was a very important progress in digital technology, bringing along the development of the main diagnostic tool in most clinical fields—the ultrasound. With the increasing utility of the transvaginal ultrasound, the female pelvis became more and more accessible, a wider variety of gynecological pathology was open to diagnosis and treatment. Real time conventional scan and Doppler analysis are now part of the routine pelvic exam and an accurate evaluation allows gathering a number of anatomical and even histological details, in search for functional information, such as lutheal phase deficiency or the implantation prognosis. In this field, the 3D ultrasound seemed a natural step. Regarded as an experimental investigation tool with few clinical utilities, gynecological examination was initially doomed by the lack of a fluid environment. The first images obtained were least disappointing. Only after the development of the new technologies and rendering modes, it became possible to acquire valuable diagnostic images of the female genital organs. The most important advantage is the visualization of the coronal plane.

It was a point of view completely new for pelvic examination, even though it is based on the well-known fact that conventional ultrasound is a two-dimensional rendering mode of a three-dimensional (3D) organ. Even with technical advances in gynecological 3D ultrasound, the coronal plane still remains the most important acquisition.[1] The basis of the 3D examination in gynecology derived straight from the surface rendering mode in obstetrics, consists in a progressive plane-by-plane two-dimensional scan with digital image reconstruction. Starting from this point, there are several possible rendering modes which are employed according to the examiner's purpose, such as enhance contrast or transsonic structures, visualize the coronal plane, or perform volume or vascularity calculations. With 3D US, there is no limit in object rotation, volume acquisition takes only a few seconds and the calculated 3D imaging with the complete volume scan can be stored on hard-disk drive. In enables later retrieval and further analysis of stored data.

UTERINE EVALUATION

Normal uterus is easily assessed using 3D ultrasound, where the coronal plane gives a good image of the endometrial cavity, the surrounding myometrium and of the uterine external contour, a fact of most importance. Conventional ultrasound, with a thorough scan in both sagittal and transverse sections, offers an almost complete description of the uterus, endometrial thickness and vascularization pattern. Three-dimensional ultrasound does not substitute but completes the examination by offering a complete image of the uterine cavity in single acquisition, static rendering mode or VCI-C (Figs 1A and B), calculating the endometrial volume with VOCAL II as well as vascularity indices (Fig. 2).

In addition with these techniques, sonohysterography provides further details of the uterine cavity and tubes. Sonohysterography is the instillation of fluid into the uterine cavity to act as a negative contrast agent. Saline infusion sonohysterography (SIS) is a minimally invasive office technique designed to maximize investigation of the female genital tract. Transvaginal sonography (TVS) is performed while sterile saline is simultaneously infused into the uterus to distend the endometrial cavity. The fluid contrast enhances ultrasound visualization by outlining intracavitary defects or growths. The result is a simple screening method for pelvic anomalies with major advantages over imaging modalities and without the



Figs 1A and B: VCI-C rendering mode; image of the endometrial cavity in a transverse acquisition (A). The endometrial cavity—inversion mode during saline infusion. Offers the best data about the uterine cavity shape (B)

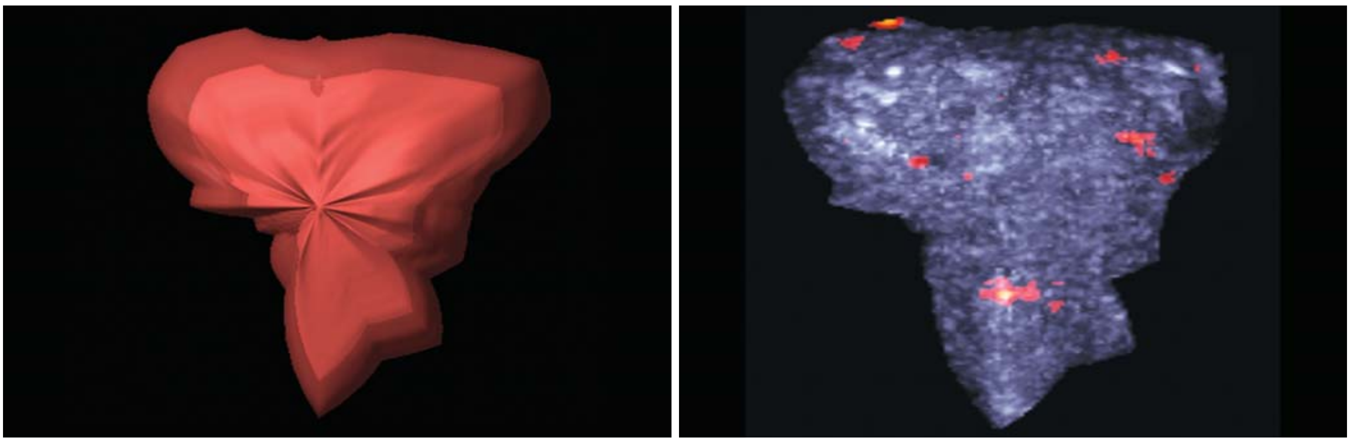
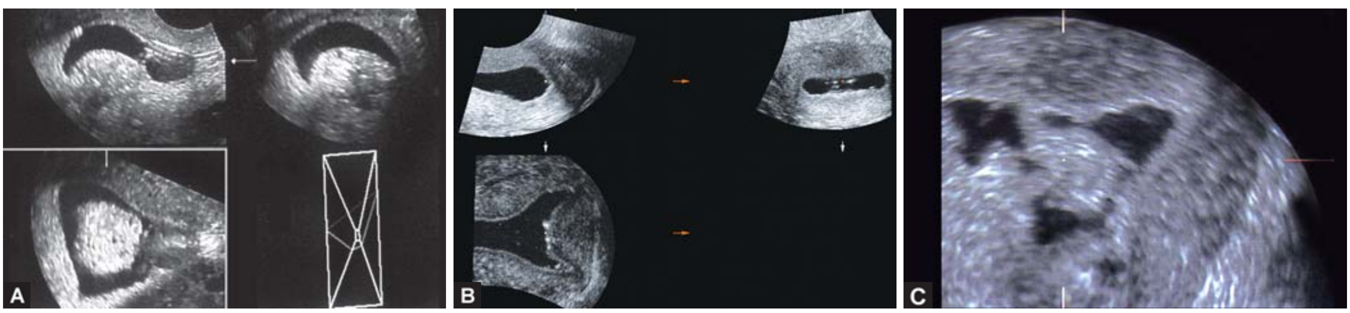


Fig. 2: VOCAL II—digitally reconstructed image of the endometrium, including a periendometrial region (shell), useful for vascularity indices calculations



Figs 3A to C: 3D multiplanar acquisition showing endometrial polyp (A) arcuate uterus (B) and Asherman syndrome with hyperechogenic avascular bridges within the uterine cavity (C)

invasive risks or expense of surgical evaluation. Although, SIS provides an indirect look inside the uterus, its ability to accurately diagnose intracavitary filling defects, such as myomas, polyps, adhesions (intrauterine synechia) and congenital uterine anomalies matches that of the gold standard hysteroscopy. SIS adds more information than TVS alone; in addition, its performance is consistently much more sensitive and specific than that of hysterosalpingography without exposing the patient to either ionizing radiation or contrast allergy. This procedure images far more in the female pelvis than simply the uterine cavity; yet, it is relatively simple to learn and perform, and it can easily be provided by those gynecology practitioners already offering TVS.

The combination between 3D ultrasound and SIS offers the great advantage of rapidly acquire and store a set of volume data about the entire uterus which has some potential advantages:

1. The volume data can be evaluated in any plane desired, retrospectively, possibly reducing the usual amount of time necessary during two-dimensional SIS for uterine distension and multiple still images

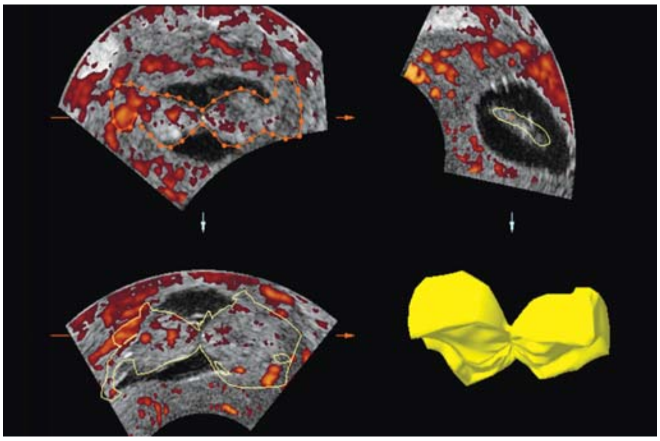


Fig. 4: Two endometrial polyps in SIS 3D multiplanar acquisition with power Doppler and inversion mode

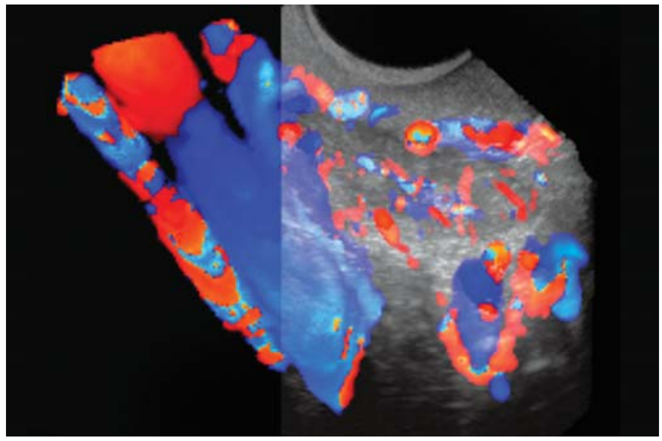


Fig. 6: Three-dimensional angiography of the iliac artery and the uterine artery origin

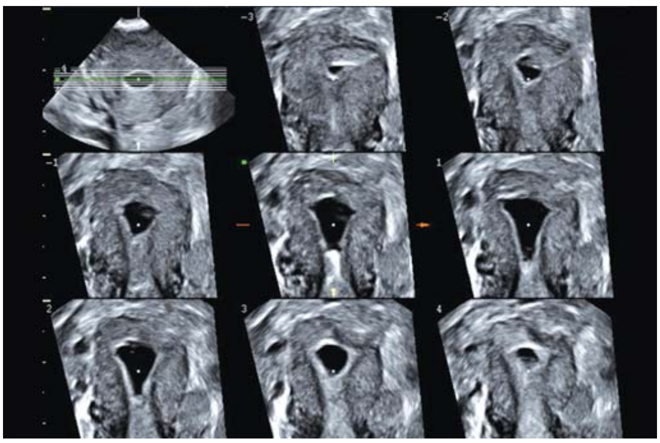


Fig. 5: Tomographic image rendering during SIS

2. The true C-plane, or coronal view of the uterus maximizes the information about the endometrial cavity, the myometrium, and the fundal contour to potentially improve diagnostic accuracy in the setting of congenital uterine anomalies (Figs 3A to 4). Its value in assessing intrauterine adhesions is limited. Also, tomographic ultrasound imaging (TUI) can be used (Fig. 5).

Gel infusion sonohysterography—GIS (viscous gel containing hydroxyethyl cellulose and glycerine) is an alternative for saline infusion and can be used effectively and safely for sonohysterography. GIS offers a more stable filling of the uterine cavity allowing better detailed 3D-examination without inconveniences and discomfort due to fluid leakage and pain for both patient and ultrasonographer.[2]

Endometrium

Ultrasound measurement of the endometrium is now an indispensable part of ovulation induction monitoring and assisted reproductive technologies. It has also a role in evaluation of unexplained infertility.

Endometrial thickness is measured from the echogenic interface at the junction of endometrium and myometrium at the level of the maximum anteroposterior diameter in the sagittal plane. For standardization and accuracy, the measurement should be taken between the two endometrial—myometrial interfaces within 5 to 10 mm from the fundus of the uterine cavity. The clinical significance of the endometrial sonographic changes during menstrual cycle. The relation between endometrial thickness and echogenicity and pregnancy outcomes is still unclear and subject to debate.

More recent studies, however, brought two new elements: endometrial vascularization and endometrial volume. The human endometrium undergoes intense angiogenesis during menstrual cycle, and angiogenesis is a key process for successful embryo implantation and development.

The uterine artery may be detected in virtually all premenopausal women with color or power Doppler anywhere along its trajectory, but the measurement is recommended to be performed as close as possible to its origin from the internal iliac artery[3] (Fig. 6). The characteristic waveform presents a high velocity/high resistance pattern in nonpregnant women. The uterine flow is dependent on the estrogen level.[4] Within the reproductive age group, the resistivity index (RI) varies with the menstrual phase. It is statistically lower during the luteal phase (0.84 ± 0.06) than during the proliferative phase (0.86 ± 0.06).[5] The RI starts to decrease 1 to 2 days before midcycle, reaches a nadir 48 hours after ovulation, then it remains at the same level for the rest of the cycle. These changes do not occur in anovulatory cycles. There is no significant difference between left and right uterine arteries, related to the site of ovulation. Also, a good implantation prognosis is related to a uterine pulsatility index (PI) between 2 and 3 in both arteries. The pregnancy chances decrease significantly with a value over 3 or when there is absent diastolic flow.[6] Flow changes regard also the radial and endometrial arteries. Generally, they follow the same pattern with a decrease in vessel resistance during the second half of an ovulatory cycle. The human endometrium undergoes intense angiogenesis during menstrual cycle, a key process for successful embryo implantation and development. Power Doppler combined with 3D US is a noninvasive way to study the layers of the whole endometrium using perfusion

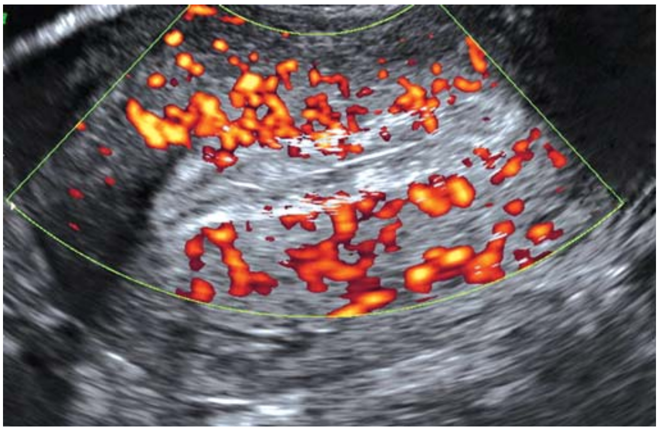


Fig. 7: Endometrial vascularization and midcycle—the radial and spiral arteries. Power Doppler is used to visualize the low velocity flow in small vessels penetrating the endometrium. In this case, the flow reaches the inner half of the endometrium (type III)

analysis. The spiral arteries are responsible for the endometrial vascularization with a very high impact on early embryonic development. Doppler mapping of the subendometrial flow[7] depicted four types of endometrial flow during early luteal phase, as follows:

Type 0: vascularization far from subendometrial region

Type 1: peripheral—vessels reaching the outer echogenic layer of the endometrium

Type 2: intermediate—flow within the middle hypoechogenic layer

Type 3: central—blood flow on the entire endometrial thickness.

The evaluation should be performed with power Doppler in order to visualize even low-flow vessels and to avoid loss of signal with increasing insonation angle (Fig. 7). The vascularity type may be predictor of ovulation and implantation, therefore, it is important to be assessed in infertile patients. Usually, there is poor vascularity in anovulatory cycles. Each type correlates with a different implantation prognosis which varies from 0% for type 0 to 37.9% for type 3.

Using the three-dimensional techniques, endometrial vascularization may be quantified in a semiautomatic manner. The volume organ computer aided analysis (VOCAL) provided three indices:

- Vascularization index (VI) represents total number of color voxels or total number of voxels from region of interest and reflects the number of vessels in the tissue.
- Flow index (FI) represents total intensity of color voxels or total number of color voxels in the volume and reflects the total blood volume.
- Vascularization/flow index (VFI) represents total intensity of color voxels or total number of voxels (color and grey) in the volume and combines information about the quality and quantity of vascularization.

It also offers a general view of both subendometrial and endometrial blood flow along with the measurement of endometrial volume (Fig. 2).

Changes in endometrial and subendometrial flow were investigated in 27 healthy, fertile volunteers with regular menstrual periods, using 3D power Doppler on alternate days, starting on cycle day 3 until ovulation, and then every 4 days afterward until initiation of menses.[8] With the use of the VOCAL, the vascular indexes were calculated for each time point. For the subendometrial vascular index, an arbitrary limit of 5 mm was established, and the inner third of the endometrium and the area irrigated by the radial arteries. Both endometrial and subendometrial vascular flow increased to a maximum 3 days prior to ovulation, then decreased until postovulatory day 5, and finally begun a gradual increase during the rest of the luteal phase. The proliferative phase increment was related to estradiol levels and its vasodilating effects, while the luteal phase increase was related to serum progesterone. Interestingly, the flow indexes continued to increase during menstruation regardless of a drastic drop in progesterone levels; this might be explained by the high endometrial vascular density due to progressive compaction of the spiral arteries. The reduction in the postovulatory vascular indexes is explained by vasodilatation of the subepitelial capillary plexus, which induces the required stromal edema to allow embryo implantation. Another study found that the lowest vascularization index occurred 2 days after ovulation and progressively increased during the luteal phase.[9]

Thus, 3D US is a reliable technique for investigating cyclic, physiological changes in endometrial vascularization, showing that there are maximum values 2 to 3 days prior to ovulation, decreasing to minimal values 2 to 5 days postovulation and increasing thereafter. Vascular flow is delicately orchestrated in order to provide human embryos a favorable microenviroment for implantation, although the amount of oxygen the embryo needs from the endometrium during the implantation process is still controversial. More studies are needed to definitively establish the role of endometrial/subendometrial vascular oscillations in embryo implantation.

The question at this moment is, when there are so many sonographic tools, which one is better and more predictive in evaluating endometrial receptivity and a potential pregnancy outcome. The most reproducible measurement seems to be the endometrial volume, but in similar stimulated cycles the 2D and 3D endometrial parameters are similar.[10]

A recent study[11] evaluating the predictive value of power Doppler angiography and three-dimensional endometrial parameters for endometrial receptivity in IVF cycles, found a very good correlation between endometrial volume, VI, FI, VFI and pregnancy outcome. Moreover, the indices are even better predictive when one grade I embryo or one no grade embryo are transfered with an important role in management of single embryo transfer politics. On the other hand, endometrial pattern (triple line aspect) and endometrial thickness were of less predictive value.

Measuring endometrial volume by 3D US is the latest acquisition in gynecological ultrasound and offers extended data based on all three acquisition planes. The endometrium has a variable thickness, normal < 13 ml in menopause. This may be calculated automatically or semiautomatically (VOCAL II).

The Endometrium in Infertile Women

3D US facilitates noninvasive evaluation of the endometrium and identifies some organic problems that can negatively influence the implantation process in infertile women.[12] Specifically, endometrial volume determination and evaluation of endometrial angiogenesis using vascularization indexes can easily and accurately be performed using 3D US.

The vascularization indexes are different in fertile women than in patients with unexplained infertility; the latter shows a dramatic decrease in both endometrial and subendometrial vascularization indexes that are unrelated to both estradiol or progesterone levels and endometrial thickness and volume. This suggests that vascular dysfunction may compromise embryo implantation.[13] Similarly, vascular changes that take place during natural menstrual cycles have been compared with those occur in stimulated cycles, and appeared a 35% decrease in endometrial and subendometrial vascularization in stimulated cycles.[14]

Endometrial Studies in Women undergoing ART

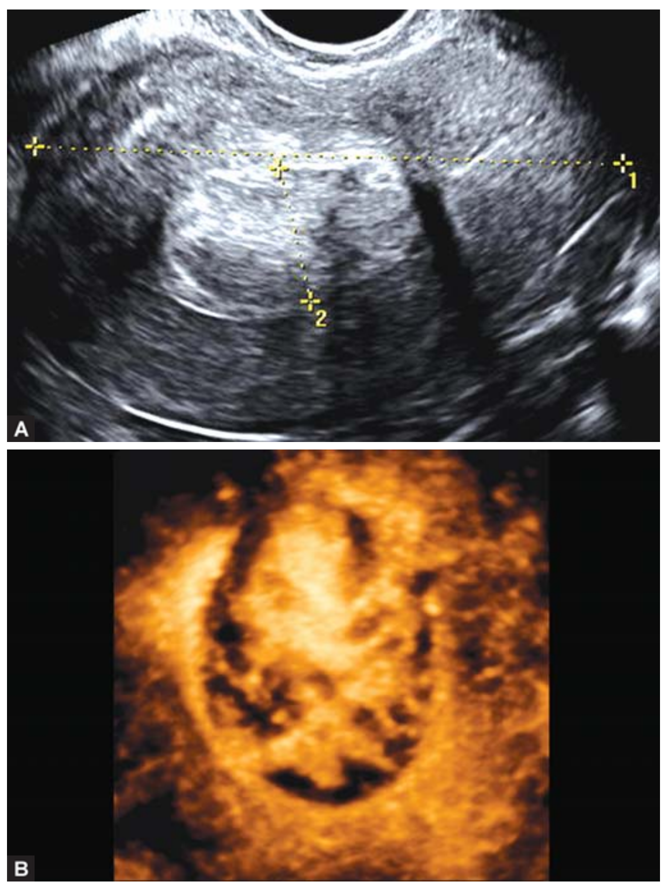
Only 30% of embryos transferred into the uterine cavity after ART successfully implant. In many cases, this may be due to the embryo, but in all cases, endometrial receptivity may also be impaired. Prognostic endometrial receptivity markers are still needed to identify patients with a good, fair, or poor prognosis. Patients with a good prognosis might benefit from single embryo transfer, whereas patients with a poor prognosis may be advised to have embryo frozen, and transferred at a later stage in a natural cycle.

Three-dimensional US allows prompt, integrated evaluation of all known receptivity markers by measuring endometrial thickness, texture, pattern, volume and global perfusion. Endometrial/subendometrial perfusion provides a more direct estimate of endometrial receptivity. It has been evaluated in different phases of the stimulated ART cycle, on the day of hCG administration,[15] the day of egg retrieval,[16] and the day of embryo transfer.[17] There is no generally consensus about the area that should be studied for adequate assessment of subendometrial vascularization. While some groups consider 1 mm outside the endometrium adequate,[18] others postulate that 5 mm[8] or 10 mm margin[16] should be used. The choice of a smaller margin (i.e. 1 mm) is based on the fact that cyclic changes in vascularization occur in that region in response to sex steroid secretion throughout the cycle. A wider margin may inadvertently include leiomyomas which could interfere with the accuracy of indexes. Not unexpectedly the results of these studies have been variable. Some authors found a direct relationship between pregnancy rates and subendometrial vascularization (VI, FI, VFI) on the day of hCG administration[11] or on the day of embryo transfer,[19] whereas others found no correlation with the day of hCG,[18] or even found the opposite (a higher pregnancy rate when endometrial/subendometrial flow was absent). Although, no differences were found in patients with a good prognosis, cycle outcome seemed improved in patients with poor embryo quality but with better endometrial vascularization (VI, FI, VFI). This was true for *in vitro* fertilization as well as for cryopreserved embryo transfers.

Endometrial/subendometrial vascularization may also serve as a prognostic marker of ongoing pregnancy, as lower perfusion correlates with miscarriages. None of the other study parameters—endometrial thickness, volume or texture—had any predictive value in terms of pregnancy evolution. This finding may be helpful in order to appropriately counsel patients with a high chance of miscarriage and also as a guideline for implementing early preventive measures.

Endometrial Polyp

Polyps are common cavity lesions, well-defined within the endometrial cavity, that originate from endometrial tissue. Benign endometrial polyps are found in up to 30% of women. They range in size from 5 to 30 mm in diameter and are usually sited at the fundus. Polyps are associated with abnormal intermenstrual bleeding, premenstrual spotting and occasionally abdominal pain and dysmenorrhea, but are often asymptomatic and detected at the time of an ultrasound for another indication, typically assessment of infertility. They typically assume a slightly higher echogenicity that the endometrium itself with a single feeding vessel. They induce an unequal thickening of the endometrium (Figs 8A and B). Large polyps may appear as diffuse endometrial thickening, being difficult to differentiate



Figs 8A and B: Large endometrial polyp—conventional transvaginal sagittal scan (A) and 3D image in the coronal plane (B)

Figs 9A to C: Endometrial polyp during SIS: Conventional acquisition (A) 3D static render (B) and inversion mode (C)

from simple hyperplasia. A differential diagnosis for an endometrial polyp is a submucosal fibroid. Because the polyp is echogenic, it is more easily identified within the proliferative phase of the cycle, whereas a small submucosal fibroid would be more easily seen in the secretory phase. The shape, the dimensions, the origin and the impact on the endometrial cavity are clearly visualized, guiding the therapeutic procedure. 3D sonography may facilitate diagnosis, using static acquisition (Figs 8A and B), direct or inversion mode during SIS and also help to differentiate between endometrial polyp and submucosal fibroid. The extraordinary capacity of the multiplanar mode to study the whole endometrium simplifies identification of polyps, which can hamper embryo implantation if they are larger than 10 mm.

Saline infusion sonography (SIS) may also be used to improve the detection rate and reduce the number of false positives. It often helps to define the position and size of the polyp (Figs 9A to C), which can allow the surgeon to modify their approach and resect the larger, more broad-based polyps rather than list them for simple polypectomy.

The TUI mode provides tomographic sections of the uterus, permitting global evaluation of the uterus.

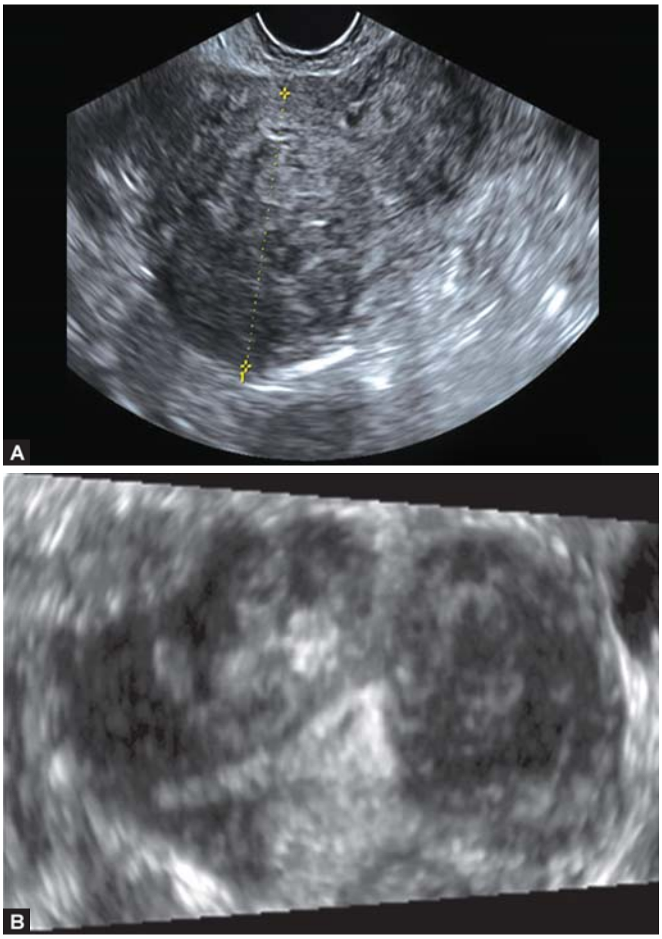
Leiomyomas

Leiomyomas are benign smooth-muscle growth of the uterus that can occur as a single lesion, though it more often presents as multiple lesions. Together with endometrial polyps are the most frequent benign uterine pathologies and both can interfere with the reproductive process. Uterine myomas may be generators of infertility by obstructing the fallopian tubes, distorting the endometrial cavity and causing subendometrial ischemia, thus interfering with gamete transport and implantation.[20] The relationship of the fibroids to the uterine cavity is better examined by TVS. A fibroid outline is usually well visualized by TVS, even in the very small lesion, because of the pseudocapsule.

Sonographically, they present as focal enlargements of the uterus with a texture similar to the myometrium and posterior shadowing. The appearance greatly depends upon the presence of calcification or necrosis. Fibroids are commonly hypoechoic compared to adjacent myometrium, but they can also be isoechoic or even hyperechoic. Very large fibroids are best seen with TAS as they often extend beyond the effective range of transvaginal probe.

The exact position, the impact on the ostium tubae and the uterine cavity may be difficult to assess by conventional ultrasound. A very easy solution in many cases is offered by a static 3D acquisition or static VCI-C, which can show the fibroid in the coronal plane (Figs 10A and B). The increased echogenicity of the endometrium improves the visualization of the uterine cavity contour, but sometimes, especially in large myomas located on the anterior wall, this may be extremely difficult. It can be used to precisely establish the size, vascularization and location of myomas and can determine their relation to the endometrial cavity.

Saline infusion sonohysterography (SIS) has become a vital tool in the assessment of the cavity distortion caused by fibroids. Instillation of saline enhances contrast and delineates the uterine myoma. By distending the cavity with saline, it is usually possible to view clearly both the separated cavity surfaces for significant cavity wall distortion or irregularity and the potential cavity for space-occupying lesions (Fig. 11). If a fibroid impinges on the cavity then assessment is made of what percentage of the lesion projects into cavity, and its degree of extension into the myometrium. It can be categorized as a type



Figs 10A and B: Uterine fundic leiomyoma distorting the uterine cavity. 2D scan (A) and VCI-C rendering (B)

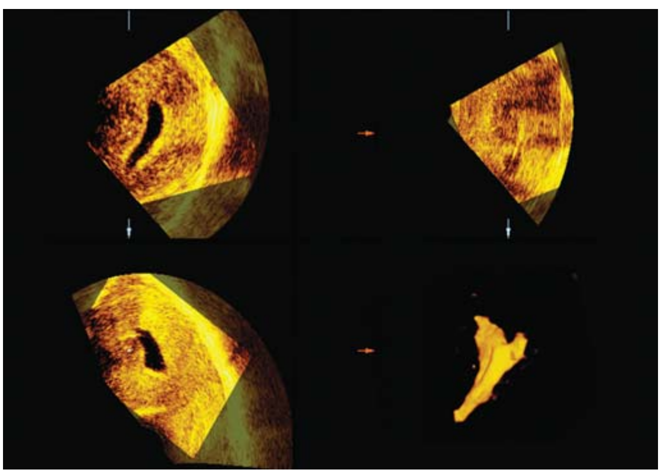


Fig. 11: Submucous small myoma distorting the uterine cavity. SIS inversion mode

0, I or II (Wamsteker and de Blok classification) to help plan the mode of surgical treatment. 3D scanning can be performed in conjunction with SIS to provide the additional coronal plane for further diagnostic accuracy, and with reconstruction of the volume creates a very good hysterographic image without supplementary investigations. Inversion mode and rotation of the image may offer exact data regarding the dimension, position of the tumor and degree of distortion of the cavity. In the same procedure, it is possible to assess tubal patency by direct view of the fluid spillage through the fallopian tubes under Doppler control, or indirectly, by the easy depletion of the uterine cavity with fluid accumulation in the Douglas pouch. If a fibroid is situated close to the ostia, a hysterosalpingo contrast sonography (HyCoSy) test may help to clarify whether the fibroid is causing an ostial obstruction, as indicated by an absence of cornual exit of contrast. Echovist (the contrast for HyCoSy) also provides a positive contrast for clearly outlining submucosal fibroids.

3D scanning guides the therapeutic procedure in cases deferred to hysteroscopic resection by evaluating the degree of protrusion in the uterine cavity. In the same manner, it also selects the cases to benefit from laparoscopic or classic myomectomy.

It is recommended to remove myomas that distort the endometrial cavity, so 3D US is a valuable tool when surgery is being discussed. Similarly, 3D US provides a more reliable postsurgical evaluation of the uterine cavity.

Müllerian Anomalies

Congenital uterine abnormalities (müllerian anomalies) are associated with infertility, recurrent miscarriage, preterm labour and malpresentations.

The exact incidence of congenital uterine anomalies is difficult to determine since many women with such anomalies are not diagnosed, especially if they are asymptomatic, but it seems to be around 2 to 4% of live births and, according to various studies range from 1 to 26% in infertile females.[21] The most common type of müllerian anomalies are uterine anomalies with a distribution as follows: septate/arcuate uterus (90%), bicornuate uterus (5%) and didelphic uterus (5%).

The uterus develops from fusion of the paramesonephric ducts, which join in the midline at about the 10th week of gestation to form the unified body of the uterus. Abnormalities in resorption of the fused midline tissues occur by the 20th week and can result in the formation of septa of variable length and position. The various müllerian anomalies are the consequence of four major disturbances:

1. Failure of one or more müllerian duct to develop (agenesis, unicornuate uterus without rudimentary horn).
2. Failure of the ducts to canalize (unicornuate uterus with rudimentary horn without proper cavities).
3. Failure to fuse or abnormal fusion of the ducts (uterus didelphys, bicornuate uterus).
4. Failure of resorption of the midline uterine septum (septate uterus, arcuate uterus).

Among all types of congenital uterine anomalies, the septate uterus presents the highest rate of miscarriage.[22] Clinically, this is of greatest importance, as septate uterus is considered a mild anomaly and the differential diagnosis with bicornuate uterus, anomaly with a better fertility prognosis, is difficult.

An accurate diagnosis in all cases implies a very good visualization of the uterine cavity, with focus on the fundus, and a delineation of the uterine external contour. So far, the most commonly used diagnostic method was hysterosalpingography (HSG). It provides excellent view of the uterine cavity and cervical canal as well as information related to tubal patency but no data regarding the fundal shape. MRI may be employed in certain cases with very good results, but at high costs.

Transvaginal 2D US is a good screening test with high sensitivity for detection of müllerian uterine anomalies. However, 2D US has a limited ability to distinguish different types of uterine abnormalities and is operator dependent.[23] Consequently, 3D US is now used extensively. Transvaginal 3D US has the ability to generate accurate images of both the endometrial cavity and the external contour of the uterus. A major advantage of 3D US is the multiplanar capability, the ability to image the three orthogonal planes of the uterus, of which the coronal view of the uterus and the cervix are the most important. Coronal view is essential for assessing the external uterine contour and viewing the fundus, shows the relationship between the endometrium and the myometrium at the uterine fundus, delineates the entire cervical canal, and depicts the corneal angles. Also shows the whole length of the uterus down to the cervix, and consequently for determining the exact type of uterine anomaly. This enables the operator to measure the depth of the uterine septum or depth of the fundal cleft and the distance between the apex of the septum and the internal os. In addition, the use of 3D enables us to diagnose new types of the uterine septum, such as unequal sides. 3D US is more accurate than HSG when estimating the depth of the septum (accuracy 98%).[24] Using 3D power Doppler, vascularization of the septum can also be determined. Furthermore, 3D US can differentiate between arcuate uterus and a short, incomplete septum which is not always possible with hysteroscopy. It can therefore differentiate different müllerian anomalies with good reported sensitivity and specificity.[25]

3D US has become a key tool for diagnosing uterine malformations, because is noninvasive, reproducible, relatively inexpensive and well tolerated compared with techniques, such as laparoscopy/hysteroscopy, MRI or HSG. The main sources of error are uterine leiomyomas, synechiae or other distorting process within the cavity.

Assessment of cervical length in this specific group: of all müllerian anomalies, unicornuate uterus had the highest rate of cervical shortening and preterm delivery.[26] A further advantage of ultrasound is that allows for the simultaneous screening for urinary tract abnormalities commonly associated with uterine abnormalities (20-30% of women).

Optimal imaging of the endometrium and myometrium may require saline infusion sonohysterography (SIS) for distension of the uterine cavity with to separate the walls of the uterus to make clear the outline of the endometrial contour and to detect uterine septum. The consensus by the experts in the area of ultrasonography of uterine cavity disorders is that SIS and HSG are highly sensitive in the diagnosing of major uterine malformations. However, SIS is not sufficiently sensitive in the diagnosis of minor uterine abnormalities.[27] A recent report suggests the use of a very small volume of viscous gel (GIS) with impressive results. Sonohysterography performs better in the diagnosis of müllerian anomalies than HSG and, with TVS, has no false-positive diagnoses.[28]

Also, with 3D US, a volume of ultrasonographic data are rapidly stored and made available for later analysis and is a reproducible method in diagnosing uterine congenital malformations. This is particularly helpful in case of SIS, the amount of time during which the uterine cavity must remain distended decreases. 3D US permits an unlimited number of scan planes to be obtained form the original data set, an advantage that should significantly reduce operator-dependent bias. Additional findings not initially detected during the real-time examination can be made by scrolling through the volume data, without inconveniencing the patient by prolonged or repeated vaginal scanning. Combining SIS with 3D US can add to the accuracy of both procedures.

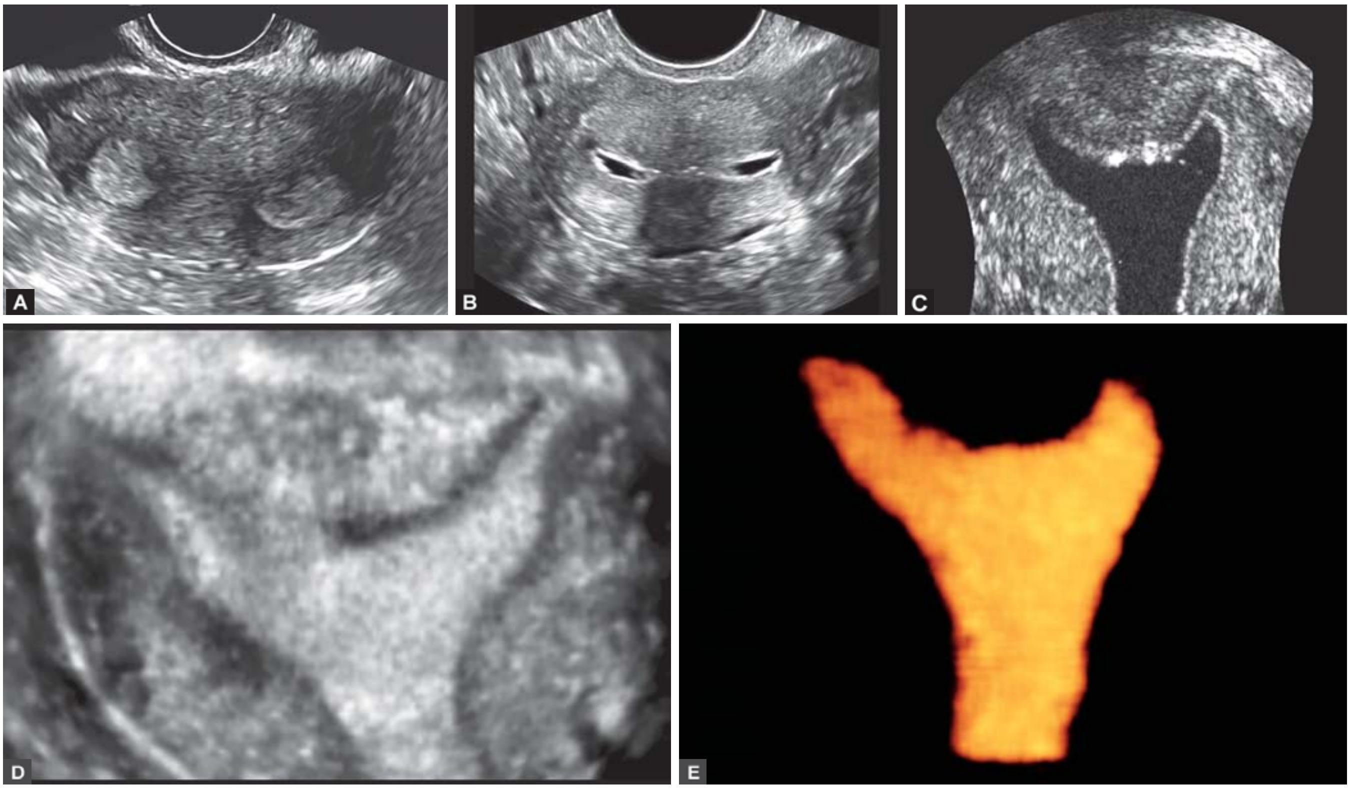
One limitation of 3D US is shadowing caused by uterine fibroids, irregular endometrial lining or thickened endometrial lining (as seen during the periovulatory period) as well as the decreased volume of the uterine cavity (in cases of intrauterine adhesions). When the uterus is retroverted in position some difficulty is encountered in making the diagnosis of subtle uterine septum or arcuate uterus by 3D US.

3D US has been reported to have sensitivity and specificity of 100% in diagnosing arcuate uteri compared with 67 and 94% respectively for transvaginal 2D US. Interestingly, in diagnosing major müllerian anomalies, while the sensitivity and specificity of transvaginal 3D US are both 100% compared with 100% sensitivity and 95% specificity for transvaginal 2D US, the positive predictive value is 100% for 3D US but only 50% for 2D US. Because of the higher accuracy of the 3D US in diagnosing müllerian disorders, higher prevalence (6%) was reported when 3D US was applied for detecting those disorders. Compared with HSG, 3D US has a higher accuracy.

Use of 3D ultrasound to examine patients with recurrent miscarriage as compared with normal controls showed no difference in the relative proportions of congenital uterine anomalies in the two groups of women; arcuate and septate uterus were the most common anomalies prevalent (90%). The measurement of depth of the uterine septum and residual cavity depth showed that in both arcuate and subseptate uteri the length of remaining uterine cavity was significantly shorter ($p < 0.01$), and the distortion ratio was significantly higher ($p < 0.01$) in patients with recurrent miscarriage.[29]

Arcuate/Septate Uterus

Müllerian ducts can develop in two distinct types of tissue: the smooth muscle tissue of the uterus and the fibrous tissue of the cervix. This could explain the various structural subtypes of uterine septum containing different proportions of fibrous and muscle structure. Such structural disparity might be a cause in



Figs 12A to E: Arcuate uterus seen on 2D scan (A) SIS (B) 3D reconstructed coronal plane during SIS (C) 3D VCI-C rendering (D) and 3D inversion mode (E)

the mechanism of reproductive failure associated with uterine septum.

The septate/arcuate uterus develops from a defect in canalization or resorption of the midline septum between the two müllerian ducts. The classification of uterine anomalies divides the uterine septum into complete (septate) or partial (subseptate) groups respectively, according to whether the septum approaches the internal os or not. The complete septum that divides both the uterine cavity and the endocervical canal may be associated with a longitudinal vaginal septum.

A septate or arcuate uterus has a normal external surface, but two endometrial cavities, in contrast to a bicornuate uterus which has an indented fundus and two endometrial cavities. The distinction between arcuate and septate uterus is rather difficult and up to some point subjective. It is accepted that the arcuate uterus has a slight midline septum with a broad, fundal basis and normal external surface, while the septate uterus presents a more important septum and sometimes may have a small indentation that does not exceed 10 mm depth. Septate uterus is the most common müllerian anomaly and is known to result in adverse obstetric outcomes; it is therefore of great importance to differentiate septate from bicornuate uterus, which is much less common, so that hysteroscopic septum excision can be performed.[30] Surgery has reportedly improved pregnancy rate from 3-20% to 70-90%.

Sonographically, in case of arcuate uterus, the two uterine cavities are seen as split endometrial echoes, best visualized during secretory phase (Figs 12A to E). With anteroposterior/transverse diameter < 0.6, the width is larger than height on axial (transverse) section. Arcuate uteri are less obvious and have a subtle indentation at the fundus.

The typical ultrasound appearance of a septate uterus is a convex, flat or mildly concave, but notch < 10 mm, minimally indented fundal contour with an echogenic mass dividing the cavity. Proximally, the septum has the echogenic appearance of myometrium, distally the mass consists of hypoechoic fibrous tissue (Figs 13A to C). The septum is partial or complete.

The degree of septation may be assessed by conventional scan or, much better, by three 3D US, thick slice or VCI-C. The coronal plane offers a very good diagnostic image of the endometrial cavity as well as the fundal contour. In unclear cases, saline infusion gives a perfect image of the uterine cavity. 3D acquisition with inversion mode creates a hysterogram sometimes of better quality than the radiological image.

3D SIS is advantageous compared with 2D SIS with the coronal plane being the most important in providing information. Addition of sonohysterography to 3D imaging allows precise recognition and localization of the lesion.

Evaluation of the vascularity of the septum by Doppler US provides important information about structure and the risk of reproductive problems. Color and pulsed Doppler, SIS and 3D US are superior to 2D US in diagnosing septate uterus.[31] Patients with vascularized septa have significantly higher prevalence of early and late pregnancy complications than those with avascular septa, and this may reflect an increased amount of muscle in

Figs 13A to C: Septate uterus seen on 3D VCI-C (A) septal vessels on 3D power Doppler (B) and 3D SIS with coronal plane (C)

the septum, producing local uncoordinated myometrial contractility that resulted in adverse obstetric outcomes.

Bicornuate Uterus

A bicornuate uterus refers to a uterus in which the fundus is indented (arbitrarily defined as 1 cm)—incomplete fusion of the fundus. The vagina is generally normal.[32] This anomaly results from only partial fusion of the müllerian ducts. This leads to a variable degree of separation of the uterine horns that can be complete or partial. Characteristically, there is only one cervix. Thus, the diagnosis depends on the very good visualization of the two endometrial cavities and the cervix. Sonographically, there are two separate uterine horns with a variable depth of the fundal cleft, more than 10 mm (18 $\pm$ 12 mm) and anteroposterior/transverse diameter ratio of < 0.7 suggests bicornuate or septate uterus. From a theoretical point of view, it is easy to obtain a good coronal plane, but sometimes, it may turn out to be quite difficult, due to some degree of uterine rotation. SIS remains a very good method of clearing up a diagnosis, when necessary (Fig. 14).

Didelphic Uterus

Uterus didelphys or double uterus occurs when the two müllerian ducts fail to fuse, thus producing duplication of the reproductive? Generally, the duplication is limited to the uterus and cervix (uterus didelphys and bicollis—two cervices)

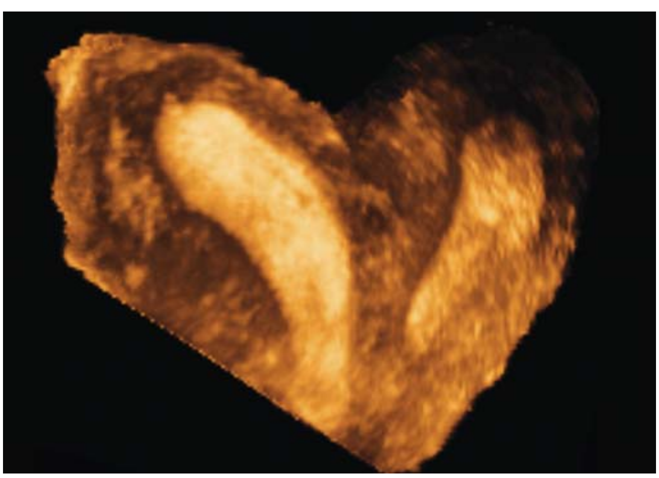


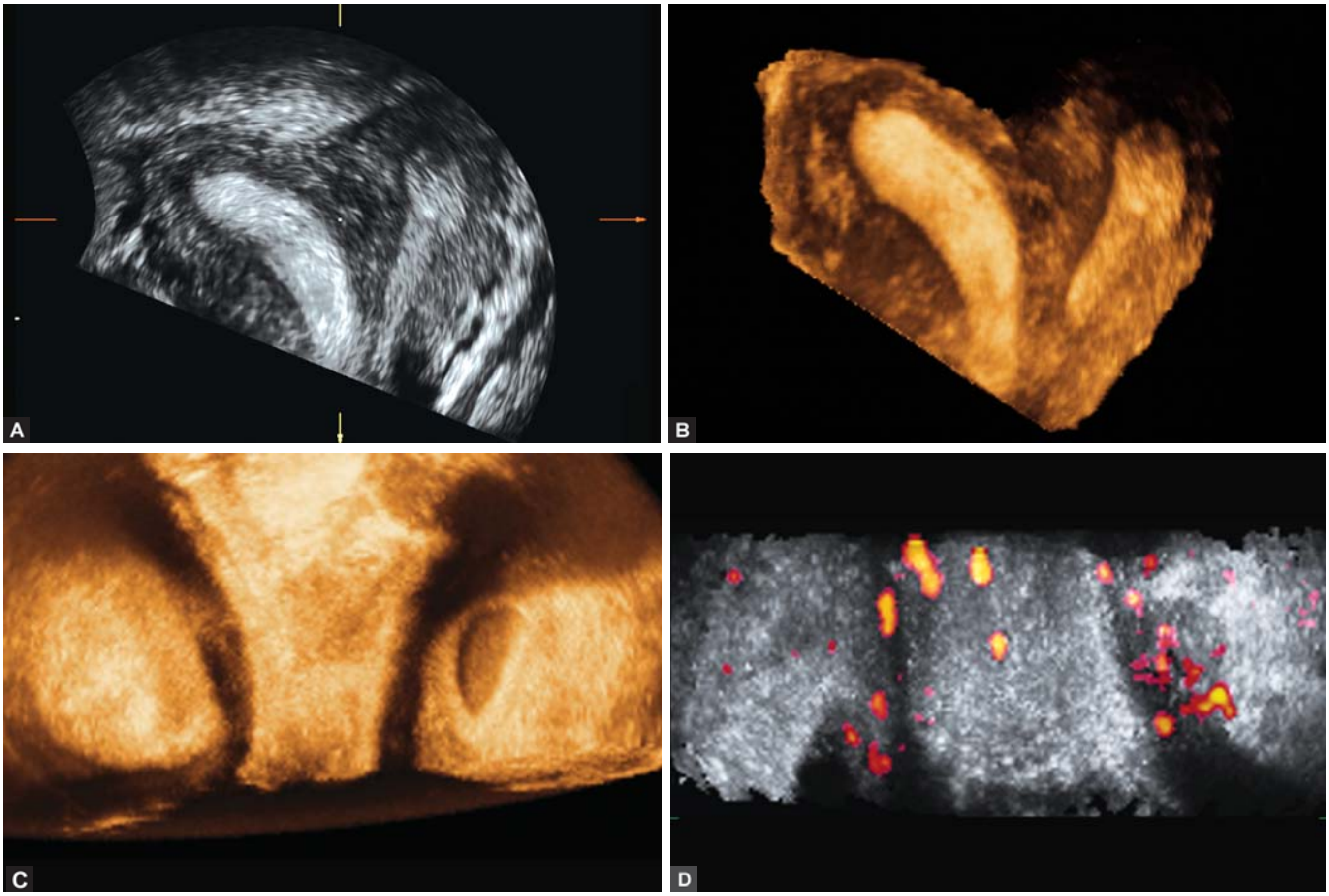
Fig. 14: Bicornuate uterus on 3D US. Visible notch in coronal plane, two cavities

although duplication of the vulva, bladder, urethra, vagina and anus may also occur. A complete vaginal septum, generating an obstructed hemivagina, may be associated with ipsilateral renal agenesis.

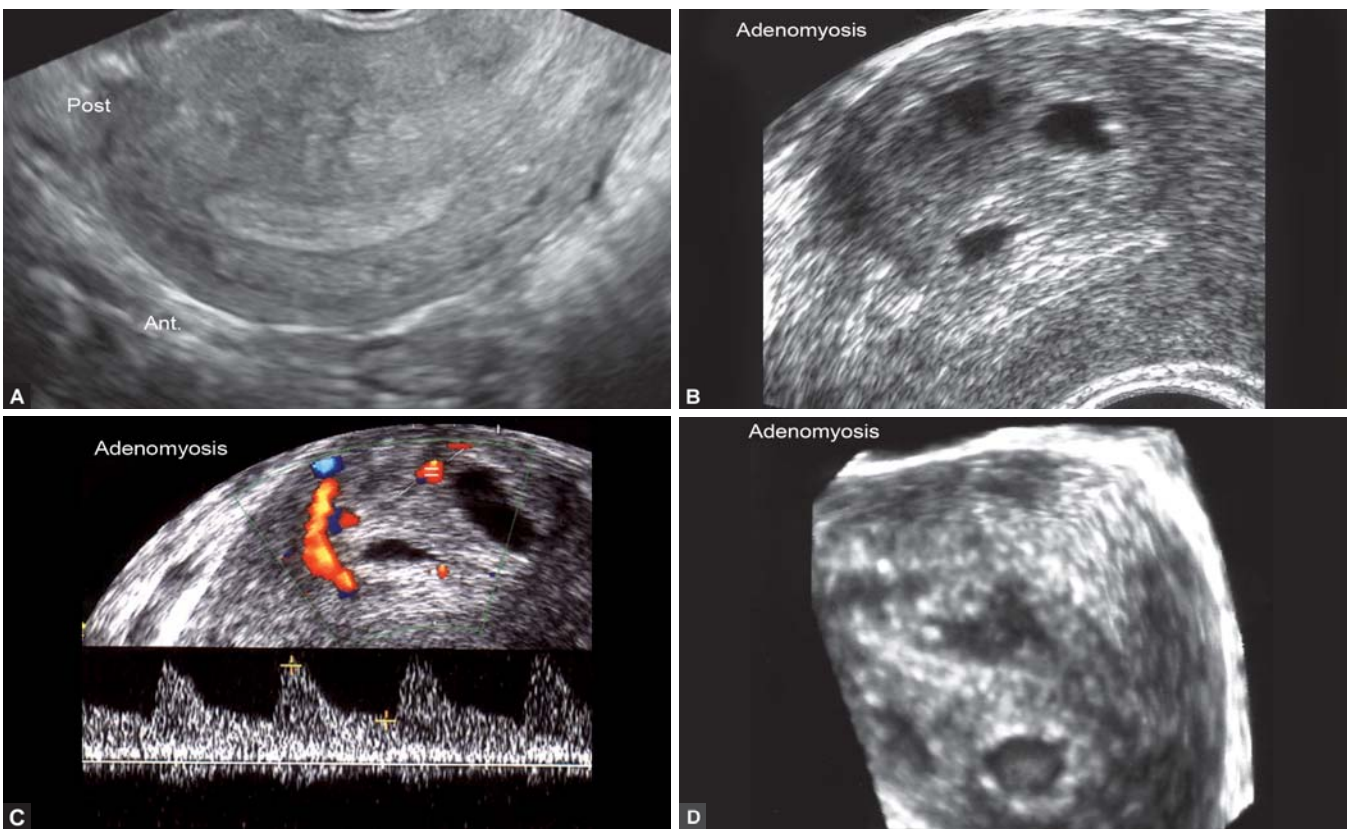
Sonographically, the features are: deep fundal cleft (average 32 mm), two separate endometrial cavities, two cervices. A septated vagina occurs in 75% of cases and may cause difficulty with sexual intercourse or vaginal delivery.[33] A correct diagnosis was stated in both cases using 3D ultrasound with the remark that sonography cannot evaluate vaginal septum (Figs 15A to D). Women with a didelphic uterus and bicollis often have good reproductive outcomes.

Adenomyosis

Adenomyosis is a benign disease of the uterus characterized by the presence of ectopic endometrial glands and stroma within the myometrium with adjacent smooth muscle hyperplasia producing diffuse uterine enlargement. Frequently underdiagnosed is evident in 40% of hysterectomy specimens. It is associated with menorrhagia, dysmenorrhea and chronic pelvic pain. Generalized adenomyosis typically involves the inner two-third of the myometrium and is often found at the fundus. In 75% patients, moderate symmetrical uterine enlargement is present, the uterus appearing smooth in outline with a normal myometrial and endometrial echo texture. Multiple shadowing in the myometrium described as a "rain-in-the-forest" picture, may occur. Occasionally, small cystic areas are seen measuring 2 to 4 mm representing distended endometrial glands containing menstrual blood. The myometrium is divided structurally into an outer myometrial layer and an inner subendometrial layer or junctional zone. Adenomyosis causes disruption of the myometrial-endometrial border and an irregular thickened junctional zone. This can be demonstrated with MRI or 3D US. Traditionally, the gold standard for the diagnosis of adenomyosis has been histopathological, but noninvasive methods are increasingly providing reliable alternatives. Transvaginal ultrasound is reported to have a sensitivity of 53 to 70% and specificity of 65 to 97% with a PPV and NPV of 42 to 92% and 85 to 96% respectively. MRI has a sensitivity of 70 to 82% and a specificity of 84 to 92% with a PPV and NPV of 58 to 83% and 86 to 95% respectively (Figs 16A to D). The level of gray scale imaging



Figs 15A to D: Didelphic uterus on 3D VCI-C scan (A and B) with early pregnancy in one hemiuterus (C and D)



Figs 16A to D: Adenomyosis with diffuse, asymmetrical thickening of the myometrium on 2D US (A) mottled grey scale appearance with small, numerous focal lesions. Disturbed echogenicity of the middle myometrial layer with multiple small cysts within (B) myometrium with increased vascularity, moderate vascular resistance and uterine artery with lower RI values (C) and 3D image of adenomyosis (D) currently available and, in particular, color Doppler sensitivity has significantly increased the accuracy of ultrasound in predicting the likelihood of adenomyosis.

TUBAL EVALUATION

Evaluating the tubal patency represents a key step in the assessment of the infertile couple, especially in situations with risk factors for tubal damage. Over the past 20 years there has been a shift in the causes of infertility, passing from the ovarian and uterine anomalies to tubal and male infertility factors. Obstruction and damage of the fallopian tubes are accounting for almost 35% of all infertility cases.[34]

Normally, the fallopian tubes are not accessible to ultrasound evaluation, unless their diameter is increased by a pathological process, such as hydrosalpinx, pyosalpinx, ectopic pregnancy, tubal carcinoma or torsion. The diagnosis of tubal patency has changed very little during time, laparoscopy with chromo per tubation being still considered the gold standard, as it was 20 years ago, along with radiological HSG. Even though it is not possible in all situations 3D US may represent a very good diagnostic tool, in cases with dilated tubes and a good image of the female pelvis. The most representative rendering mode is inversion mode, very spectacular and easy to handle, especially in patients with an amount of fluid in Douglas pouch. A special remark has to be made regarding the evaluation of tubal patency in patients with nondilated salpingae.

Even though very little related to 3D US, SIS may beneficiate from its techniques. A variable amount of saline solution is injected in pulses under continuous vaginal scan. Power Doppler permits a good image of the tubal passage (Fig. 17) and it may be combined with 3D acquisition, creating a graphic representation of the fallopian tube. In some cases during the saline passage the tube is dilated, such as a static acquisition with inversion is possible, but is rather accidental, as it requires a long saline pulse and an important tubal diameter.

Hysterosalpingocontrast sonography (HyCoSy) is a procedure that uses a technique similar to SIS to evaluate tubal obstruction in infertility patients. It is effective as first-step examination in the evaluation of infertile women. It involves the introduction of a fluid into the uterine cavity and the fallopian tubes. Sterile saline is used as an echo-free (negative) contrast medium for the assessment of the uterine cavity. For the examination of the fallopian tubes, a positive contrast medium is used, such as air, albumin with microbubbles or galactose with micro-air bubbles. These positive-contrast agents outline the fallopian tubes, giving a hyperechoic appearance. The advantage of this low acoustic pressure technique is that the bubbles are not immediately destroyed but can be detected for several minutes. This permits an easier evaluation of tubal patency even by inexperienced sonographer. HyCoSy proved to be as effective as HSG in diagnosing tubal patency, and the detection rate for tubal obstruction was 80%.[35] Complete visualization of the entire fallopian tube using B-mode and Echovist may not always be possible. Pulsed-wave Doppler is recommended as a supplement to gray scale imaging in cases of suspected tubal occlusion or if there is intratubal flow demonstrable only over a short distance.[36] The color Doppler gate is placed over the presumed mural portion of the tube and movement of contrast medium is registered. In this way, a pulsed Doppler range gate can be used to obtain a flow velocity waveform, diagnostic of tubal patency. Characteristic Doppler spectra can be generated, representing patent, partially occluded, and completely occluded tubes. Adding color and pulsed Doppler to 2D HyCoSy (Fig. 18) and power Doppler to 3D HyCoSy contribute to an increase in the diagnostic precision in detection of tubal patency (Fig. 19).

Since the surrounding bowel and the fimbrial ends have similar echogenicity, it is not easy to visualize spillage of the saline-air mix at the distal portion of the tubes. Recently, evolved 3D HyCoSy with coded contrast imaging technology with many advantages:

1. The imaging of the tube is produced only by contrast microbubbles and the broadband ultrasonic signals from surrounding tissue are filtered out completely.

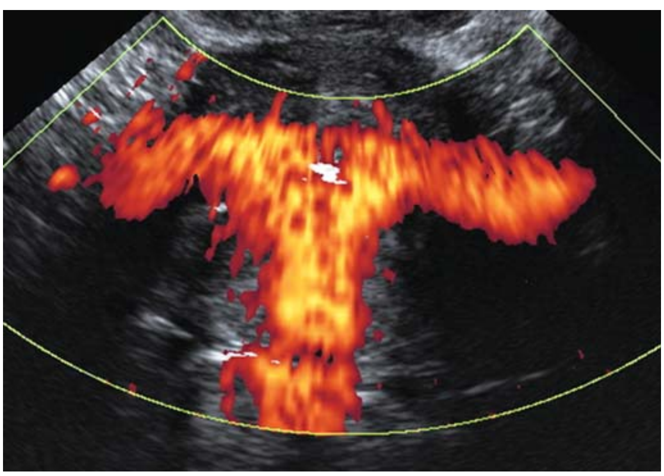


Fig. 17: Saline infusion hysterosalpingography under power Doppler control shows easy passage of the fluid through both fallopian tubes

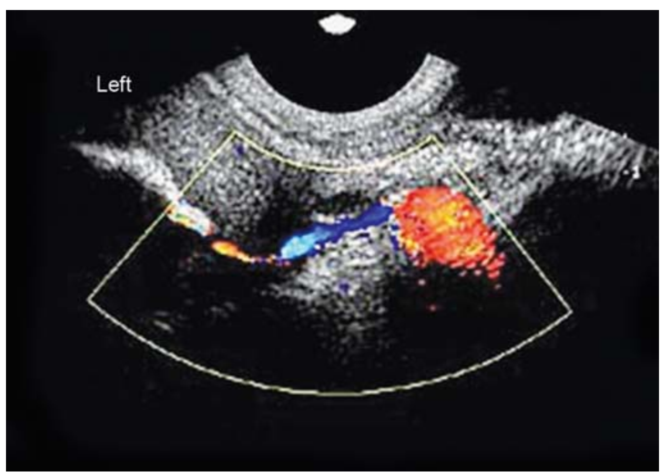


Fig. 18: Color Doppler imaging of the fallopian tube during HyCoSy

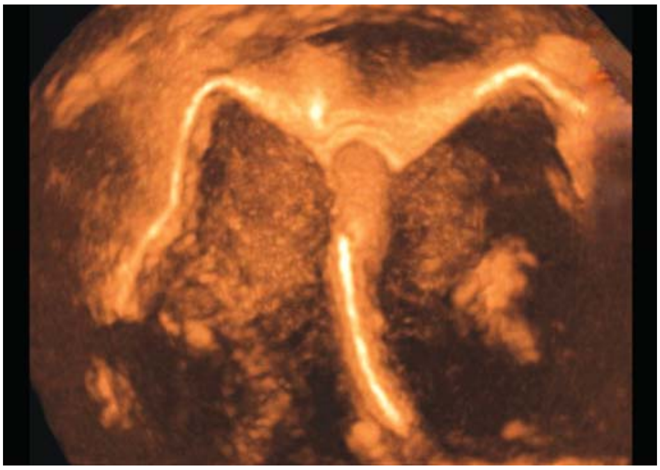


Fig. 19: 3D HyCoSy showing the coronal plane

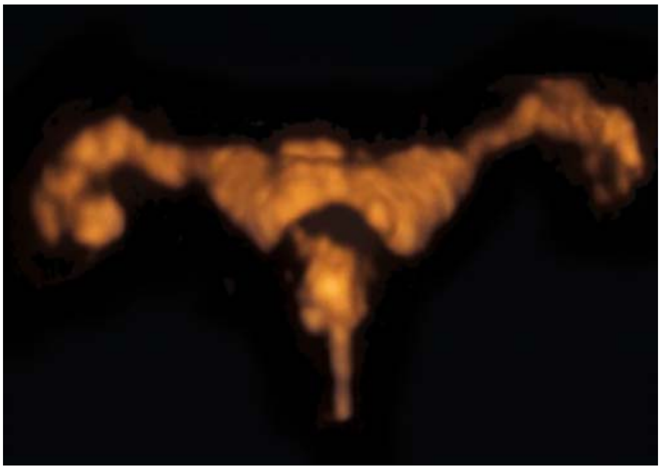


Fig. 20: Fallopian tube during HyCoSy with coded contrast imaging technology

2. The clarity with which spillage is seen, when there is tubal patency, of the hyperechoic contrast media in a completely anechoic pelvic cavity, make this diagnostic method easier for even an inexperienced sonographer.
3. The visualization for few minutes of the contrast media makes possible the use of 3D examination showing the tubal course in different planes and in the space[37] (Fig. 20).

Insonation of echo-enhancing contrast agents with high acoustic power produces disintegration of microbubbles, resulting in a phenomenon called stimulated acoustic emission (SAE). SAE techniques were successfully applied to HyCoSy and allowed the visualization of the free spill of contrast agent into the peritoneal cavity in the majority of cases. SAE-HyCoSy showed good agreement with HSG.[38]

With all its disadvantages (case-to-case variability, time consuming technique and high rate of false-positive results), the ultrasound evaluation of the fallopian tubes still represents the main developing direction for future tubal investigation.

CONCLUSION

It is obvious that ultrasound is the most useful tool in gynecology and infertility and has completely changed our clinical judgement. Detecting gross gynecological pathology is always the main use of ultrasound. With advancing sonographic technique and clinical knowledge, a new territory of research is open. 3D US has many advantages compared with 2D US: rapid acquisition of volume, no limit in image rotation, vascular investigation, later retrieval and further analysis of stored data. Furthermore, SIS combined with 3D US offers improved imaging of uterine and tubal pathology. With the advantage of a noninvasive technique, it becomes the first choice among other investigation tools, like histerosalpingography and hysteroscopy, with similar or even better image quality.

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