

Rational Use of TVS/Color and 3D in Evaluating Subfertile Women

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ABSTRACT

Infertility is defined as the failure to conceive a desired pregnancy after 12 months of unprotected intercourse and affects approximately 10% of married couples. With recent technological development and proper use of medically assisted reproduction techniques, one half of these couples will become pregnant.

More than any other new method, ultrasound has made significant improvements in the modern management of female infertility. Transvaginal sonography provides the reproductive endocrinologists with a tool that cannot only evaluate normal and stimulated cycles but also assist in follicle aspiration and subsequent transfer of the embryo. The addition of color Doppler capabilities to transvaginal probes permits visualization of small intraovarian and endometrial vessels, allowing depiction of normal and abnormal physiologic changes in the ovary and uterus. This article reviews on the assessment of ovarian, uterine and tubal causes of infertility and on the current and future role of color Doppler and three-dimensional ultrasound in the field of reproductive endocrinology.

Keywords: Infertility, Transvaginal ultrasound, Color Doppler, Three-dimensional ultrasound, Power Doppler angiography.

INTRODUCTION

The application of transvaginal ultrasound in the evaluation and assessment of the infertile couple is expanding each day. The transvaginal ultrasound picture depicts accurately the pelvic anatomy of the scanned area safely, quickly and reproducibly.

The quality of depiction of the pelvic anatomy is dependent on the ultrasound equipment being used and the experience and proficiency of the person performing the scan.

It should be mandatory for the person performing the scan to know about the female endocrinology and be well versed with the causes and management of infertility, specially with the ovulation induction protocols.

Till date there are no known adverse biological effects of transvaginal ultrasound on the patient, on the oocytes or on the ultrasound operator.¹

Transvaginal sonography has an important role in the management of infertility. Serial pelvic ultrasound examinations are useful in monitoring patients undergoing ovulation induction using ovulation-inducing drugs. In addition, the correct prediction of timing of ovulation is critical for infertility therapies, such as intrauterine insemination, artificial or therapeutic insemination using donor sperm and the timing of intercourse during ovulation induction therapies.

VAGINAL AND CERVICAL FACTOR FOR INFERTILITY EVALUATION

Vagina and the cervix is the first obstacle that the spermatozoa have to negotiate on their way to reach the oocyte. Vaginal

septae, stenosis, vaginismus and coital difficulties are best assessed by a perspeculum examination, however, TVS helps to locate vaginal cysts and vaginal infiltrations.

Cervix is composed of cervical glands which secrete mucus in response to estrogens stimulation and this secretion assists passage of sperms. About 5 to 10% of causes of infertility are due to cervical factors, which may be anatomical or functional abnormalities.

Transvaginal ultrasound can very accurately assess both anatomical and functional problems of the cervix.

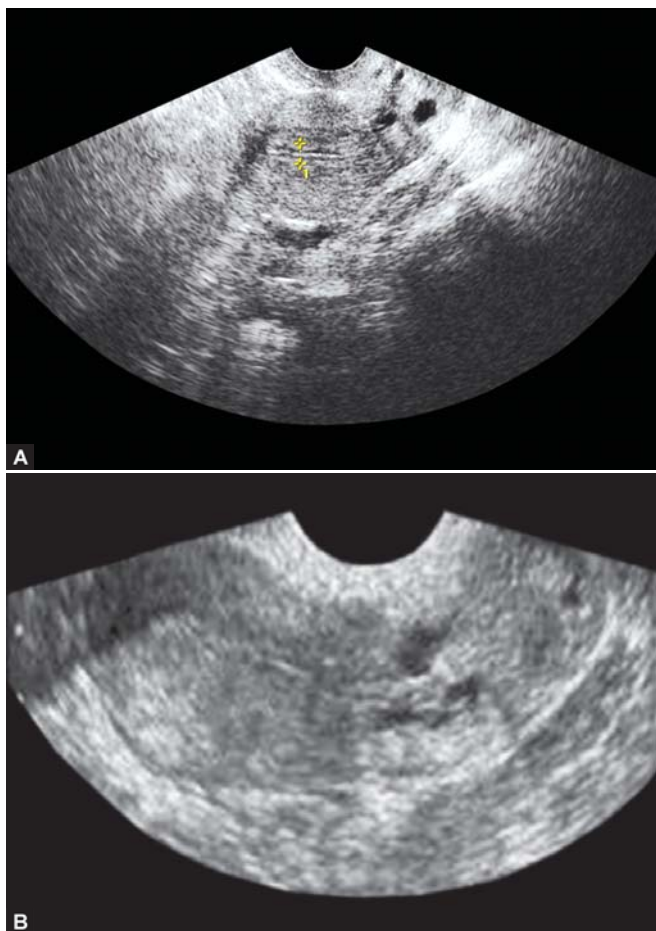
Assessment of cervicitis, nabothian cysts at internal os, poor cervical mucus, cervical agenesis and cervical stenosis are possible and should be done (Figs 1A and B). Cervical conization and cervical infections should always be kept in mind and assessed clinically before a TVS scan.

UTERUS

Transvaginal ultrasound examination of the body of the uterus is done to observe detailed view of the myometrium, endometrium, its cavity and any other anomalies (Fig. 2).

Congenital Malformations

Congenital anomalies of the uterus are variable in frequency and are usually estimated to represent 3 to 4%. Congenital anomalies of the uterus cause infertility and also is a significant



Figs 1A and B: Nabotian cysts in cervix (possible cause of cervical factor infertility)

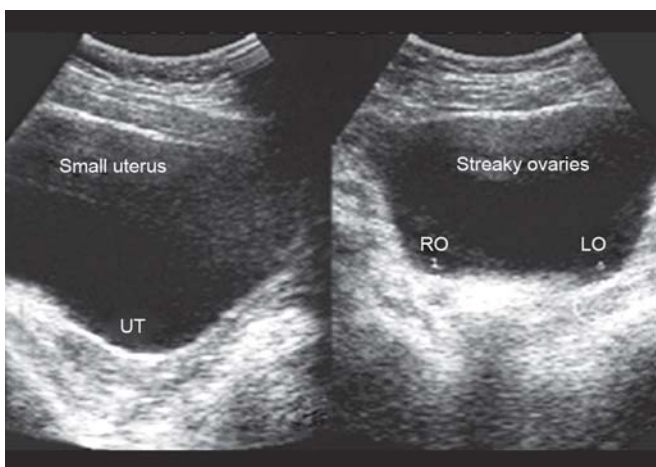


Fig. 2: Small uterus and streaky ovaries (hypoplastic uterus)

cause of recurrent pregnancy loss.^{2,3} About 80% of women with congenitally abnormal uterus may have no problems in conceiving but are responsible for almost 20% of recurrent pregnancy loss and hence should be carefully looked for and treated whenever encountered during infertility evaluation.

Uterine congenital anomalies can be diagnosed by HSG, TVS, contrast sonohysterography, hysteroscopy and



Fig. 3: Bicornuate uterus

laparoscopy and MRI. The anomalies which can be diagnosed are bicornuate uterus, unicornuate uterus, intrauterine septa (complete, incomplete or arcuate) (Fig. 3).⁴

Myometrium

Leiomyomas are one of the most common benign neoplasm. A leiomyoma may be suggested by generalized enlargement of the uterus, irregularities in the surface contour, distortion of the endometrial echo, or as areas of hyper or hypoechogenicity compared with the surrounding normal myometrium. A submucosal myoma within the uterine cavity may be imaged as an area of increased echogenicity and may be mistaken initially for blood, mucus or a polyp in the uterine cavity.

Fibroids can cause infertility by blocking the cervical canal (Fig. 4) or by blocking the fallopian tubes mechanically. Fibroids pressing over the endometrial cavity may diminish the available endometrium for implantation and also interfere with the transport of sperms and oocytes. Intramural myomas also increase the uterine irritability and are implicated in causing implantation failures or early pregnancy losses (Fig. 5).

Adenomyosis is a condition where there is ectopic menstruating endometrium within the myometrium. It is usually asymptomatic, but may be presented by uterine bleeding, pain and infertility. A diffusely enlarged uterus without discrete fibroids, an intact endometrium and multiple small cysts in the myometrium have been reported as a suggestive appearance of adenomyosis (Figs 6 and 7).

Endometrium

The endometrial cavity should be visualizable as a separate entity within the uterus in virtually all menstruating patients (Fig. 8). It is generally centrally located in the uterus. The cyclic histologic changes and changes in the thickening of the endometrium with hormonal stimulation can be imaged using

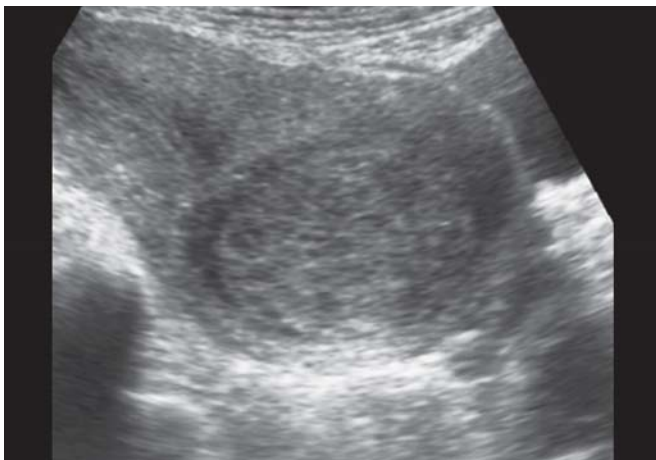


Fig. 4: Cervical fibroid

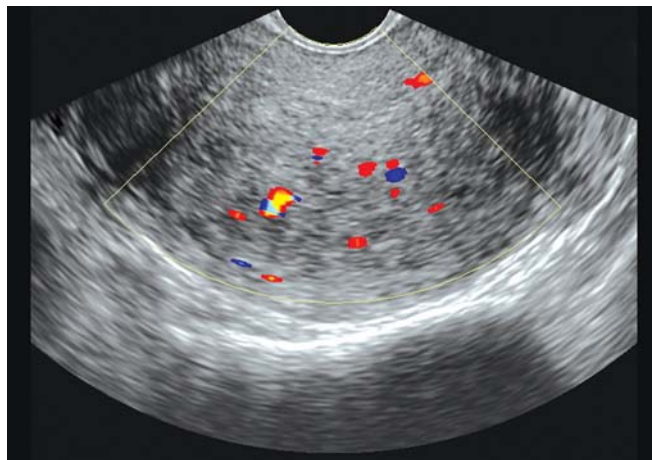


Fig. 7: Adenomyosis. Color Doppler scan of the same patient showing scattered vascularity

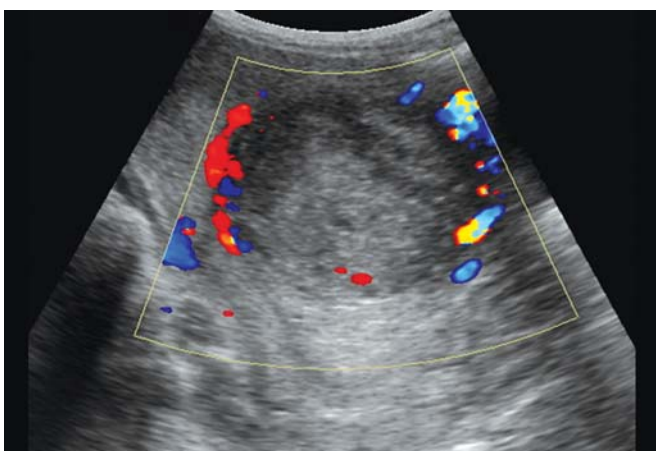


Fig. 5: Intramural fibroid

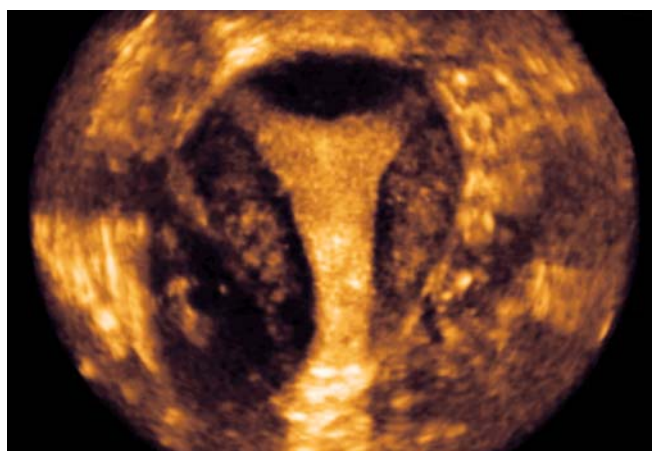


Fig. 8: 3D rendered image of normal endometrium



Fig. 6: Transvaginal scan showing asymmetric thickness of the myometrium with tiny subendometrial cysts representing ectopic endometrial glands (Adenomyosis)



Fig. 9: Triple line endometrium

transvaginal ultrasound during the different phases of the menstrual cycle.⁵

Sakamoto described the characteristic sonographic images noted during the menstrual cycle in 1985. The proliferative endometrium is characterized by:

a. The presence of a well-defined three-line sign.

b. A hypoechogenic functional layer.

c. A minimal or absent posterior acoustic enhancement.

The three-line sign is formed by the central hyperechoic reflection representing the endometrial cavity and the additional hyperechoic reflection representing the thin developing layer of endometrium. There is also a surrounding hypoechoic halo (Fig.9).



Fig. 10: Secretory (luteal phase) endometrium

Luteal phase endometrium is (Fig. 10):

- Hyperechoic
- Posterior enhancement is present
- Three-line sign and halo are absent.

Endometrial Thickness and Menstrual Cycle^{6,7}

Phase	Appearance
Menses (day 1-5)	Hypoechoic area is blood. Myometrial contractions are frequent Thickness < 4 mm
Early follicular phase (day 6-10)	Distinct 'triple-line' pattern Hypoechoic endometrium thickness 7-9 mm.
Late follicular phase (day 11 ovulation)	Endometrial appearance similar to myometrium. Thickness 9-12 mm at ovulation
Luteal phase	Bright, fluffy appearance absence of triple line Thickness 10-14 mm

Uterine Biophysical Profile (UBP)—Applebaum's USSR Scoring System

During the normal mid-cycle certain sonographic qualities of the uterus are noted.

- Endometrial thickness in greatest AP dimension of 7 mm or greater (full-thickness measurement).
- A layered (5 line) appearance to the endometrium
- Blood flow within zone 3 using color Doppler technique
- Myometrial contractions causing a wave-like motion of the endometrium
- Uterine artery blood flow as measured by PI less than 3.0
- Homogeneous myometrial echogenicity
- Myometrial blood flow seen on gray-scale examination (internal to the arcuate vessels).

Uterine Cavity Evaluation

Transvaginal ultrasound with sonohysterography can very accurately delineate the cavity and pick up irregular



Fig. 11: B-mode transvaginal scan showing a nodular echogenic lesion within the endometrium suspected to be an endometrial polyp. Histopathology confirmed a polyp

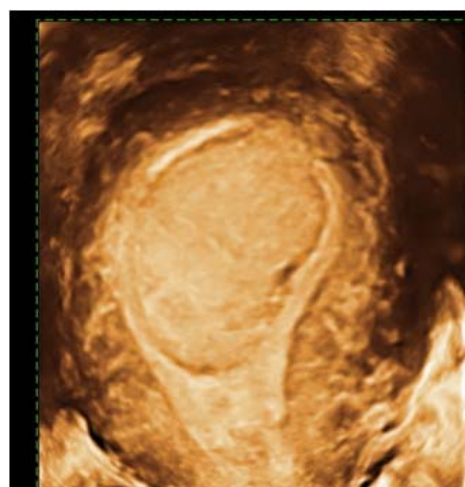


Fig. 12: 3D image of an endometrial polyp



Fig. 13: Asherman syndrome

endometrium, polyps, Asherman syndrome, submucous fibroids, double cavity, septum, unicornuate and T-shaped uterus (Figs 11 to 13).

Sonohysterography or contrast sonohysterography (Hycosy) is done by introducing a No. 8 Foley's catheter or an infant feeding tube into the uterine cavity and injecting a sterile fluid media under ultrasound visualization (normal saline,



Fig. 14: Polyp as seen on sonohysterography



Fig. 15: Foley's catheter *in situ* for SSG

hydrotubation fluid or commercially available echocontrast media—Echovist). This offers a very accurate noninvasive method to evaluate cavity and should be routinely done after SSG and also in all infertile cases (Fig. 14).

3D ultrasound and 3D reconstruction with echo contrast media are also a very accurate and good method for uterine cavity evaluation.

TUBES

Fallopian tubes are isoechoic and cannot be normally seen on ultrasound unless pathological or fluid surrounds the tubes.

Sonosalpingography also known as 'Sion Test' uses transvaginal sonography to confirm the tubal patency by visualizing the spill of fluid from the fimbrial end of fallopian tubes (Figs 15 and 16). This test is not a substitute for hysterosalpingography or laparoscopy but is a noninvasive, cheap outdoor screening procedure in infertility patients.

Method: Prior to the procedure the patient is asked to evacuate the bladder and baseline vaginal scan is performed. No. 8 Foley's catheter is put inside the uterus. The bulb is inflated with 2 ml of distilled water. 20 to 60 ml of solution containing ciplox, hylase and dexamethasone is taken in a 50 ml catheter tip syringe and pushed via Foley's catheter; spill is studied by TVS from the fimbrial ends. A waterfall sign is noted on color Doppler scan. The Foley's bulb is then deflated and some saline is pushed slowly to evaluate the uterine cavity as sonohysterography.⁸

We have done the Sion procedure in the patients of suspected pelvic factors. In this we have flooded the pelvis using the same fluid about 200 to 300 ml, pushed via Foley catheter and visualized the fallopian tubes.

Sonosalpingography is a good noninvasive screening test for evaluating tubal patency. It, however, does not replace the good old hysterosalpingography in certain specific indications.

Laparoscopy has its additional advantage of having a therapeutic value also (Table 1).

Sion procedure has an additional advantage of visualizing pelvic adhesions and tubo-ovarian mobility.

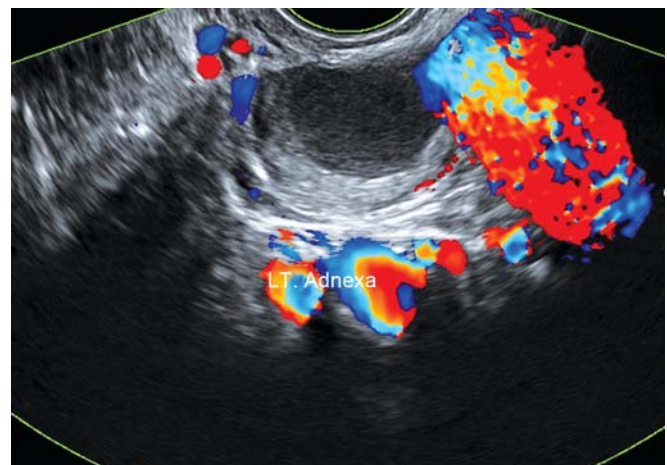


Fig. 16: Color spill on SSG (sonosalpingography)

Ovary

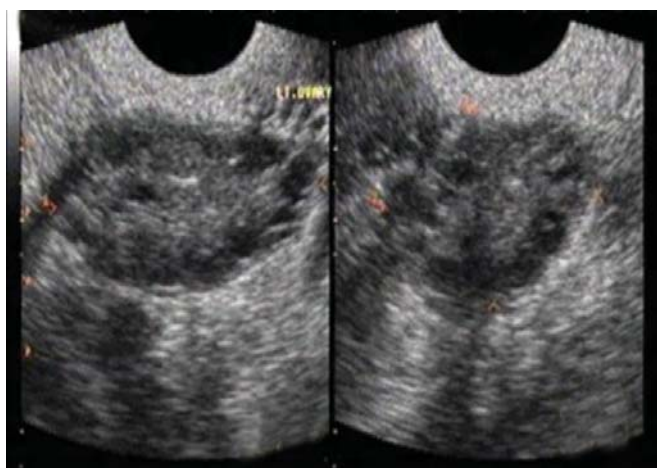
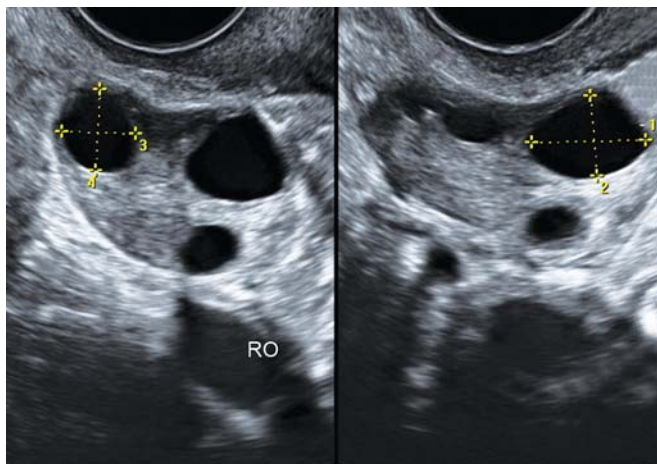
TVS can accurately inform about the follicular development, prediction of ovulation and confirmation of ovulation.

Follicular Development

There are often a few follicles (less than 10 mm in diameter) that can be imaged throughout the menstrual cycle and even during menstruation and these preantral follicles are too small to be imaged (Figs 17 and 18). Under the influence of follicle stimulation hormone (FSH) released by the anterior pituitary gland in response to pulsatile GnRH during the early part of the menstrual cycle, a few follicles will undergo progressive development. Granulosa cells in developing follicles will secrete increasing amounts of estrogen and follicular fluid, and the follicles will increase in size. As follicular stimulation progresses, one or occasionally two follicles will continue to develop into the dominant follicle(s). Many of the developing follicles will not pass the development stage of 10 to 14 mm diameter before they degenerate. Hackeloer et al⁹ noted a linear increase in the size of the dominant follicle through a normal menstrual cycle

Table 1: Comparison of three procedures

Factors to be assessed	HSG	Laparoscopy	Sonography
Cervix			
Congenital abnormalities	+	–	+
Cervicities	–	–	+
Uterus			
Congenital abnormalities	+	Hysteroscopy	+
Myometrium	–	–	++
Endometrium	–	–	++
Tubes			
Morphology	+	+	+
Mobility	–	+	+
Patency	+	+	+ SSG
Ovaries			
Morphology	–	+	+
Follicles	–	+	++
Adhesions	–	++	+
Pouch of Douglas	–	+	+
Cost/time	++	+++	+
Radiation/GA	+	+	–
Therapeutic value	–	++	+

**Fig. 17:** Normal sonographic appearance of ovary**Fig. 18:** Antral follicle count

(Fig. 19). Developing follicles destined to ovulate increase in size 2 to 2 mm/day and reach a maximum diameter of 16 to 33 mm before ovulation selection of the dominant follicle is thought to occur by cycle days 5 to 7, but is not apparent sonographically until cycle days 8 to 12. Other antral follicles of the developing cohort will generally undergo atresia and will not exceed 14 mm in diameter. However, in 5 to 11% of natural cycles, two dominant follicles may develop, but they are generally in opposite ovaries. Potential ovulatory follicles will have a diameter of 10.5 mm or greater (Fig. 20). In clomiphone stimulated cycles follicular rupture occurs between 18 and 24 mm (O'Herlihy 1980), whereas in HMG stimulated cycle it occurs between 15 and 20 mm (Ylostalo 1979). For timing of accurate ovulation, serial scanning is needed.

Prediction of Ovulation

Potential signs of impending ovulation are:¹⁰

- Presence of a dominant follicle (usually > 16-18 mm)
- Presence of cumulus oophorus (ovulation is reported to be within 36 hours) (Fig. 21)
- Anechoic area, double contour, around the follicle (possible ovulation within 24 hours) by Picker et al¹¹
- Separation and folding of the follicle lining (ovulation within 6-10 hours)
- Irregular and crenated margin of the follicle
- Thickened proliferative endometrium.

Confirmation of Ovulation¹²

- Disappearance of the follicle (91% cases)
- Decrease in follicle size (9% cases)

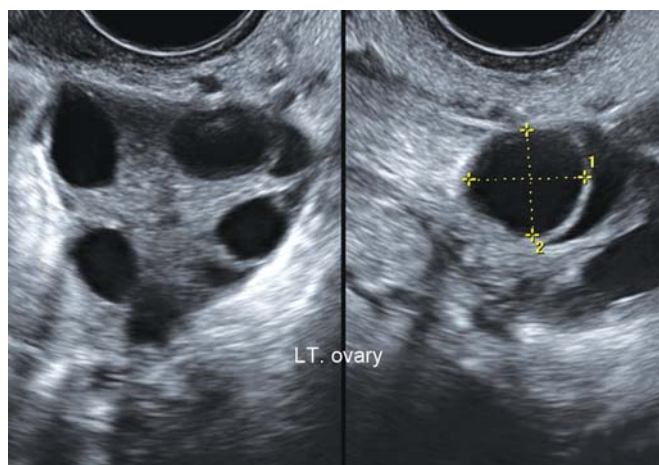


Fig. 19: Dominant follicle



Fig. 22: Fluid in cul-de-sac



Fig. 20: Follicular measurement



Fig. 23: Hemorrhagic corpus luteum



Fig. 21: Cumulus oophorus

- iii. Fluid in cul-de-sac when not present in a previous scan (Fig. 22)
- iv. Development of intrafollicular echoes suggesting the formation of a hemorrhagic corpus luteum (Fig. 23).

Ovary in Anovulatory Cycles

1. Lack of any follicular development particularly in the hypogonadotropic hypogonadal patient
2. Few nonovulatory (less than 11 mm) follicles
3. A cyst
4. PCOD (Figs 24 to 26)—characterized by
 - i. Enlarged ovary (volume $> 8 \text{ cm}^3$)
 - ii. Multiple small cysts (0.2-0.6)
 - iii. Anovulation (lack of follicular development)
 - iv. Resting of endometrium.

ULTRASOUND-GUIDED ASSISTED REPRODUCTION TECHNIQUES

Historical Review

The ultrasound-guided oocyte aspiration was initially performed transabdominally through the full bladder or directly through the anterior abdominal wall. Subsequently, transvesical and preurethral approaches were developed. However, the first description of oocyte collection with transvaginal transducer was described by Wikland in 1985.



Fig. 24: Polycystic ovary

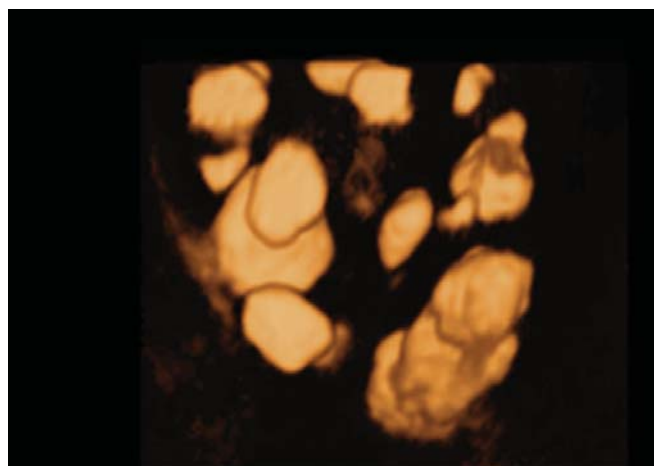


Fig. 26: 3D image of a polycystic ovary

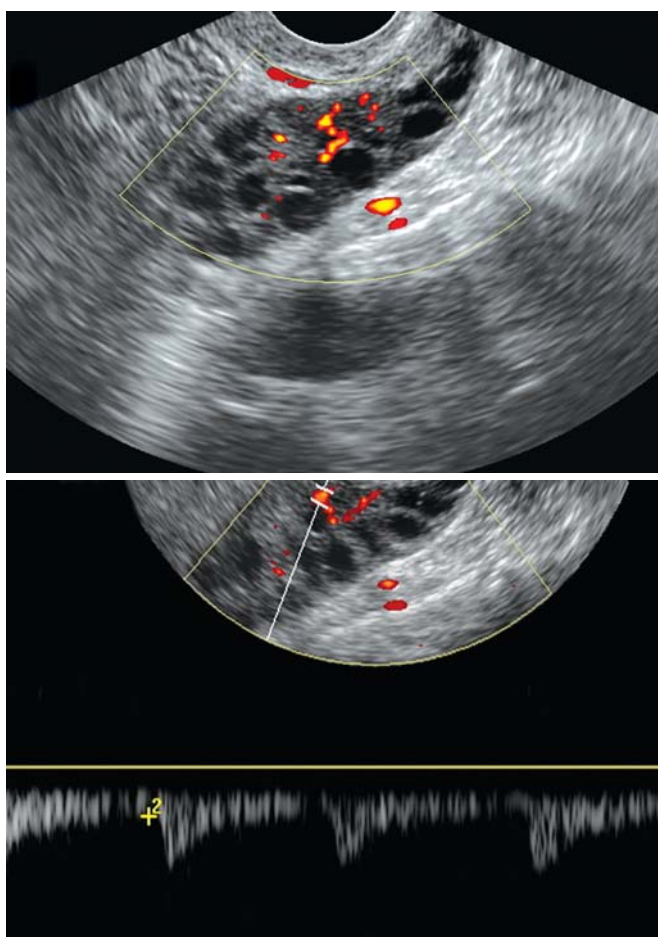


Fig. 25: Color flow in a polycystic ovary

Oocyte Retrieval

After performing a preliminary scan to assess the number of follicles, position of both the ovaries, intervening bowel loops, adhesion, chocolate cysts, etc. follicles in the ovary are tapped by a sterile disposable ovum pickup needle with attached silicon tubing and suction apparatus (set at 150 mm Hg). At the end of one side, the needle is withdrawn and flushed with culture medium before proceeding to the ovary on the opposite side.

Vaginosonographic Puncture Procedures

Patient is given short GA placed in lithotomy position. Vagina is cleaned with betadine followed by normal saline. Transvaginal transducer is cleaned with absolute alcohol solution followed by normal saline. It is then covered with a disposable, sterile plastic sheath. Biopsy guide washed with normal saline is attached to the transducer. The assembly is introduced within the vagina. The software-generated biopsy guideline on the monitor is lined up with the follicle to be punctured. Gauge 16/17 biopsy guide is used for these procedures. The Cook's IVF ovum aspiration needle (gauge 17) is used for puncture. The bung is introduced into the Falcon test tube, the other end of tubing is connected to suctions apparatus with foot-controlled device. Suction is adjusted at 100 mm Hg.

Under ultrasound guidance, the needle is introduced into the follicle and fluid is aspirated by applying the suction. A single-channel needle is used, curetting of the follicle is done at the end of the aspiration and when the follicle has completely collapsed, the needle guide is aligned to the next follicle and procedure repeated. All the follicles of one ovary are aspirated with a single puncture. If need be, the needle is flushed with culture medium, on completion of one ovary or when there is a bloody tap. After all follicles are aspirated, including the intermediate ones, the transducer is removed and the guide detached. The vagina is swabbed with normal saline and bleeding from the puncture site looked for.

ROLE OF COLOR DOPPLER IN INFERTILITY

Introduction

The advent of transvaginal color Doppler sonography has added a new dimension to the diagnosis and treatment of infertile female. Color Doppler innovation is a unique noninvasive technology to investigate the circulation of organs, like uterus and ovaries. Dynamic changes occur almost every day of the menstrual cycle in a reproductively active female. These events are picked up very well by transvaginal color Doppler and definite conclusions can be drawn regarding the diagnosis,

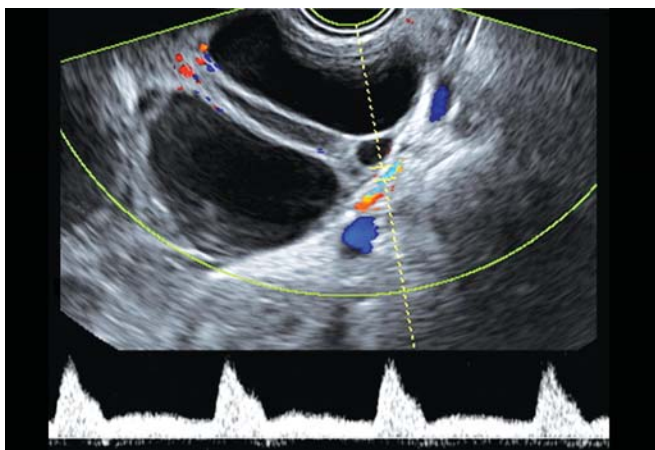


Fig. 27: Spectral Doppler analysis of ovarian vessel

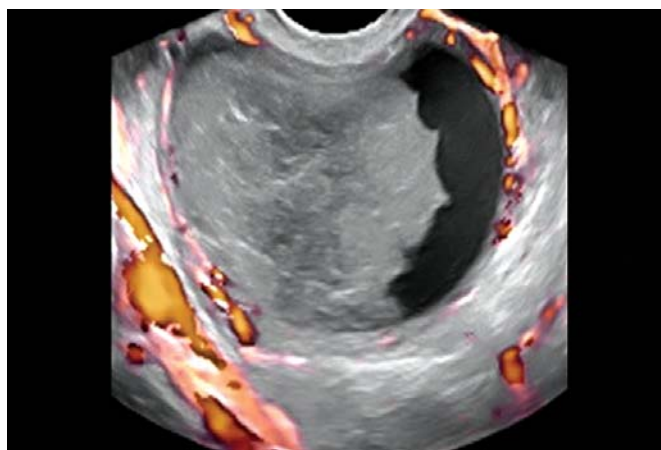


Fig. 29: Corpus luteum vascularization

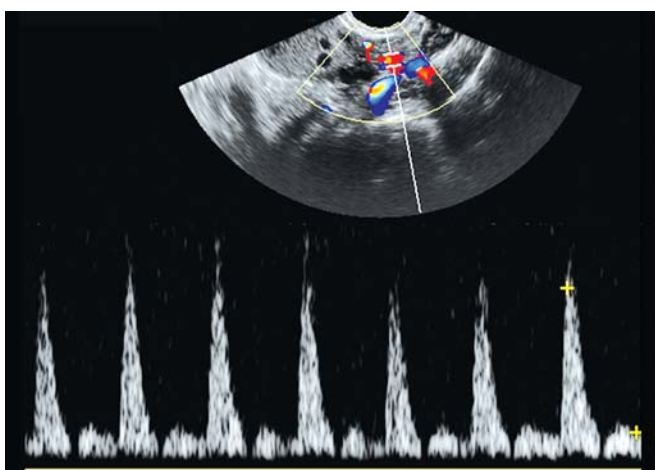


Fig. 28: Uterine artery spectral analysis

prognosis and treatment of infertile patients. As the vaginal probe lies close to the organs of interest, various vessels supplying these structures can be studied in detail, like the uterine artery, ovarian artery and their branches (Figs 27 and 28).

Study of Menstrual Cycle by Color Doppler

It is very important to study the whole of the menstrual cycle by transvaginal color Doppler during the evaluation of infertility. It provides vital information about follicular dynamics, like blood flow to the growing follicle, the vascular supply of the endometrium and corpus luteum vascularization (Fig. 29), which are very important for a successful outcome in terms of pregnancy.

Changes in the Ovary

The ovaries are situated on either side of the uterus and measure about 2.2 to 5.5 cm in length, 1.5 to 2.0 cm in width and 1.5 to 3.0 cm in depth and are recognized by the presence of follicles of different sizes. The blood supply is by ovarian artery via the infundibulopelvic ligament and ovarian branch of the uterine artery. There is anastomosis between the two sources of blood supply. The primary and secondary branches of the ovarian artery grow along with the development of the follicle. Dominant follicle within the ovary can be recognized by transvaginal color Doppler by day 8th or 10th of the cycle by a ring of angiogenesis

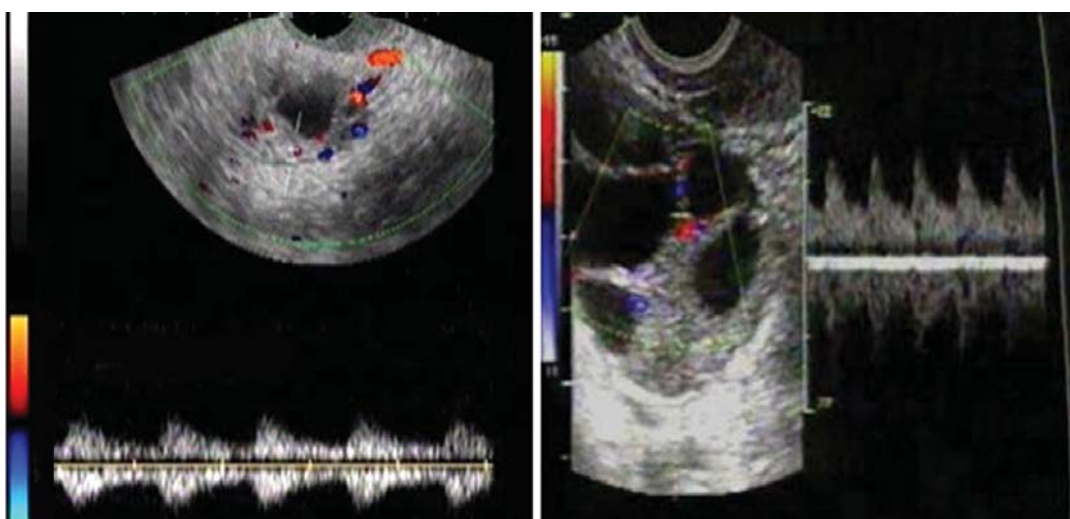


Fig. 30: Ovarian artery flow in (A) early proliferative phase (B) periovulatory phase

around it, when compared to the subordinate follicles which do not demonstrate this. These vessels become more abundant and prominent as the follicle grows to about 20 to 24 mm in size.

The phases are described as early follicular (day 5-7), late follicular (day 11-13), early luteal (Day 15-17) and late luteal (day 26-28). In general the index values are high in the early part of menstrual cycle and fall as ovulation approaches. According to Kurjak et al, the RI in the early proliferative phase is 0.54 ± 0.04 and declines the day before ovulation (LH peak) when it is about 0.44 ± 0.04 (Fig. 30).

This is the best time for administration of surrogate HCG. The increase in peak systolic velocity with a relatively constant RI is a particularly interesting finding that might herald impending ovulation. It is hoped that information on ovarian perfusion may be used to predict ovulation and to investigate ovulatory dysfunction. The lowest RI values were obtained during the mid-luteal phase ($RI\ 0.42 \pm 0.06$) with a return to higher vascular resistance (0.50 ± 0.04) during the late-luteal phase.

The dominant ovary corpus luteum shows a low impedance waveform with an RI of 0.39 to 0.49 characteristic of blood flow in early pregnancy. The contralateral ovary shows a high impedance flow with an RI of 0.69 to 1.00 characteristic of non-dominant ovary (Kurjak et al). If the ovary having corpus luteum shows a high RI (> 0.50), it is associated with nonviable outcome.¹³

Uterine Perfusion

The uterine artery gives rise to the arcuate arteries which are oriented circumferentially in the outer third of the myometrium. These vessels give rise to the radial arteries, which after crossing the myometrium-endometrium border, further branch and give rise to the basal arteries and the spiral arteries.

The RI in the uterine artery hovers around 0.88 ± 0.04 until day 13 of the 28 days menstrual cycle. Increased uterine artery impedance is seen 3 days after the LH peak (day 16). This is explained by increased contractility and compression of vessels traversing the uterine wall, which decrease their diameter and consequently cause higher resistance to flow. Lowest blood flow

impedance occurs during peak luteal phase ($RI = 0.84 \pm 0.04$) during which implantation is likely to occur. RI of radial vessels is 0.78 ± 0.10 (Fig. 31).

Velocity waveform changes in the spiral arteries during normal ovulatory cycles are characterized by lower velocity and lower impedance to blood flow than are those observed in the uterine arteries with larger diameter. It seems that features of endometrial blood flow may be used to predict the implantation success rate and to reveal unexplained infertility problems more precisely than evaluation of the main uterine artery alone.

Changes in the Endometrium

Michael Applebaum in his study with transvaginal color Doppler divided the endometrium and periendometrial areas into four zones. In the study conducted by him no pregnancy was reported in IVF patients unless vascularity was demonstrated in Zone III or within Zone III or IV prior to transfer (Fig. 32).¹⁴

Zone 1: 2 mm thick area surrounding the hyperechoic outer layer of the endometrium.

Zone 2: The hyperechoic outer layer of the endometrium.

Zone 3: The hypoechoic inner layer of the endometrium.

Zone 4: The endometrial cavity.

Ultrasound Technique for Uterine Biophysical Profile (UBP) (Table 2)

To perform the UBP special care should be taken. The following guidelines are recommended (Applebaum 96).¹⁵

1. To determine the presence of a 5-line appearance, information from both the transabdominal and transvaginal studies may be useful. For example, although a 5-line appearance may be noted transabdominally, it may not always be possible to see it endovaginally due to uterine position (and vice versa). In this case, a 5-line appearance is considered to be present and endometrial vascular penetration may be estimated when performing the endovaginal study.
2. Perform the Doppler study slowly. The flow of blood in the endometrium is of low velocity, it may take time for the

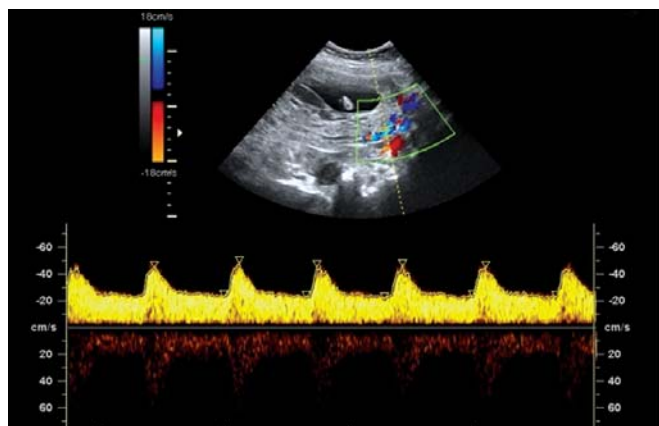


Fig. 31: Periovalutary uterine artery Doppler

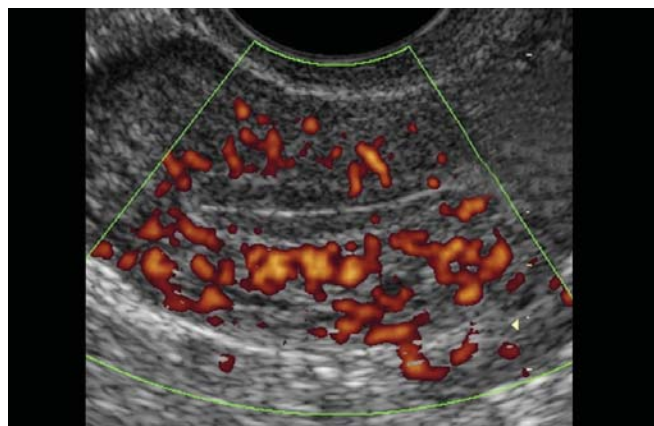


Fig. 32: Endometrial flow

Table 2: Appelbaum's uterine scoring system for reproduction (USSR)

Parameter	Determination	Score
Endometrial thickness (mm)	< 7	0
	7-9	2
	10-14	3
	> 14	1
Endometrial layering	No layering	0
	Hazy 5-line appearance	1
	Distinct 5-line appearance	3
Endometrial motion [no. of myometrial contractions in 2 minutes (realtime)]	< 3	0
	≥ 3	3
Myometrial echogenicity	Course, inhomogenous	1
	Relatively homogenous	2
Uterine artery Doppler flow (PI)	2.99-3.0	0
	2.49	1
	< 2	2
Endometrial blood flow in zone 3	Absent	0
	Present, but sparse	2
	Present multifocally	5
Myometrial blood flow (gray scale)	Absent	0

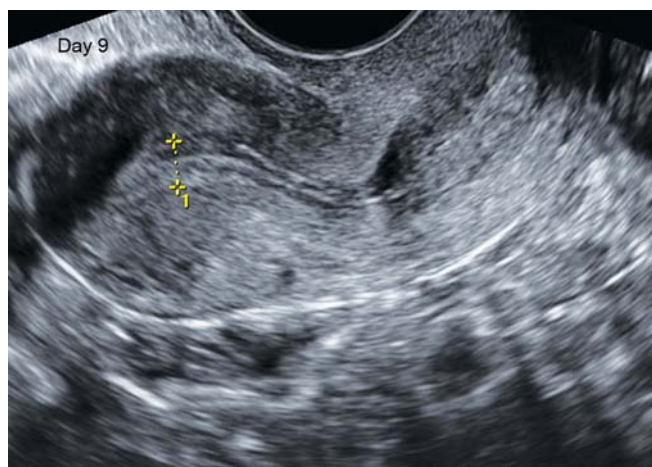
ultrasound machine to register the presence of blood flow and create the image. If one sweeps through the endometrium too quickly, flow may not be seen. Additionally, endometrial blood flow has a mercurial personality, it may appear as if it comes and goes. It may also appear in some areas and not others. Do not observe hastily.

3. Endeavor to make the endometrium as specular a reflector as possible. Use the techniques of manual manipulation of the anatomy and probe pressure to achieve this.
4. Scan endovaginally both coronally and sagittally. There may be a difference in how well the blood flow is imaged.
5. When measuring the endometrium in the A-P dimension (Fig. 33), try to obtain the value when no contraction affecting, it is present. Contractions may affect this value. Also when possible, obtain the measurement in a standard plane as when both the endometrial and cervical canals are continuous.

The uterine scoring system for reproduction (USSR) comprises evaluation of the following parameters:

1. Endometrial thickness (full-thickness measured from the myometrial-endometrial junction to the endometrial-myometrial junction)
2. Endometrial layering (i.e. a 5-line appearance)
3. Myometrial contractions seen as endometrial motion
4. Myometrial echogenicity
5. Uterine artery Doppler flow evaluation
6. Endometrial blood flow
7. Gray-scale myometrial blood flow.

The values assume a technically adequate ultrasound examination with no abnormalities of uterine shape or development, no other gross uterine abnormalities (e.g.

**Fig. 33:** Endometrial measurement

significant masses) and a normal ovarian cycle (e.g. without evidence of ovarian-uterine dyscoordination). A male factor component to the infertility is not present.

In our limited experience (Applebaum) with this system thus far, a USSR "perfect score" of 20 has been associated with conception 100% of the time. The number of patients in which we predicted successful conception cycles based upon the UBP and USSR perfect score was five. The group included two spontaneous cycles (non-IVF, non-IUI), two IUI and one IVF. Scores of 17 to 19 (10 patients) have been associated with conception 80% of the time. Scores of 14 to 16 (10 patients) have a 60% chance, while scores of 13 or less (25 patients) have resulted in no pregnancies.

Absent endometrial flow despite the highest values for the other parameters, has always been associated with no conception.¹⁶

Role of Transvaginal Color Doppler in other Conditions Associated with Infertility

Luteinized Unruptured Follicle

This condition is recognized by serial ultrasonography to monitor the growth of follicle with failure to see expected changes at the time of ovulation.¹⁷

The typical blood flow pattern seen in the corpus luteum is absent.

Luteal Phase Defect

This is due to decreased vascularization of corpus luteum. The three to seven fold increase in blood supply is necessary to deliver the steroid precursors to ovary and removal of progesterone as shown in experimental animals (Fig. 34).

An increasing corpus luteum resistance index indicates less chances of embryo survival specially within first 8 weeks of pregnancy.

Fibroid

To define the borders of fibroid, color Doppler is of real help as the vascular supply at the periphery of the leiomyoma can be delineated very well. Good vascularity denotes a favorable response to GnRH if used before laparoscopic surgery (Fig. 35).

Endometriosis

On gray-scale scan endometrioma is seen as a homogeneously echogenic intraovarian mass. Color Doppler may demonstrate the flow around and not within the endometriotic cyst (Figs 36 and 37).

Tubal Causes

During active phase of PID low impedance blood flow signals are usually detected and after effective antibiotic therapy flow tends to return to normal. In the absence of this change surgery is indicated (Figs 38 and 39).

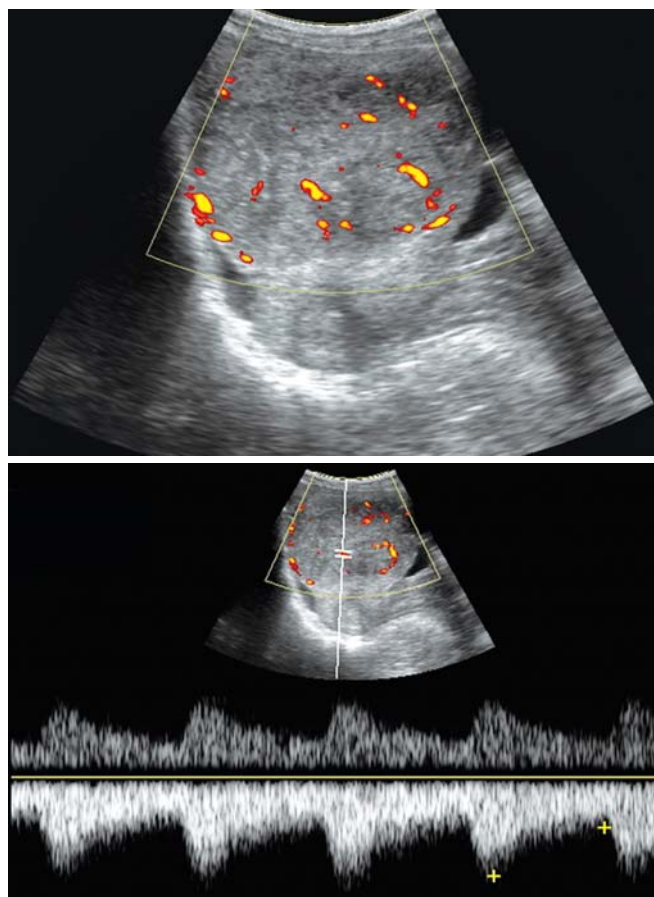


Fig. 35: Color flow in a fibroid



Fig. 36: Endometrioma



Fig. 34: Luteinized unruptured follicle

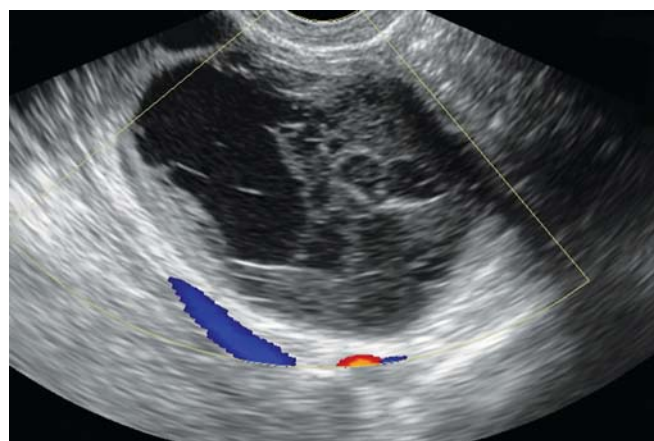


Fig. 37: Color flow in an endometriotic cyst. No vascularity is seen



Fig. 38: Hydrosalpinx



Fig. 39: Pyosalpinx

Polycystic Ovarian Disease (PCOD)

Contrary to the normal ovarian blood flow, which is seen around the growing follicle, PCOD subjects show abundantly vascularized stroma. Waveforms obtained from the ovarian tissue showed a mean resistance index of 0.54 without cyclical change between repeated examinations (Fig. 25).

Uterine Factor

The possibility of decreased uterine blood flow may be associated with infertility as already discussed in proceeding paragraphs, Goswamy et al depicted in their study that uterine artery indices which were high in failed IVF cases improved after the patients were put on oral estrogen therapy and pregnancy rate improved when compared to those who did not get this treatment.

Color Doppler and its Contribution towards *in vitro* Fertilization

During stimulation protocols color Doppler ultrasound has its greatest contribution in monitoring follicular development and guiding oocyte harvesting procedures. The use of color Doppler ultrasound can occasionally be of help as it avoids accidental puncture of iliac vessels and also vessels on the surface of ovary.

Avoidance of Ovarian Hyper Stimulation Syndrome (OHSS)

In a stimulated cycle resistance of the intraovarian vessels measured by transvaginal color Doppler correlates well with number of follicles, those with more than 15 mm size. This correlation exists even during the early follicular phase, when follicular recruitment and development have just started. This suggests that vascularization of the follicles may play a role in their maturation from early follicular phase onwards. This study in the early follicular phase can prevent OHSS.

Optimal Conditions for Embryo Transfer

As shown in a recent work by Campbell, it is possible to calculate the probability of pregnancy by using PI values of uterine artery on the day embryo transfer. The highest probability of pregnancy was predicted for patients who had medium values for PI. Those with high PI had failure rate up to 35%. In other words, the lower PI value more the chances of pregnancy. Steer et al have shown that if PI is > 3 before ET no pregnancy results.

ROLE OF 3D USG

Three-dimensional ultrasonography (USG) enables 3D imaging of 3D structures. Organ structure and spatial relationship are simultaneously visualized, facilitating recognition of spatial anomalies. Although 3D images are more informative than two-dimensional, disadvantages limited its application in clinical praxis included long processing period needed for image generation and condition that required the absence of movements during scanning period (Figs 40 and 41).¹⁸

4D (live 3D) ultrasound has recently been introduced in clinical practice, overcoming the limitations of 3D sonography. 4D sonography is characterized by spatial visualization in almost real-time.

The acquisition of volume data-sets is performed by 2D scans by special transducers designed for 2D scans, 3D and real-time 4D volumes. Real-time 4D mode is obtained by simultaneous volume acquisition and computing of 3D images.¹⁹

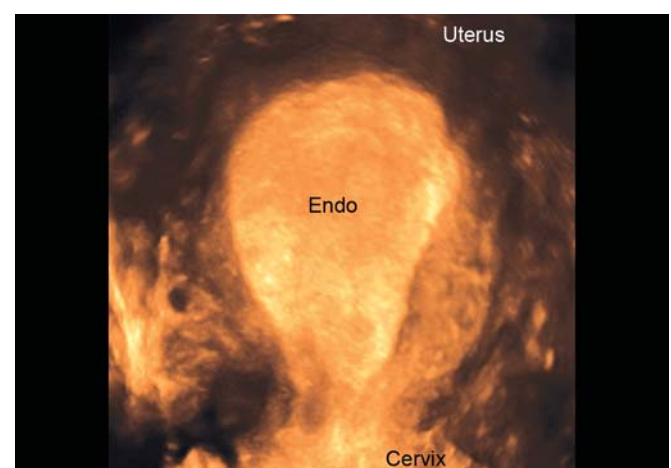


Fig. 40: 3D image of thickened endometrium

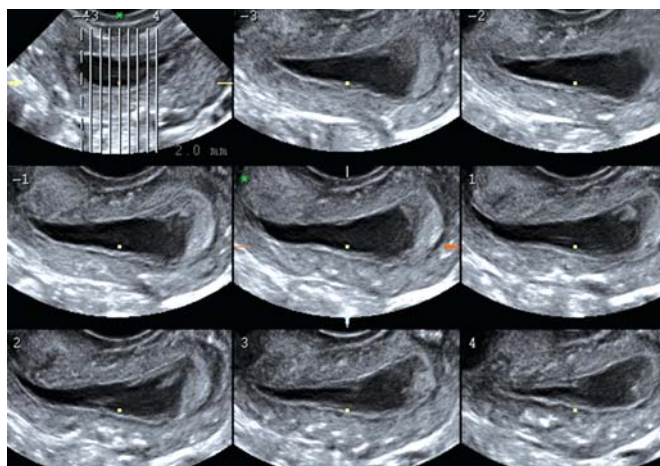


Fig. 41: Tomographic ultrasound image of ca endometrium. Fluid is also seen within the endometrial cavity

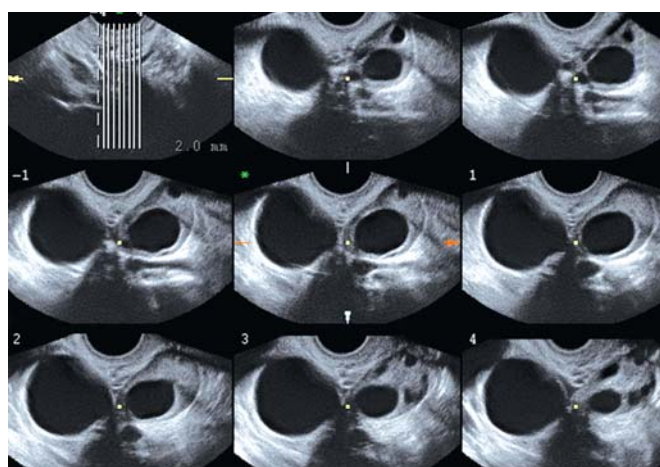


Fig. 42: Tomographic ultrasound image of a parovarian cyst

Applications and advantages of 3D/4D ultrasound in gynecology include:

1. Exact volume measurement of endometrial hyperplasia
2. Virtual hysteroscopy using slicing technique
3. Exact volume measurement of cysts, polyps or myomas
4. Exact localization and measurement of ovarian and endometrial lesions (Figs 42 and 43)
5. Contrast media use to check vascularization and blood supply
6. Placental abnormalities (placenta previa).

Three-dimensional power Doppler angiography is an emerging technology in the field of ultrasound and Doppler diagnostics in obstetrics and gynecology. In 1996, Ritchie et al reported the appearance of a new technology to produce three-dimensional angiograms from slices obtained by bidimensional power Doppler. 3D power Doppler image is essentially characterized by its high sensitivity to depict any vessel, as much the great vessels as the microvascularization.

One of the first clinical applications of 3D power Doppler was in the field of assisted reproductive technologies. It has been basically applied on the study and quantitative evaluation of the ovarian, follicular and endometrial microvascularization

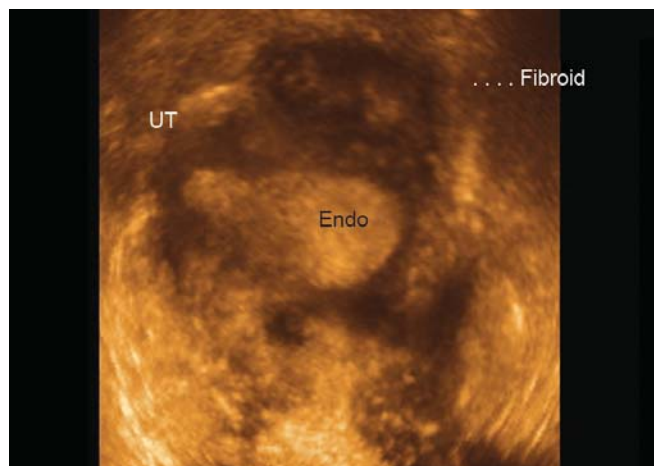


Fig. 43: 3D image of a subserous fibroid

as possible markers of ovarian response, oocyte developmental competence and embryonic implantation respectively.²⁰

Ovarian Response Markers

The 3D power Doppler has proven the progressive decrease of the stromal ovarian blood flow from premenopause to postmenopause as the follicular reserve runs out. It has also been demonstrated that 3D Doppler indices are diminished after gonadotropin ovarian stimulation on surgically treated ovaries of endometriosis without differences in the whole ovarian volume but with a number of oocytes retrieved significantly smaller. On the contrary, polycystic ovaries show increased 3D Doppler indices with regard to normal ovaries at the beginning of the menstrual cycle although these differences are not found after the GnRH agonist treatment.

Oocyte Competence Markers

The development of the optimal perifollicular vascular network determines the intrafollicular oxygen concentration, whose deficit has been related to oocyte cytoplasmic defects, embryos with multinucleated blastomere and abnormal chromosomal arrangement.

Although it is possible to assess the follicular flow as expressed by the peak systolic velocity and perifollicular color map, it is the 3D power Doppler which proves the most precise information about the vascularization and follicular blood flow.

Studies with 3D power Doppler have proven that the perifollicular vascularization of the dominant follicle is greater than the average vascularization of the whole ovary. The 3D vascular indices from the corpus luteum are higher than those from the preovulatory follicle and luteinized unruptured follicle.

Implantation Markers

The endometrial blood flow reflects more properly the uterine receptivity because the endometrium is the place where the embryonic implantation is going to take place. The absence of

the color map at the endometrial and subendometrial levels leads to a significantly decrease of the implantation rate whereas the pregnancy rate increases when vessels reach the subendometrial halo and the endometrium.

Ultrasonography and 3D power Doppler have the advantage to assess simultaneously the endometrial volume and subendometrial and endometrial blood flow. For all the 3D vascular indices from the endometrium and subendometrium an excellent intra- and interobserver reproducibility have been observed with intraclass correlation coefficients greater than 0.90.²¹

CONCLUSION

Transvaginal sonography offers a very accurate, easy and reproducible method to evaluate the female pelvis and the female factors of infertility. Addition of color gives us more information about organ perfusion and addition of 3D has opened a new dimension to diagnosis of pelvic pathologies.

Undoubtedly, 4D ultrasound is the technology of future whose potential still needs to be discovered and evaluated. For proper evaluation of benefits of 4D sonography full range of its options should be used.

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